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B.R. Wells Rice Research Studies 2006

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B.R. Wells

RICE RESEARCH STUDIES 2006

R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer, editors

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Cover photo by John Crone of rice paddies surrounding a surviving, historic Federal Emergency Relief Act farmhouse near Plum Bayou, Arkansas.

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B.R. Wells
RICE
Research Studies
2006

R.J. Norman, J.-F. Meullenet,
and K.A.K. Moldenhauer, editors

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

Bobby R. Wells

Dr. 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. in agronomy from the University of Arkansas in 1961, and his Ph.D. in soils from the University of Missouri in 1964. Dr. 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 U of A Rice Research and Extension Center near Stuttgart. In 1982, he moved to the U of A Department of Agronomy in Fayetteville.

Dr. 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. Dr. Wells developed an upper-level course in rice production and taught it for many years. Dr. Wells was appointed head of the U of A Department of Agronomy in 1993 and became university professor that year in recognition of his outstanding contributions to research, service, and teaching.

Among the awards he received were: the Outstanding Faculty Award from the U of A 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).

Dr. 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 Dr. 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 series.

FEATURED RICE COLLEAGUE

J. Neil Rutger

Dr. J. Neil Rutger was born on a farm at Noble, Illinois, the last in a family of eight children. Neil Rutger served two years in the military before enrolling at the University of Illinois, where he received his B.S. degree in agricultural science in 1960. He earned an M.S. in agronomy in 1962 and a Ph.D in genetics in 1964, both from the University of California at Davis. His first professional position was a 1964 to 1970 faculty appointment in the Department of Plant Breeding at Cornell University. He joined USDA's Agricultural Research Service at Davis, California, in 1970, conducting rice genetics research in the Department of Agronomy on the UCD campus.

In his 18 years at Davis, Dr. Rutger developed the first semidwarf table rice variety in the U.S., 'Calrose 76', by induced mutation, and another semidwarf, 'M-101', by putting Calrose 76 to work in a cross-breeding program. Calrose 76 became the ancestral source of semidwarfism for numerous additional varieties developed by others: 13 in California, 10 in Australia, and 2 in Egypt. These semidwarfs resulted in farm yield increases of 15% to 20% and thus tens of millions of dollars of increased income for rice growers. This work became a poster child for the International Atomic Energy Agency, as an example of successful use of induced mutation in plant breeding. At Davis, Dr. Rutger held an adjunct professor appointment that enabled him to train 12 M.S. and 12 Ph.D. graduate students as well as receive numerous international rice scientists as visiting researchers. His former students occupy responsible rice genetics and breeding positions in California, Texas, Brazil, China, Egypt, Korea, and Taiwan, and at the International Rice Research Institute (IRRI).

From 1989 to 1993, Dr. Rutger served as ARS associate director of the MidSouth Area in Stoneville, Mississippi, with joint responsibilities for ARS research at 9 locations in Alabama, Kentucky, Louisiana, Mississippi, and Tennessee. In 1993, Dr. Rutger returned to rice research as the first director of the National Rice Germplasm Evaluation and Enhancement Center at Stuttgart, Arkansas. Upon completion of construction in 1998 the facility was renamed the Dale Bumpers National Rice Research Center. For the 1998 dedication of the Center, Dr. Rutger and colleagues organized an international symposium with over 100 national and international rice scientists in attendance. Dr. Rutger recruited scientists and directed the research at this world-class facility, and also conducted an active personal research program, producing numerous additional semidwarf and early-flowering mutants in Arkansas germplasm as well as in aromatic rice germplasm. In the last decade he initiated an indica base-broadening program to develop high-yielding indica (tropical) rice adapted to the U.S., which to date has been a japonica (temperate) rice-growing nation. In 2003, Dr. Rutger established the Genetic Stocks – *Oryza* collection (GSOR) in order to develop and accumulate specialized rice genetic stocks for the U.S. rice research community. By late 2006 the GSOR had 902 entries, with primary emphasis on domestic stocks but also including 192 genetic stocks from Japan.

Dr. Rutger retired as chief scientist at the Dale Bumpers National Rice Research Center on January 3, 2007 after over 38 years of federal service, including 32 years on rice research. In his career, Dr. Rutger authored or coauthored over 200 papers and released 60 improved germplasm lines plus numerous genetic stocks. He has received many awards, including fellow of his three professional societies: the American Society of Agronomy (1981), Crop Science Society of America (1985), and American Association for the Advancement of Science(1991). He also received the 1983 ARS-Western Region Scientist of the Year Award, the 1986 California Rice Industry Award, the 1995 American Nuclear Society Award for Application of Nuclear Techniques in Food Production, the 2005 Outstanding Alumni Award from UCD, and the 2006 Distinguished Service Award from the Rice Technical Working Group (RTWG). Professional activities included: Chair, RTWG, 1982; ARS Administrative Advisor to RTWG, 1983-2006; Founding Chair, U.S. Rice Crop Advisory Committee, 1983-90; USAID Scientific Liaison Officer to IRRI, 1982-91; Chair of Crop Science Rice Subcommittee for Crop Registration for two periods, 1986-88 and 2004-06; President, Stuttgart Rotary Club, 2003-04; and Chair of the Board, Arkansas Science and Technology Authority, 2005-06. Over the past 30 years, Rutger has presented invitational papers or participated in rice research reviews in Argentina, Australia, Austria, Brazil, China, Colombia, Egypt, India, Indonesia, Italy, Jamaica, Japan, Korea, Pakistan, Philippines, Russia, Sierra Leone, Sri Lanka, Taiwan, Thailand, Uruguay, and the U.S.

In retirement, Neil and his wife of 49 years, Peg, moved back to the Davis, California area, where their two children, Ann and Robyn and their husbands, and grandchildren live. Retirement plans include service in local civic organizations and travel.

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. 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 Communication Services, (501) 575-5647.

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UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

OVERVIEW AND VERIFICATION

Trends in Arkansas Rice Production

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

ABSTRACT

Arkansas is the leading rice-producing state in the U.S., representing 49.5% of the total U.S. production and 49.6% of the total acres planted to rice. 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 influence 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 were obtained from the USDA National Agricultural Statistics Service.

INTRODUCTION

Arkansas is the leading rice-producing state in the U.S., representing 49.5% of the total U.S. production and 49.6% of the total acres planted to rice. 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 influence 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 in August 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. Rice variety distribution information 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 acreage distribution of the most widely produced varieties. 'Wells' was the most widely planted variety in 2006 at 31.0% of the acreage, followed by 'CL 131' (13.1 %), 'Francis' (9.6%), 'Cheniere' (10.6%), 'CL 161' (6.7%), and 'Bengal' (4.9%). The acreage planted to Wells in 2006 decreased slightly from over 37% in 2005 while the acreage planted to CL 161 declined from more than 19% in 2005 to just under 7% in 2006. The biggest increase was by CL 131 which increased from less than 1% in 2005 to 13.1% in 2006. The adoption of the Clearfield rice system represents a significant factor that plays a significant role in the management of red rice. It provides an opportunity for red rice control that has never been available to rice farmers. Clearfield rice (all varieties combined) accounted for over 30% of the total rice acreage in 2006.

Arkansas rice acreage represented 49.6% of the total 2006 U.S. rice crop (Table 2). The state-average yield of 6,850 lb/acre (152 bu/acre) was the fourth highest average in the U.S. behind California, Texas, and Mississippi. It represents a second-best yield for Arkansas, only 100 lb/acre less than the record established in 2004 of 6,980 lb/acre. The total rice produced in Arkansas was 95.9 million hundredweight (cwt). This represents 49.5% of the 193.7 million cwt produced in the U.S. during 2006. Over the past three years, Arkansas has produced 47.8% of all rice produced in the U.S. The five largest rice-producing counties in 2006 included Poinsett, Arkansas, Lawrence, Cross, and Jackson, representing 37.2% of the state's total rice acreage (Table 1).

Planting began in 2006 slightly ahead of the 5-year average due to dry weather during the end of March and beginning of April. Approximately 50% of the crop was planted by 15 April in 2006, compared to a 5-year average of 28% (Fig. 1). This is nearly a week earlier than normal. Compared to the 5-year average, harvest proceeded approximately one week ahead of normal (Fig. 2).

Based on the survey conducted with the cooperation of our county extension agents, approximately 56% of the rice produced in Arkansas was planted using conventional tillage methods in 2006 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. This is essentially equal to 2005. The most common conservation tillage system utilized by Arkansas rice farmers is stale seedbed planting following fall tillage, representing approximately 33% 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, this accounts for approximately 9% of the rice acreage in Arkansas.

The majority of rice is still produced on silt loam soils (Table 3). However, an increasingly important factor is the amount of rice produced on clay or clay loam soils (22% and 16% 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 tripled over the last 20 years, increasing from approximately 15,000 acres each in 1984 to about 49,000 in 2005 (Arkansas Agricultural Statistics, 1984; Table 1). 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.

As expected, rice most commonly follows soybean in rotation, accounting for almost 80% of the rice acreage (Table 3). Approximately 14% of the acreage in 2006 was planted following rice, with the remaining 6% made up of rotation with other crops including corn, grain sorghum, cotton, wheat, oats, and fallow. Rice following wheat declined dramatically during 2005 and 2006, which is a reflection of the significant drop in wheat acreage during the 2005 and 2006 growing seasons. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only approximately 5% using a water-seeded system. Approximately 75% of all the Arkansas rice acreage is drill-seeded, with an additional 20% 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 all available water and re-using. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Approximately 80% of the rice acreage in Arkansas is irrigated with groundwater, with the remaining 20% irrigated with surfacewater obtained from reservoirs or streams and bayous (Table 3).

During the mid 1990’s, the University of Arkansas began educating producers on the use of multiple-inlet irrigation with poly-tubing as a means of irrigating rice to conserve water and labor. As of 2006, rice farmers have adopted this practice for almost 27% of the rice acreage (Table 3). This is down slightly from 2005 but is a reflection of the 14% decline in acreage across the state. However, the adoption of multiple-inlet irrigation using poly-tubing has increased from 17% in 2002, which constitutes an increase of approximately 166,000 acres irrigated using this technique. Approximately 72% 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 either sprinkler- or furrow-irrigation systems. A number of producers have increased the amount of rice produced using a furrow-irrigated system where they have found it to be particularly efficient in fields that have steep slopes and often contain more area in levees than in paddies. This has increased from less than 1,000 acres in 2002 to more than 6,000 acres in 2006.

An additional means of conserving water for rice irrigation is through precision leveling. This results in more efficient water management and typically less total water usage. Approximately 46% of the 2006 rice acreage in Arkansas has been precision leveled, with 5% utilizing zero-graded fields (Table 3). Approximately 54% of the rice still utilizes contour levees.

Stubble management is important for preparing the fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. Approximately 24.3% of the acreage was burned, 26.8% was tilled, 32.5% was rolled, and 21.5% was winter flooded (Table 3). Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl is also rolled. Some practices are inhibited by fall weather. For example, heavy rainfall in the fall may reduce the amount of stubble that can be burned and will also affect the amount of tillage that can be done.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state average yields in Arkansas have increased approximately 2,300 lb/acre (about 51 bu/acre) or 2.6 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

I would like to extend thanks to all of the county extension agents who participated in this study and the Arkansas Rice Research Board for funding.

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Table 1. Arkansas harvested

	Harvested acreage[z]		Medium-grain			
County	2005	2006	Bengal	Others[y]	Cheniere	CL131
Arkansas	121,513	110,876	2,020	1,210	13,551	11,568
Ashley	17,211	11,536	0	0	1,823	3,541
Chicot	37,011	25,228	0	0	5,399	4,995
Clay	86,295	79,826	2,120	986	5,244	13,311
Craighead	86,637	79,274	7,188	0	11,807	11,557
Crittenden	39,534	36,167	953	447	321	5,130
Cross	111,433	98,038	3,903	813	1,059	4,618
Desha	50,422	26,536	239	531	6,767	4,007
Drew	19,492	11,176	0	0	469	6,196
Faulkner	3,256	2,628	0	0	0	0
Greene	75,440	73,078	2,034	0	7,735	15,326
Independence	13,025	9,607	0	0	0	0
Jackson	99,990	89,945	10,536	5,117	7,032	6,000
Jefferson	69,308	56,049	43	0	10,652	11,493
Lafayette	4,280	3,966	0	0	178	119
Lawrence	109,063	102,712	1,958	5,307	11,703	34,572
Lee	30,891	21,449	1,051	99	2,366	992
Lincoln	33,676	26,740	68	0	560	13,216
Lonoke	88,030	76,145	8,527	0	13,259	8,031
Miller	6,864	3,047	0	0	0	0
Mississippi	49,263	39,489	0	40	635	40
Monroe	58,581	47,943	570	958	6,024	6,518
Phillips	30,985	28,077	0	0	11,034	393
Poinsett	133,339	119,389	32,349	338	4,402	4,280
Prairie	72,328	55,721	4,616	297	12,378	5,627
Pulaski	4,718	3,243	80	0	79	0
Randolph	34,789	33,094	957	0	3,490	5,202
St. Francis	54,835	39,126	4,389	1,062	2,259	837
White	15,618	13,950	462	0	2,248	524
Woodruff	63,574	57,867	3,110	649	5,958	4,134
Others[x]	8,252	7,591	736	0	572	539
Unaccounted[w]	5,346	10,497				
2006 Total		1,400,000	87,160	17,854	149,002	182,766
2006 Percent		100.00%	6.23%	1.28%	10.64%	13.05%
2005 Total	1,635,000		80,801	22,089	118,018	14,777
2005 Percent	100.00%		4.94%	1.35%	7.22%	0.09%

[z] Source: Arkansas Argicultural Statistics and FSA.

[y] Other varieties: ‘AB647’, ‘Ahrent’, ‘Banks’, ‘Clearfield 131’, ‘Cybonnet’, ‘Cypress’, ‘Della’, ‘Delmatti’, ‘Dellrose’, ‘Drew’, ‘Jupiter’, ‘Koshihikari’, ‘LaGrue’, ‘Medark’, ‘Newbonnet’, ‘Nortai’, ‘Pirogue’, ‘Presidio’, ‘Rice Tec XP 710’, ‘Rice Tec XP712’, ‘Rice Tec XP716’, ‘Rice Tec XP 723’, ‘Saber’, ‘Spring’, and ‘Trenasse’.

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

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

rice acreage 2006 summary.

Long-grain						
CL 161	CLXL8	CLXL730	Cocodrie	Francis	Wells	Others[y]
3,085	2,754	992	4,737	27,763	35,915	7,271
692	311	288	1,973	0	473	2,434
1,791	1,665	177	2,725	0	3,736	1,741
1,694	5,002	4,760	1,936	9,197	17,264	18,313
9,894	6,402	3,908	748	1,663	22,865	3,243
712	962	356	0	214	26,788	285
20,685	2,501	962	1,347	10,198	48,970	2,982
372	1,937	3,901	3,184	0	5,121	478
960	201	592	514	0	1,998	246
944	0	581	0	836	268	0
5,228	9,024	12,963	2,650	3,939	9,525	4,665
0	0	0	0	0	9,607	0
10,126	6,657	3,844	1,688	0	36,847	2,063
785	0	0	12,446	0	20,183	449
167	301	0	2,443	0	531	226
7,760	8,482	8,697	5,476	3,006	9,448	6,225
1,577	1,645	2,254	0	5,341	6,873	0
0	1,998	1,599	0	6,821	2,478	0
5,986	4,470	3,334	1,591	8,940	18,790	2,995
0	0	0	0	0	3,047	0
1,270	437	397	397	3,056	28,178	5,040
296	1,778	2,469	3,901	10,369	13,283	1,778
533	1,460	1,432	6,149	4,998	2,078	0
7,582	6,604	2,201	611	11,125	46,958	2,935
1,350	2,138	2,588	3,488	7,708	11,197	4,335
0	816	215	231	746	206	870
4,774	3,918	3,721	428	1,383	3,885	5,334
0	0	502	753	4,518	21,795	3,012
2,207	1,186	1,255	372	0	2,207	3,489
2,189	4,195	3,526	1,581	12,341	17,752	2,432
716	581	127	134	247	2,378	1,560
93,345	77,426	67,638	61,503	134,413	433,643	84,456
6.67%	5.57%	4.83%	4.39%	9.60%	30.97%	6.03%
311,491	39,473	4,000	153,309	164,443	609,499	130,400
19.05%	2.41%	0.24%	9.38%	10.06%	37.28%	7.98%

Table 2. Acreage, grain yield, and production of rice in the United States from 2004 to 2006[z].

	Area planted			Area harvested			Yield			Production		
State	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
	(1,000 acres)						(lb/acre)			(1,000 cwt[y])		
AR	1,561	1,643	1,406	1,555	1,635	1,400	6,980	6,650	6,850	108,560	108,792	95,917
CA	595	528	526	590	526	523	8,600	7,380	7,660	50,759	38,836	40,040
LA	538	530	350	533	525	345	5,390	5,900	5,820	28,730	30,983	20,093
MS	235	265	190	234	263	189	6,900	6,400	7,000	16,146	16,832	13,230
MO	196	216	216	195	214	214	6,800	6,600	6,400	13,261	14,124	13,696
TX	222	202	150	218	201	150	6,840	6,800	7,170	14,906	13,668	10,760
US	3,347	3,347	2,838	3,325	3,325	2,821	3,942	3,942	3,868	230,818	230,818	193,736

[z] Source: USDA-NASS, 2007.

[y] cwt = hundredweight.

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

	2004		2005		2006	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,555,000	100.00	1,635,000	100.00	1,400,000	100.00
Soil texture						
Clay	332,278	21.4	389,176	23.8	309,871	22.1
Clay loam	222,728	14.3	273,576	16.7	231,958	16.6
Silt loam	860,836	55.4	811,125	49.6	734,525	52.5
Sandy loam	114,970	7.4	110,598	6.8	79,915	5.7
Sand	47,386	3.1	50,525	3.1	43,730	3.1
Tillage practices						
Conventional	944,474	60.7	920,897	56.3	782,071	55.9
Stale seedbed	488,394	31.4	565,432	34.6	491,924	35.1
No-till	150,819	9.7	148,671	9.1	126,001	9.0
Crop rotations						
Soybean	1,207,692	77.7	1,287,726	78.8	1,116,486	79.7
Rice	228,381	14.7	238,710	14.6	200,866	14.3

continued

Table 3. Continued.

Cultural practice	2004 Acreage	2004 % of total	2005 Acreage	2005 % of total	2006 Acreage	2006 % of total
Crop rotations - continued						
Cotton	23,891	1.5	25,343	1.6	18,765	1.3
Com	44,619	2.9	36,951	2.3	27,911	2.0
Grain Sorghum	17,130	1.1	14,061	0.9	6,908	0.5
Wheat	19,301	1.2	3,924	0.2	3,700	0.3
Fallow	13,246	0.9	28,122	1.7	25,223	1.8
Oats	165	<0.1	164	<0.1	140	<0.1
Seeding methods						
Drill seeded	1,175,367	75.6	1,233,935	75.5	1,057,600	75.5
Broadcast seeded	308,156	19.8	297,407	18.2	278,344	19.9
Water seeded	87,394	5.6	103,659	6.3	64,056	4.6
Irrigation water sources						
Groundwater	1,273,186	81.9	1,315,358	80.5	1,121,786	80.1
Stream, rivers, etc.	133,772	8.6	150,420	9.2	128,327	9.9
Reservoirs	147,867	9.5	169,223	IOA	139,887	10.0
Irrigation methods						
Flood, levees	1,122,068	72.2	1,121,610	68.6	1,014,984	72.5
Flood, multiple inlet	428,183	27.5	503,744	30.8	378,396	27.0
Furrow	4,904	0.3	9,042	0.6	6,619	0.5
Sprinkler	537	<0.1	605	<0.1	0	0.0
Precision-leveled soils						
Contour levees	945,637	60.8	900,600	55.1	758,240	54.2
Precision leveled	609,363	39.2	734,400	44.9	641,760	45.8
Zero grade	75,629	4.9	82,548	5.0	69,149	4.9
Stubble management						
Burned	256,371	16.5	362,722	22.2	340,400	24.3
Tilled	402,246	25.9	540,751	33.1	375,898	26.8
Rolled	641,800	41.3	461,087	28.2	453,900	32.5
Winter flooded	339,622	21.8	329,672	20.2	300,455	21.5

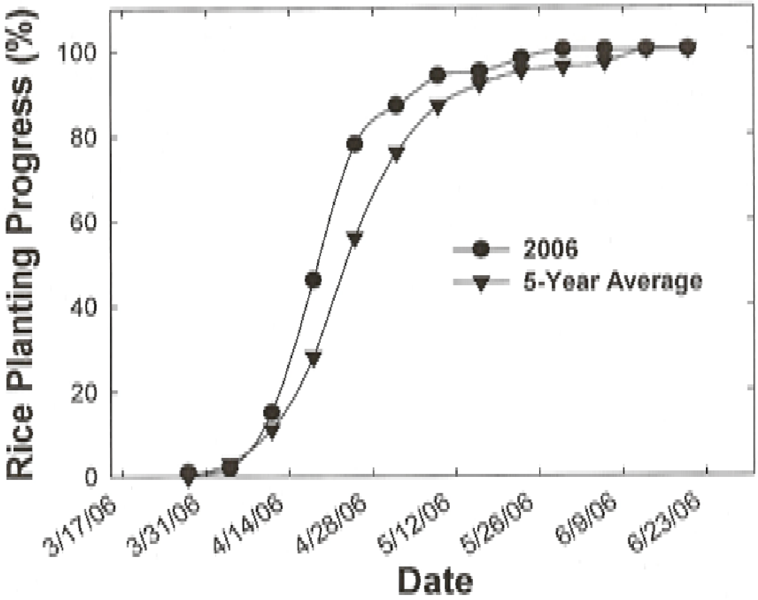

Fig. 1. Arkansas rice planting progress during 2006 compared to the five-year average. [Data obtained from the USDA National Agricultural Statistics Service (NASS), 2006].

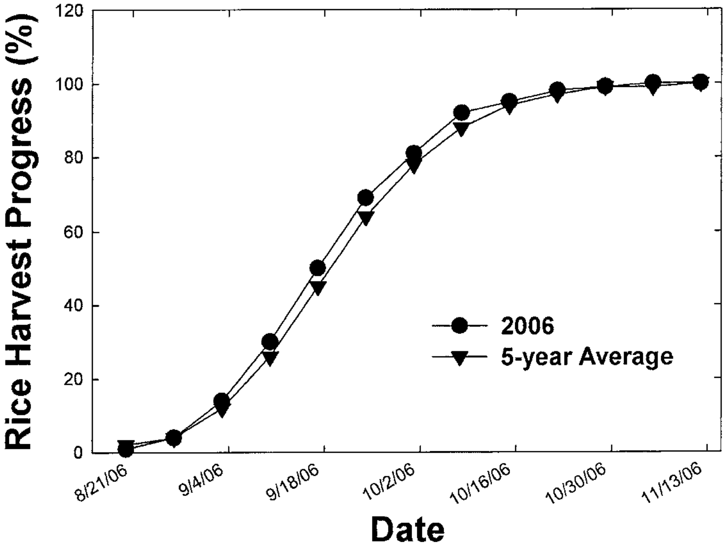

Fig. 2. Rice harvest progress during 2005 compared to the five-year average. [Data obtained from the USDA National Agricultural Statistics Service (NASS), 2006].

OVERVIEW AND VERIFICATION

2006 Rice Research Verification Program

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ABSTRACT

The 2006 Rice Research Verification Program (RRVP) was conducted on twenty commercial rice fields across the state. Counties participating in the program included Arkansas, Clark, Clay, Craighead, Crittenden, Desha, Independence, Lafayette, Lawrence, Lee, Lonoke (2 fields), Mississippi, Phillips, Poinsett (2 fields), Prairie, Randolph, St. Francis, and White for a total of 1103 acres. Grain yield in the 2006 RRVP averaged 164 bu/acre ranging from 100 to 217 bu/acre. The 2006 RRVP average yield was 14 bu/acre greater than the estimated Arkansas state average of 150 bu/acre. The highest yielding fields were in Lonoke and Craighead counties with grain yields of 217 and 213 bu/acre. The lowest yielding field was in White County and produced 100 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 58/71.

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 optimal 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 that contribute to more profitable production, and 5) incorporate data from RRVP into extension educational programs at the county and state levels. Since 1983, the RRVP has been conducted on 263 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 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 2006 included Arkansas, Clark, Clay, Craighead, Crittenden, Desha, Independence, Lafayette, Lawrence, Lee, Lonoke (2 fields), Mississippi, Phillips, Poinsett (2 fields), Prairie, Randolph, St. Francis, and White. The twenty rice fields totaled 1103 acres enrolled in the program. Eight varieties were seeded (‘Wells’, ‘Cocodrie’, ‘Francis’, ‘Cheniere’, ‘Cybonnet’, ‘XP 723’, ‘CL XL 730’, and ‘XP 710’) in the 20 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, plant dry-matter accumulation, temperature, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

RESULTS

Yield

The average yield of all the RRVP fields was 164 bu/acre with a range of 100 to 217 bu/acre (Table 1). The RRVP average yield was 14 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 2006 RRVP average yield was 7 bu/acre less than the programs highest average yield of 172 bu/acre that was set in 2003. The highest-yielding fields yielded 217 and 213 bu/acre and were seeded with CL XL 730 in Lonoke and Craighead counties, respectively. Three fields, Desha, Independence, and Phillips counties, exceeded 190 bu/acre. The lowest-yielding field (i.e., 100 bu/acre) was water-seeded with the Cheniere rice variety in White County. A significant portion of the White County field failed to emerge due to seed midge and not presoaking the seed prior to application. Red rice control was not achieved and multiple sproutings of red rice occurred. The disease blast occurred in the field late in the season and caused further yield loss.

Milling data were recorded on all of the RRVP fields. The average milling yield for the twenty fields was 58/71 (head rice / total white rice) with the highest milling yield of 65/74 occurring in Arkansas County (Table 1). The average milling was greater than 55/70, which is considered the standard used by the rice milling industry. The lowest milling field was seeded with Cocodrie in Lafayette County and only milled 48/71.

Planting and Emergence

All the fields were planted in the optimal time frame beginning with Lafayette County planted 2 April and ending with Crittenden County planted 22 May (Table 2). An average of 75 lb/acre were seeded in the RRVP fields). Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 12 days was required for emergence. Stand density ranged from 5 to 28 plants/ft^2, with an average of 16 plants/ft^2. The seeding rates in several fields were higher than average due to planting method and soil texture. Broadcast seeding and clay soils require elevated seeding rates. In 2006, the early-planted fields required flushing in order to get a stand and the low temperatures slowed emergence. In several fields, two or more emergences were observed.

Irrigation

Well water was used to irrigate seventeen of the twenty fields in the 2006 RRVP. Clark, Lafayette, and White county sites were irrigated with surfacewater. Fields in Arkansas and Lee counties were furrow-irrigated. Five of the twenty fields used multiple-inlet (MI) irrigation (Clay, Lawrence, Lonoke 1, Phillips, and St. Francis). Flow meters were used in fourteen of the fields to record water usage throughout the growing season and compare MI to conventional flooding. In fields where flow meters were not utilized, an average of 30 acre-inches was used.

An average of 31.7 acre-inches of water was used across both irrigation methods (Table 2). The fields with MI irrigation averaged 34.9 acre-inches of water compared to 29.5 acre-inches for fields using conventional flooding. This difference in water used was due in part by field location in the state and rainfall amounts. Typically a 25% reduction in water usage has been measured when using MI irrigation.

Fertilization

Nitrogen rate 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 corn was the previous crop and the soil texture is a clay. These factors increase the nitrogen requirements significantly compared to a silt loam soil where soybeans were the previous crop.

Ammonium sulfate was applied at 100 lb/acre and flushed in at the 2- to 3-leaf stage in Arkansas, Crittenden, Lawrence, Lonoke 1 and 2, and Poinsett 2 counties as a management tool to speed development and shorten the time required to get the rice to flood stage (Table 3). Mid-season nitrogen was applied as urea at 100 lb/acre across all varieties in all the counties with the exception of Arkansas, Clark, Craighead, Crittenden, Desha, Lawrence, Lee, Phillips, and Poinsett 2 Counties.

Phosphorus, potassium, and zinc were applied based on soil test results (Table 3). Phosphorus and/or potassium and zinc were applied preplant in most of the fields. Phosphorus was applied to Desha, Lafayette, and White counties in the form of diammonium phosphate (DAP; 18-46-0) and flushed in at the 2- to 3-leaf stage. The average cost of fertilizer across all fields was $88.61 (Table 4), which was less than the $99.89 spent in 2005.

Weed Control

In 2006, the average herbicide cost was $58.23 (Table 4). Command was utilized in eighteen of the twenty fields for early-season grass control (Table 5). All but three of the fields required an additional herbicide application for grass weed control. Three fields (Crittenden, Independence, and St. Francis counties) did not require a postemergence herbicide application for grass weed control, which resulted in inexpensive herbicide programs. Lee County had the most expensive weed control program at $112.11/acre (Table 4). Independence County had the most inexpensive herbicide cost at $16.32/acre.

Disease Control

Fungicides were applied to four of the fields in 2006 for control of sheath blight and/or blast (Table 6). The average cost for fungicide was $5.29/acre (Table 4). Sheath blight pressure was not heavy in 2006. The disease appeared late in the season but appeared to hang on and continue development throughout the season. Quadris or Stratego were used to control sheath blight and rates were determined based on variety, growth stage, climate, disease incidence/severity, and disease history (Table 6).

Insect Control

Two of the RRVP fields were treated for rice water weevil in 2006 (Lafayette and Poinsett 2 counties; Table 6). Weevil traps were placed in the RRVP fields in cooperation with the entomologist, Dr. John Bernhardt. The traps and thresholds are being developed as a more accurate way of scouting for weevils as compared to the leaf scarring method.

Eight fields (Arkansas, Craighead, Desha, Independence, Lafayette, Lawrence, Lonoke 2, and Prairie counties) were treated for rice stinkbugs in 2006 (Table 6). Stinkbug numbers were highest in the first and last fields to head. The average cost for insecticides was $5.66/acre (Table 4).

Economic Analysis

This section provides information on the development of estimated production costs for the 2006 RRVP fields (Table 7). 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 operating costs, specified ownership costs, and total specified costs for each of the fields. Break-even prices for the various cost components and returns above specified expenses at the average 2006 price are also presented.

Specified operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application (Table 4 and 7). Actual quantities of all operating inputs were used in this analysis. The average of the actual prices paid by cooperating producers was used to calculate costs. 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 $2.20/gal was used for 2006 ($1.80 was used for 2005). Therefore, the producers' actual machinery costs may vary from the machinery cost estimates that are presented in this report. Specified operating costs for the twenty RRVP fields ranged from $294/acre for Clark County to $510/acre for Desha County with an overall average of $396/acre.

Land costs incurred by producers participating in the RRVP would likely vary from land ownership, cash rent, or some form of crop-share arrangement (Table 7). 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 typical 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 operating costs including the assumed 20% crop-share rent was $3.00/bu. Furthermore, break-even prices ranged from $2.25/bu in Independence County up to $4.03/bu in White County.

Table 7 includes estimated net returns above Specified Operating Expenses and Total Specified 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 $19.35/acre for the irrigation-system fixed costs. All costs for risk, overhead, and management were not included.

Crop price was estimated based on a harvest season average price of $4.01/bu, which was a reported total cash price average for the period of 15 August 2006 to 10 October 2006 (Table 7). The associated premium-above-loan rate was $1.05/bu based on the $6.58/CWT loan rate for long-grain rice. Crop prices were calculated based on milling yields for each field and the 2006 USDA loan rates for whole and broken rice kernels. Estimated prices varied from $3.87/bu in Lonoke County, with an average of $4.11/bu.

Net returns ranged from a $12/acre loss in White County to a $311/acre profit in Independence County (Table 7). Much of the difference in net returns across RRVP fields can be attributed to yields, herbicide use, and irrigation amounts, i.e. irrigation of 49.0 acre-inches in Crittenden County versus 14.0 acre-inches in Clark County (Table 2).

DISCUSSION

Field Summaries

Furrow-irrigated rice is not a new concept; however, this year was the first time the management practice was implemented in the RRVP. Arkansas County was one of two counties that used furrow irrigation instead of holding a continuous flood once the rice reached tillering. The field was seeded with XP723 at 28 lb/acre. Many factors can cause problems in this production system, such as the height of the bed. In this field the beds were a little too high, which led to some of the seed in the middles not getting covered with soil. The stand was reduced in these areas, but the average stand count was sufficient. Weed control proved to be the most challenging component in this practice. Weeds that are not usually a problem in flooded rice can become a huge problem in furrow-irrigated rice. Multiple flushes of pigweeds were a major part of the $101/acre spent on herbicides in this field. Command and Facet were applied preemergence, but provided little control of pigweeds. Aim in combination with Prowl was applied early postemergence for control of emerged pigweeds and to provide residual control. Prowl provided residual control that lasted approximately 10 days. Three of the four herbicide applications in this field were due to pigweeds. Insects that are usually not economically important can also present problems in this system. Bill bug damage was significant in both furrow-irrigated fields. This insect usually only causes damage on the levees, but without the flood the insect can cause widespread damage. The yield was 155 bu/acre, but the soil type was extremely sandy and the yield was in line with the historical yields for this field. The yield was also achieved without the expense of building levees or the expense of tearing them down.

Clark County was one of two fields in the southern part of the state planted at the end of May. The field was to be planted the third week of April, but one day prior to planting rainfall was received. Periodically for the next 4 weeks rainfall occurred and delayed planting until 20 May. The field was seeded with Cybonnet and emerged quickly to a uniform stand. However, the weather had changed dramatically since the field was planted. Hot and dry weather had replaced the cool and wet climate experienced in early spring. This weather pattern can lead to chinch bugs moving into the rice. Chinch bugs are not usually a problem in rice, but prior to flood they can cause serious damage. Smut was also a severe problem and played the largest role in determining the yield. Smut blanked out as much as half of the grains on almost all panicles. This was the second year in a row for the field to be planted in rice. Very little smut was observed in the previous rice crop. An infestation this heavy without a strong field history of the disease is uncommon, but can occur under certain environmental conditions combined with a late planting date.

The Clay County field was planted 11 April in Wells. It took longer than the average 14 days to get a stand with parts of the field emerging another week later. The field was flushed and then received a rain. The temperature dropped and stayed cool for a period of time. Holes in the field held water and the rice never did emerge. Plant stand counts averaged 16 plants/ft^2. It felt like we were pushing the field all season. The nitrogen applications were made on the earlier side of the application window as was recommended. In this field with uneven emergence, some of the rice plants were 2- to 3-leaf while the majority of the field was 4-leaf or larger. It took a long time for the field to finally take off and grow. Red rice pressure was heavier than expected in this field and may have reduced yields significantly. No significant insect or disease pressure was present.

The Craighead County field was planted very early on 4 April. The field was seeded in CL XL 730 at a rate of 30 lb/acre. The field required flushing in order to get a stand. Stand counts averaged 10 plants/ft^2. No herbicides were used pre-emergence. Barnyardgrass, sprangletop, and scattered red rice were present following the flush. Clearpath was used for the first herbicide application and was applied by air in the mud. The Facet component of the herbicide program for this field was necessary for control of the larger barnyardgrass plants. The herbicide did an excellent job and held until flood. A second application of Newpath was applied preflood. The rice appeared to be stunted and yellow after the first Newpath application. The cool wet conditions played a factor in this delayed growth. After a couple of weeks and some warm weather, the field recovered and growth and development was normal the rest of the season. The field was sprayed for stink bug control as it was one of the first fields to head in the area. The field yielded an impressive 213 bu/acre.

The zero grade, heavy clay soil of the field in Crittenden County took a long time to dry out so that it could be planted. It was the last field in the program to be planted on 22 May. The field was a little wet when planted. Good drill row closure was not achieved in some areas, causing uneven emergence. The stand was a little thin, but averaged 16 plants/ft^2. Facet and Prowl applied delayed-preemergence were the herbicides and application time of choice. The field was flushed about a week after the application. Ammonium sulfate and DAP were applied at rates of 50 lb/acre of each product ahead of the flush. The herbicide did an excellent job and no other herbicide applications were required. Three hundred pounds of urea were applied by ground around 2 weeks later than recommended. The producer was waiting for the soil to dry so that a ground application could be made. Due to unforeseen circumstances, the recommended midseason nitrogen application was not made. The field yellowed up and appeared to be deficient of nitrogen at midseason. The plants greened up eventually after tapping some reserve nitrogen in the soil. The plants did not tiller well and the field appeared thin all year. No disease or insect pressure was present. The field yielded a disappointing 124 bu/acre.

The field in Desha County recorded the third highest yield in the history of the program at 207 bu/acre. The field was seeded with the hybrid XP723 on 13 April, but failed to establish a uniform stand, and was replanted on 16 May. The field emerged quickly with the warmer temperatures in May and was ready to establish the flood in 2.5 weeks. Stink bugs were the only other problem that occurred in the Desha County field. Since the field was younger than the surrounding fields, stink bug numbers increased rapidly at the end of the season and required treatment.

In Independence County this year, everything seemed to go just right. From a perfect seedbed and stand to virtually no weed pressure. The field was planted in Wells on 10 April, Command was applied, and it was off to the races. The plants took off and grew like crazy. As is the case with most “lush or rank” fields, disease pressure was heavy. This field was one of only two in northeast Arkansas that were sprayed for sheath blight. The field also was treated for stink bugs as it was one of the first fields to head in the area. Neck blast was observed late in the season but did not seem to cause any significant loss. I was impressed with this field every week. The end result was 199 bu/acre.

The verification field in Lafayette County was the first field in the program to be planted. The field was seeded with Cocodrie on 2 April. Emergence was slow and the field had to be flushed to ensure emergence. A somewhat uniform stand was achieved, but there were places in the field where the stand density was a little low. However, the average across the field was more than sufficient. The field looked good once it had reached the flood stage. Seven days following the establishment of the permanent flood heavy water weevil scarring was observed. This was not surprising due to the hundreds of acres of water-seeded rice surrounding the field. Karate was applied to about 33% of the field and provided excellent control of the rice water weevils. The field was utilizing surfacewater for irrigation. With the extremely high temperatures and low rainfall the surfacewater was gone when the rice started heading. A nearby well was used to try and get water back on the field, but the well was not able to keep up with the demands of the rice and the August temperatures. Approximately 7 acres were affected by the shortage of water. Glyphosate drift was also apparent once the rice started to head. No visible symptoms of drift were observed prior to heading. Around 30 % of all panicles were severely affected as well as the yield (135 bu/acre).

Cybonnet was the selected variety in Lawrence County, but a last minute good deal on XP 710 changed the variety. The soil test indicated very low potassium levels and 200 lb/acre of potash was applied. The field was seeded at 27 lb/acre with a germination of only 65%. As you can imagine, the RRVP coordinator was a little nervous. The coordinator took no chances and went ahead and flushed the field in order to get every seed possible emerged. The overall stand count was 10 plants/ft^2, which allowed the coordinator to relax a little. Areas of the field, especially the deepest cuts and areas where water stood, were thin and some spots were replanted. Overall, the field was in pretty good shape once emerged. Command was applied preemergence, and Facet was used postemergence followed by a second flush irrigation. Ammonium sulfate was applied prior to the flush in order to promote tillering and get the rice big enough to flood. Urea and the permanent flood were applied as soon as the soil in the field dried, about a week later. No significant disease pressure was observed. The field was treated for stink bugs and the field yielded a respectable 171 bu/acre.

Lee County was the second county in the program utilizing the furrow-irrigation production system. The field had similar problems as the Arkansas County furrow-irrigated field. One problem that was different was the height of the beds. In Arkansas County they were too high, but in Lee County they were too low. The field was no-tilled onto last year's bean rows. Everything looked fine until the well was turned on the first time. The low beds allowed the water to break over the beds and many of the middles were not being watered. A lot of hard work by the cooperator corrected the problem. Weed control was challenging in this field as well, but for a different reason. The field was no-till and glyphosate-resistant horseweed was everywhere. Regiment was applied and provided excellent control of this hard-to-kill weed. Bill bugs were also a problem in this field. The panicle loss in the Lee County field was greater than that observed in Arkansas County. The heads were white and blanked out down every middle in the field. The yield loss was significant, and there are no known treatments for this insect. This production practice has potential on certain fields, but this is not something that can be adapted across the farm. For the furrow-irrigated production system to remain viable, there are many areas that need to be researched.

The Lonoke County 1 field recorded the highest yield in the history of the RRVP program at 217 bu/acre. The field was seeded with CLXP-730. Newpath and Command were applied preemergence and provided excellent early-season control of grasses and sedges. The preemergence application timing with Newpath was chosen due to sensitive crops and to ensure that two applications were possible. Very little Newpath injury was observed in this field. Some stunted plants were found, but there was no visible chlorosis or dead plants following Newpath applications. Northern jointvetch was present in the weed spectrum. Grandstand combined with 1 qt/acre of propanil, instead of crop oil, provided excellent control of this troublesome and hard-to-kill weed.

The Lonoke County 2 field was also planted late due to the weather in mid-April. The field was seeded with Wells and reached flood stage quickly due to the warm temperatures and ideal growing conditions. The field had a history of poor yields which was one of the reasons this field was chosen for the program. The field was being treated like the surrounding fields that were producing 30 to 50 bu/acre more rice. The soil samples did not provide much help as far as diagnosing the problem because all of the nutrient levels were above thresholds that trigger fertilizer applications. The field had been leveled over 20 years ago, and the problem also was visible in the soybean crop every year as well. The problem turned out to be extremely low sulfur in areas of the field and 100 lb/acre of ammonium sulfate were applied. The soil samples were mixed between the good and bad parts of the field, which gave the appearance that the field average nutrient levels were acceptable. This is a common problem with soil sampling, and is one reason multiple samples should be taken. Even with the sulfur deficiency, the field yielded a respectable 176 bu/acre.

Mississippi County was a broadcast-seeded field of Wells. This was actually two 40-acre precision-leveled fields. This field was in the program last year so it was following rice. The field was flushed following the Command application with a center pivot and came up to a stand at 15 plants/ft^2 compared to last year's 20 plants/ft^2. There were areas of the field that were thinner than the average. RiceStar was used postemergence and did an excellent job as conditions were just right for the application. The herbicide was applied in the mud. Blazer was used for coffeebean control and part of the field was treated with permit for yellow nutsedge. The yield this year was 154 bu/acre, which was 15 bu/acre less than last year. The only differences one can attribute this to were a thinner stand and rice following rice. The nitrogen rate was increased as recommended, however, total nitrogen-per-acre applied last year was a little more. Last year the nitrogen was applied as urea at rates of 230 lb, 100 lb, and 70 lb/acre (preflood, mid-season, boot). This year 300 and 100 lb/acre (preflood, mid-season) of urea were applied.

The field in Phillips County was the best-looking field in the program and the worst-looking field with only 7 days in between. Glyphosate almost destroyed the entire field. When looking at the field, Glyphosate drift was not suspected because there was no drift pattern. The entire field was affected and critical decisions had to be made. The weeds were still growing, but herbicide could not be applied due to the injured rice. Fertilize and flush was the only option. Ammonium sulfate (100 lb/acre) was applied and flushed into the soil to try and stimulate growth. At one time replanting was discussed, but the decision was made to give it a few more days. Slowly but surely, green started appearing across the field. However, the grass and sedges were way ahead of the rice in development. It took two herbicide applications to get the weeds under control. The field yielded more than anyone thought possible with everything that had happened. The yield was 197 bu/acre. It was hard to believe that the field that was only a couple of days away from replanting had done so well. This fits with previous research findings that show if drift occurs prior to the reproductive stages, the yield will not be affected if the plant density is not significantly reduced.

The Poinsett County 1 field was planted mid-April in Wells. This field has a history of grape colaspis injury so the seeding rate was increased to 105 lb/acre to compensate. Mustang Max was applied with the Command on one-half of the field in order to evaluate it as a control option. This year, however, no significant pressure was observed. RiceStar was used for barnyardgrass control, and 30 acres were sprayed with Grandstand for Indigo. The field looked excellent up until the preflood nitrogen was applied. It became apparent quickly that the field had been streaked. Additional nitrogen was flown in the streaks, by another pilot, but the yield loss could never be made up. The field yielded a disappointing 145 bu/acre. This field also had a lot of blanking, which was attributed to high nighttime temperatures during flowering. It appears that fields planted in mid to late April in Poinsett, Jackson, and other counties were affected.

The Poinsett County 2 field was 9 acres, seeded in XP 723. An area in the middle of the field stayed wet and was very thin. It ended up filling in and looking fair by the end of the season. The field was hit early by water weevils and aphids. The rice plants had heavy feeding scars and appeared yellow and stunted. The field was sprayed with Mustang Max. Later, the field reached treatment level for water weevils for a second time. The field was sprayed again with Karate. The main problem with the field was that the pilot told us he had applied the preflood urea. After the field was flooded, it was determined that the urea had not been applied. The field was drained, and we started over. It is difficult to recover from a set-back like this. After the soil is saturated, the nitrogen does not move down in the soil like it should. The field yielded 168 bu/acre, which is much lower than the potential of this variety.

The Prairie County field was seeded in Cheniere on 16 May. Wet weather in April delayed planting in this field. Glyphosate and Command were applied behind the planter. The Command was not activated until the following rainfall a couple of weeks later. Some barnyardgrass and broadleaf signalgrass emerged. RiceStar was applied to wet soil and controlled the grass weeds. The field reached treatment level for stink bugs and Karate was recommended for control. Over the next 2 weeks, the stink bug numbers continued to increase. It was determined that the field may not have gotten sprayed. It is uncertain as to what happened, but the field was sprayed again with excellent results. The parties involved donated the insecticide and flying for the second application. Glyphosate and Valor drifted onto the field from a burndown application to the adjacent soybean field. The rice started to recover until the flood was applied and then the Valor was activated. The affected areas in the field were severely injured, which affected the overall yield in the field. The non-affected areas were much better than the average yield on this field of 157 bu/acre.

This was the second year in the program for the field in Randolph County. A couple of changes were made this year from what was learned last year. The seeding rate was reduced by 10 lb/acre and fewer levees were constructed in order to more effectively water the field. No benefit from Agrotain was observed last year so it was not used this year. The composite soil test did not indicate the need for phosphorus-fertilizer, only potassium and zinc. As a result, a large area in the field was phosphorus deficient. The area recovered to some extent, but yields were reduced in that area. This field was sprayed with Quadris for sheath blight. The disease appeared later this year, due to weather and a thinner stand. The field was treated with a low rate (6.4 oz/acre) of Quadris for control. The field yielded 186 bu/acre this year compared to last year 190 bu/acre. It just takes one small area in the field to reduce yields by a few bushels per acre. The field overall was as good as or better than last year.

The field in St. Francis County was one of the most inexpensive fields in the program. Command did an excellent job of controlling grasses. No postemergence grass herbicide was applied. This is the main reason for the herbicide cost being $38/acre, which is well below the average. Hemp sesbania, yellow nutsedge, and morningglory species were treated with Aim and Permit. Most of the time this combination of herbicides works; however, antagonism can occur. Aim provided excellent control of morningglory, but failed to control hemp sesbania. Disease pressure was also light and sheath blight was hard to find. The field did have a history of kernel smut, and the variety was Francis, so Quilt was applied at 14 oz/acre and no smut was observed.

The White County Field was the only water-seeded field in the program. The field was water-seeded in order to control red rice and the method was convenient for the producer. Soaking and pre-germination of the seed were recommended, but were not done. A poor stand was achieved in this field due to seed midge and the use of non-soaked seeds. Three applications of Glyphoste for "burndown" of weeds prior to seeding were applied. The field was flooded after the final glyphosate application. The seed was flown into the flood and the flood maintained until 1-in. leaves were observed on the plants. The field was then drained for "pegdown" before the plants started to float. Red rice control was not achieved in this field. Multiple emergences of red rice occurred. Command and Regiment were applied by air for control of barnyardgrass and ducksalad. The herbicide did an excellent job, however, severe root pruning occurred. The plants took a very long time to recover from the loss of roots. Nitrogen uptake was most likely affected as well. Blast disease appeared in the field, especially in areas where the flood was lost, late in the season and caused significant yield loss. This was the lowest-yielding field in the program at 100 bu/acre.

On-Farm Research

Research was conducted in many of the verification fields in 2006. Disease monitoring tests were planted in nine RRVP fields. This provides information on how varieties perform under various environmental conditions and different soil types across the state. The highest yielding variety in 2006 was CL XL 729 at 262 bu/acre in Randolph County. Hybrid yields ranged from 173 bu/acre to 262 bu/acre in Randolph County. Wells and Francis also performed well with yields averaging 204 bu/acre and 207 bu/acre, respectively. Blast disease was severe in the Arkansas County location and varieties were evaluated for resistance in that location.

Infrared Photography

Infrared photographs were taken during the growing season of each field in the program with the exception of Crittenden, Lafayette, and Poinsett 2 counties. While several patterns were observed that could be related to certain field conditions (e.g., water management problems and cold water areas), it is still necessary to "ground-check" what is observed in the photographs. While the photos may indicate a potential problem and how widespread it is in the field, the ability to diagnose a specific problem is not yet possible. There may be potential uses for this new technology in the future; however, further research is required.

SIGNIFICANCE OF FINDINGS

Data collected from the 2006 RRVP reflect the general trend of increasing rice yields and above-average returns in the 2006 growing season. Analysis of these data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

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Table 1. Variety, soil series, previous crop, acreage, grain yield, and milling yield for the 2006 RRVP by county.

County	Variety	Soil series	Previous crop	Acres	Grain yield	Milling yield[z]
					(bu/acre)	
Arkansas	XP 723	Rilla silt loam	Soybean	51	155	65/74
Clark	Cybonnet	Tuscumbia silty clay	Rice	71	104	60/70
Clay	Wells	Jackport silty clay	Soybean	36	153	54/72
Craighead	CL XL 730	Hilleman silt loam	Soybean	85	213	60/70
Crittenden	Wells	Sharkey silty clay	Rice	24	124	54/70
Desha	XP 723	Perry clay	Rice	27	207	64/73
Independence	Wells	Egam silt loam	Soybean	60	199	60/73
Lafayette	Cocodrie	Billyhaw clay	Rice	60	135	48/71
Lawrence	XP 710	Dubbs silt loam	Rice	32	171	54/72
Lee	Cheniere	Calloway silt loam	Soybean	42	142	59/69
Lonoke 1	CL XL 730	Hebert silt loam	Soybean	48	217	51/71
Lonoke 2	Wells	Rilla silt loam	Soybean	35	176	67/73
Mississippi	Wells	Sharkey clay loam	Rice	80	154	60/70
Phillips	Francis	Dubbs silt loam	Soybean	48	197	53/69
Poinsett 1	Wells	Hilleman silt loam	Soybean	80	145	59/73
Poinsett 2	XP 723	Hilleman silt loan	Soybean	9	168	59/70
Prairie	Cheniere	Calloway silt loam	G.Sorghum	37	157	65/72
Randolph	Wells	Crowley silt loam	Rice	64	186	59/71
St. Francis	Francis	Crowley silt loam	Soybean	150	173	61/71
White	Cheniere	Jackport silty clay	Soybean	64	100	50/69
Average				55	164	58/71

[z] Head rice / total white rice.

Table 2. Stand density, irrigation, seeding rate, and important dates in the 2006 RRVP season by county.

County	Stand density	Rainfall	Irrigation^z	Rainfall + Irrigation	Seeding rate	Planting date	Emergence date	Harvest date
	(plants/ft^2)	------------------	(acre-in.)	------------------	(lb/acre)			
Arkansas	7	10	31	41	29	13 Apr	24 Apr	22 Sept
Clark	26	8	14	22	120	20 May	30 May	11 Oct
Clay	16	24	30	54	80	11 Apr	25 Apr	25 Sept
Craighead	10	15	30	45	30	4 Apr	17 Apr	30 Aug
Crittenden	16	7	30	37	100	22 May	29 May	5 Sept
Desha	5	6	48	54	29	16 May	28 May	15 Sept
Independence	21	18	30	48	80	10 Apr	21 Apr	5 Sept
Lafayette	13	6	30	36	110	2 Apr	21 Apr	2 Sept
Lawrence	10	15	23	38	27	10 Apr	24 Apr	12 Sept
Lee	22	13	46	59	100	5 Apr	11 Apr	1 Sept
Lonoke 1	5	6	49	55	28	19 Apr	1 May	12 Sept
Lonoke 2	18	7	30	37	100	18 May	1 June	5 Oct
Mississippi	15	17	35	52	120	5 Apr	19 Apr	1 Sept
Phillips	15	11	48	59	55	9 Apr	26 Apr	20 Sept
Poinsett 1	25	18	26	44	105	14 Apr	23 Apr	15 Sept
Poinsett 2	7	18	30	48	24	10 Apr	20 Apr	30 Aug
Prairie	17	7	22	29	70	16 May	26 May	1 Oct
Randolph	22	17	35	52	84	10 Apr	20 Apr	18 Sept
St. Francis	28	13	30	43	90	8 Apr	21 Apr	7 Sept
White	18	16	30	46	120	21 Apr	2 May	10 Oct
Average	15.8	12.6	31.6	44.2	75			

^{z} An average of 30 acre-inches was used for fields not utilizing flow meters.

Table 3. Soil test results for RRVP 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	5.9	64	175	6	100-100-60	138	21-0-0-0.15-18[w]
Clark	5.8	25	21	4.5	275-150	191	0-0-0
Clay	6.0	60	258	11	250-100	158	0-36-72-0
Craighead	6.1	19	178	9.5	195-70	119	0-60-80-10
Crittenden	7.3	110	566	10.2	300-0	155	20-23-0-0-9[w]
Desha	6.6	26	718	7.2	250-60	157	18-46-0-0.15
Independence	6.5	55	190	21	230-100	149	0-45-60
Lafayette	7.1	52	994	8.4	300-100	198	18-46-0-0
Lawrence	5.5	112	190	7	195-70	119	0-0-120-0.15-18[w]
Lee	6.0	126	152	4.6	150-100-100	158	0-0-100-0
Lonoke 1	5.8	92	410	6	150-60	116	21-60-0.15-18[w]
Lonoke 2	5.2	148	236	15.6	230-100	169	21-46-100-10-18[w]
Mississippi	6.5	45	590	8	300-100	180	0-25-50-0
Phillips	6.5	38	154	9	100-175-75-75	209	0-45-80-0
Poinsett 1	7.5	24	156	3.4	230-100	149	0-45-80-0.15
Poinsett 2	7.6	30	130	16.6	170-70	129	21-45-80-0.15-18w
Prairie	7.3	40	172	9	250-100	190	0-36-72-0.5
Randolph	6.2	77	175	5	272-100	168	0-0-90-10
St. Francis	6.7	50	224	4	230-100	149	0-60-60-10
White	6.0	38	135	4	190-100	149	18-46-0-0

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

[y] Preflood-midseason-boot.

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

[w] A.S. flushed in 2- to 3-leaf rice.

Table 4. Selected variable input expenses from 2006 RRVP fields by county.[z]

County	Variety	Seed[y]	Fertilizer[x]	Herbicides[x]	Fungicides[x]	Insecticides[x]	Fuel[w]	Irrigation[v]
		---	--------------------------	------(Input cost /acre)	----------------------------	----------------------------	----------------------------	----------------------------
Arkansas	XP723	$92.10	$81.95	$101.12	$0.00	$5.50	$13.43	$88.53
Clark	Cybonnet	$17.18	$82.87	$62.41	$23.19	$0.00	$12.02	$18.07
Clay	Wells	$12.83	$94.90	$36.91	$0.00	$0.00	$21.19	$73.79
Craighead	CLXP730	$96.10	$72.50	$51.06	$0.00	$10.11	$22.78	$73.82
Crittenden	Wells	$15.00	$61.39	$30.69	$0.00	$0.00	$16.25	$53.60
Desha	XP723	$86.64	$81.72	$67.91	$0.00	$11.59	$11.08	$117.63
Independence	Wells	$12.68	$84.24	$16.32	$23.19	$12.52	$19.14	$73.79
Lafayette	Cocodrie	$13.50	$97.27	$52.85	$0.00	$21.54	$11.18	$43.32
Lawrence	XP710	$45.12	$94.92	$39.15	$0.00	$11.29	$18.04	$62.99
Lee	Cheniere	$16.50	$68.25	$122.11	$0.00	$6.76	$10.71	$118.25
Lonoke (1)	CLXP730	$92.97	$59.95	$69.70	$0.00	$0.00	$13.44	$126.32
Lonoke (2)	Wells	$17.47	$112.87	$83.35	$23.19	$0.00	$12.43	$44.07
Mississippi	Wells	$18.83	$90.82	$58.17	$0.00	$0.00	$13.00	$85.98
Phillips	Francis	$8.92	$122.35	$102.58	$0.00	$0.00	$14.32	$123.88
Poinsett (1)	Wells	$21.18	$100.48	$46.29	$0.00	$0.00	$15.06	$65.78
Poinsett (2)	XP723	$74.36	$96.07	$60.99	$0.00	$23.08	$13.32	$54.35
Prairie	Cheniere	$10.50	$102.37	$34.75	$0.00	$10.77	$25.46	$54.35
Randolph	Wells	$17.46	$102.09	$32.85	$18.82	$0.00	$17.84	$85.99
St. Francis	Francis	$14.85	$85.08	$38.50	$17.31	$0.00	$14.41	$80.79
White	Cheniere	$22.67	$80.09	$56.90	$0.00	$0.00	$12.48	$73.79
Average	2006	$35.34	$88.61	$58.23	$5.29	$5.66	$15.38	$75.95
Average	2005[u]	$26.68	$99.89	$52.17	$13.32	$1.35	$22.30	$92.65
Change[t]		$8.66	$-11.28	$6.06	$-8.04	$4.31	$-6.92	$-16.70

[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.

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

[u] Average costs from 2005 RRVP Fields using 2005 costs of production.

[t] Change in average costs from 2005 to 2006.

Table 5. Herbicide rates and timings for 2006 RRVP fields by county.[z]

Arkansas	**PRE[y]:** Command (0.5 pt) Facet (0.25 lb); **POST:** Aim (1.5 oz) Prowl (2.4 pt); **LATE POST:** Duet (3 pt) Permit (0.5 oz) Facet (0.25 lb); **MID-SEASON:** 2-4,D
Clark	**PRE:** Command (1.5 pt); **POST:** Propanil (4 qt) Facet (0.5 lb)
Clay	**PRE:** Command (0.66 pt) Glyphosate (0.75 qt); **POST:** Propanil (4 qt)
Craighead	**POST[x]:** Clearpath (0.5 lb) fb Newpath (4 oz)
Crittenden	**PRE:** Facet (0.5 lb) Prowl (2.4 pts)
Desha	**PRE:** Command (1.5 pt); **POST:** Propanil (4 qt) Facet (0.5 lb)
Independence	**PRE:** Glyphosate (0.75 qt) 2,4-D (1 pt) fb Command (1pt)
Lafayette	**PRE:** Command (1.5 pt); **POST:** Facet (0.4 lb) Permit (0.75 oz) Aim (0.66 oz)
Lawrence	**PRE:** Command (0.8 pt); **POST:** Facet (0.5 lb)
Lee	**PRE:** Glyphosate (0.75 qt) Command (0.8 pt); **POST:** Facet (0.5 lb) Regiment (0.4 oz); **LATE POST:** Ricestar (24 oz) Aim (1.5 oz)
Lonoke 1	**PRE:** Command (1.5 pt) fb Newpath (4 oz); **POST:** Newpath (4 oz) Grandstand (0.66) Propanil (1 qt)
Lonoke 2	**PRE:** Command (0.8 pt); **POST:** Facet (0.5 lb); **POSTFLOOD:** Clincher (15 oz)
Mississippi	**PRE:** Command (1.5 pt); **POST:** RiceStar HT (22 0z) on 50 acres fb Permit (1 oz) on 40 acres fb Ultra Blazer (0.5 pt)
Phillips	**PRE:** Command (0.8 pt); **POST:** Facet (0.5 lb) Duet (3 qt) Permit (0.5 oz); **LATE POST:** Clincher (15 oz)
Poinsett	**PRE:** Glyphosate (1 qt) 2,4-D (1.5 pt) fb Command (0.8 pt) Glyphosate (0.5 qt) fb RiceStar HT (17 oz) fb Grandstand (0.67 pt) Stam (1 qt) on 30 acres
Poinsett	**PRE:** Command (1 pt) Glyphosate (1 qt); **POST:** Aim (1.5 oz) Permit (.67 oz) fb RiceStar HT (17 oz)
Prairie	**PRE:** Command (0.8 pt) Glyphosate (1 qt); **POST:** RiceStar HT (17 oz)
Randolph	**PRE:** Command (1 pt); **POST:** Propanil (3 qts)
St. Francis	**PRE:** Command (0.8 pt); **POST:** Aim (1.5 oz) Permit (1 oz)
White	**PRE:** Glyphosate (1 qt) fb Glyphosate (1 qt); **POST:** Regiment (0.6 oz) Command (1 pt)

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

[y] PRE=pre-emergence.

[x] POST=post-emergence.

Table 6. Fungicide and insecticides applications in 2006 RRVP fields by county.

County	Sheath blight	Blast	Kernel smut	Rice water weevil	Rice stink bug
Arkansas	------	------	------	------	Mustang Max (4 oz)
Clark	Quadris (8.5 oz)	------	------	------	------
Clay	------	------	------	------	------
Craighead	------	------	------	------	Karate (1.4 oz)
Crittenden	------	------	------	------	------
Desha	------	------	------	------	Karate (1.6 oz)
Independence	Quadris (8.5 oz)	------	------	------	Karate (2.13 oz)
Lafayette	------	------	------	Karate (1.6 oz)	Karate (1.6 oz)
Lawrence	------	------	------	------	Karate (1.4 oz) Mustang Max (0.7 oz)
Lee	------	------	------	------	------
Lonoke 1	------	------	------	------	------
Lonoke 2	Quadris (8.5 oz)	------	------	------	Karate (1.6 oz)
Mississippi	------	------	------	------	------
Phillips	------	------	------	------	------
Poinsett 1	------	------	------	------	------
Poinsett 2	------	------	------	Mustang Max (3.25 oz) fb Karate (2 oz)	------
Prairie	------	------	------	------	Karate (1.6 oz)
Randolph	Quadris (6.4 oz)	------	------	------	------
St. Francis	------	------	Quilt (14 oz)	------	------
White	------	------	------	------	------

Table 7. Economic analysis of fields from 2006 RRVP by county.[z]

County	Yield	Milling yield	Crop price[y]	Specified direct expenses[x]	Specified ownership expenses[w]	Net land costs[v]	Return above direct costs	Return above total costs	BEP[u] to equal operating costs	BEP to equal total costs	Milling yield contributions to gross returns[t]
	(bu/acre)		($/bu)	----------------------------------($/acre)------------------------------					----------($/bu)---------		($/acre)
Arkansas	155	65/74	4.34	493	43	125	55	12	3.90	4.24	51.36
Clark	104	60/70	4.13	294	39	80	56	17	3.46	3.93	12.31
Clay	153	54/72	4.03	348	52	114	155	103	2.77	3.19	3.62
Craighead	213	60/70	4.13	470	58	163	246	189	2.68	3.02	25.21
Crittenden	124	54/70	3.99	263	46	91	140	94	2.58	3.04	-2.94
Desha	207	64/73	4.30	510	35	165	214	178	3.00	3.22	58.80
Independence	199	60/73	4.20	370	52	155	311	259	2.25	2.57	37.68
Lafayette	135	48/71	3.87	331	38	96	95	57	2.99	3.34	-19.17
Lawrence	171	54/72	4.03	392	48	128	170	123	2.79	3.14	4.05
Lee	142	59/69	4.08	442	37	107	30	-7	3.82	4.15	10.08
Lonoke (1)	217	51/71	3.94	504	42	158	193	151	2.83	3.07	-15.41
Lonoke (2)	176	67/73	4.37	401	39	143	224	186	2.77	3.05	62.49
Mississippi	154	60/70	4.13	371	39	118	147	108	2.94	3.25	18.23
Phillips	197	53/69	3.94	503	42	143	130	88	3.12	3.38	-13.99
Poinsett (1)	145	59/73	4.18	353	47	112	140	95	2.97	3.36	24.03
Poinsett (2)	168	59/70	4.11	438	40	128	124	84	3.18	3.48	15.91
Prairie	157	65/72	4.30	351	61	125	198	137	2.72	3.20	44.59
Randolph	186	59/71	4.13	400	48	142	226	178	2.61	2.93	22.01
St. Francis	173	61/71	4.18	366	45	134	222	178	2.57	2.89	28.66
White	100	50/69	3.87	328	38	71	-12	-50	4.03	4.50	-14.20
Average 2006	164	58/71	4.11	396	44	125	153	109	3.00	3.35	17.67
Average 2005	170	56/71	3.25	430	48	101	13	(35)	3.20	3.55	4.68
Changes	-6	--	0.86	-34	-4	24	140	144	-0.20	-0.20	12.99

continued

Table 7. Continued.

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[z] 20% crop-share rent was assumed.

[y] Loan rate milling value plus $1.05/bu premium.

[x] Includes all variable expenses from Table 6 plus drying, hauling, miscellaneous custom expenses, fuel, repairs, labor for field operations, and interest on operating capital.

[w] Excludes ownership expenses of irrigation well.

[v] Gross value of landlords 20% share of crop less drying charges.

[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] Averages from 2005 RRVP fields and the change from 2005 to 2006.

BREEDING, GENETICS, AND PHYSIOLOGY

Utilization of Trait-Linked DNA Markers in Rice Breeding

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ABSTRACT

DNA marker technology is being used in U.S. rice breeding programs to enhance development of rice cultivars with improved cooking quality and genetic resistance to rice blast disease. Because there is a continuous threat of race shifts within the *Magnaporthe grisea* populations found in rice fields that can lead to a breakdown in host-plant resistance, it is important to identify and pyramid additional sources of resistance into new cultivars. Frequently, though, highly disease-resistant cultivars possess other agronomic traits that are undesirable, including cooking qualities that are unacceptable for U.S. market classes. Simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers linked to these specific traits are used to predict cooking quality of the milled grain and screen for blast-resistance genes. A major focus of using DNA markers in the breeding process is to be able to efficiently select progeny of segregating populations with both improved blast-disease resistance and good cooking quality with marker-assisted selection (MAS). The markers can also be used to resolve issues of seed purity, cultivar identification, and correlation between genotype and phenotype. Recently the emphasis has been on using markers to genotype a collection of elite breeding lines. Genotyping this working germplasm collection gives the breeders additional information regarding the genetic background, diversity, and potential of the parental material. Over 15,000 individual genomic DNA samples were processed for MAS in 2006, and up to 27 trait-linked markers were used in their analysis.

INTRODUCTION

MAS can be a useful tool to enhance efficiency and accelerate the development process of improved germplasm by using molecular markers that are linked with important agronomic traits. However, considering the effort and expense of DNA marker analysis, it is important that the MAS program itself be as efficient as possible.

The foundation of any plant-breeding program is its germplasm collection, and it is important that it be well characterized so that the breeder can improve chances of success in developing lines for commercial release. With the impetus in recent years of using exotic cultivars and landraces to broaden the breeders' germplasm base (Eizenga et al., 2006), this characterization has become even more important. Data from genotyping the parental material make the MAS program more efficient by determining not only which current cross populations would benefit from marker analysis, but also which breeding lines to use as parents in future crosses and which cross combinations to make.

Molecular markers linked to the loci for the rice blast-resistance genes *Pi-b*, *Pi-i*, *Pi-k*^{h}, *Pi-k*^{s}, *Pi-ta*, and *Pi-z* (Conaway-Bormans et al., 2003; Fjellstrom et al., 2004, 2006; Jia et al., 2004) and the cooking quality traits of amylose content, amylopectin content, starch pasting properties, gelatinization temperature, aroma, and elongation (Bao et al., 2002; Bergman et al., 2001; McClung et al., 2004; M. Chen, pers. comm.) were used to genotype the germplasm collection and subjected to a cluster analysis.

MAS testing usually begins in the F_3 generation using an SNP marker for *Pi-ta* and an SSR marker (RM 190) associated with the *Waxy* gene, which plays a role in determining amylose content. After the first round of MAS, progeny of parents that may possess other sources of resistance or desirable cooking traits undergo a second series of marker analyses for additional blast and grain quality genes.

The objectives of this study are to (i) apply MAS to the projects of the breeding program at UA RREC, thus increasing the efficiency of selection and development time of new lines, (ii) determine the haplotype of a working germplasm collection at the loci for rice blast resistance genes and cooking quality traits, and (iii) develop a core collection of cultivars with the most diverse genetic backgrounds as determined by cluster analysis. This effort has been greatly accelerated by switching to a 384-well PCR plate format and the incorporation of small-scale liquid-handling robotics into the program.

PROCEDURES

For quick screening of large populations, seedling leaf tissue was harvested into manila coin envelopes and either sampled fresh or stored at -80°C until sampled. Sampling was performed with a single-hole punch, and the DNA was extracted using sodium hydroxide/Tween 20 and neutralized with 100mM Tris-HCl, 2 mM EDTA. Alternatively, if the DNA required long-term storage, the leaf tissue was harvested as for the rapid prep, stored at -80°C for a minimum of two hours, then lyophilized in a Virtis Freezemobile 25XL (VirTis, Gardiner, N.Y.) for 24 hours. Total genomic DNA was extracted using a modified PEX/CTAB/organic extraction method (Williams and Ronald, 1994; R.J. Fjellstrom, pers. commun.). Purified DNA samples were solubilized in TE buffer pH 8.0 and stored at 4°C. A 1:5 dilution was made of each sample and arrayed in a 96-well format and 2 µl of template used for each 25 µl PCR analysis, 1 µl for each 10 µl reaction.

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 thermalcycler (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 (Eppendorf North America, Inc., Westbury, N.Y.), separated on an Applied Biosystems 3730 DNA Analyzer, and analyzed using GeneMapper Software (Applied Biosystems, Foster City, Calif.).

Apparent amylose contents were determined by preparing the samples according to AACC method 61-03 (American Association of Cereal Chemists, 2000), and color development and measuring were performed on an AutoAnalyzer 3 Digital Colorimeter (Bran Luebbe, SPX Process Equipment, Delavan, Wis.).

Twenty-six markers were used for the cluster analysis. The genetic distance matrix developed according to Nei (1983) was used to determine the clusters of genotypes applying the Neighbor-Joining method employing NTSYSpc 2.02 (Rohlf, 1997).

RESULTS AND DISCUSSION

Molecular markers were used to analyze individual DNA samples for the purposes of screening segregating populations, identifying those progeny possessing desirable alleles, and discarding progeny with undesirable alleles (Table 1). Other uses for molecular markers included correlating with phenotypic data (Table 2), identifying the relatedness of the parental lines as visualized in the cluster analysis (Fig. 1), and developing a core collection of the most genetically diverse lines for future crossing (Table 3). Both the cluster analysis and core collection will evolve as additional marker data are added, including those not linked with any specific traits but rather spanning the entire rice genome. MAS was performed in the F_3 generation, and repeated in the F_4 generation, to further screen those lines that were comprised of heterozygous individuals in the F_3 generation.

The *Pi-ta* SNP and RM 190 markers were used to screen 9,037 F_3 individuals representing 1,291 lines from 56 different crosses. Based on combined marker data, material was discarded from the crosses. In some cases the entire cross was discarded; in others the entire cross was kept. On average 64% of the material from this study was discarded in the early generation, thereby allowing for phenotypic selection of only those lines worthy of further development (Table 1).

One hundred thirty-five accessions from the working germplasm collection screened with markers for resistance could potentially possess those resistance genes.

Resistant alleles for the genes *Pi-b*, *Pi-i*, *Pi-k*^{h}, *Pi-k*^{s}, *Pi-ta*, and *Pi-z* were identified in 37, 17, 17, 29, 35, and 20 varieties, respectively.

Cooking quality markers identified 8 CT (Cook Type) classes in this germplasm collection. Data for RM 190 and *Waxy* Exon 1 SNP agreed. Apparent amylose contents matched the CT class, ranging from a low of 16% for medium-grain quality and a high of 26.4% for a high-amylose class. Gelatinization temperatures matched the data from the *Alk* gene SNP (Table 2).

Using Nei's genetic distance determination, the accessions clustered according to subspecies and origin (Fig. 1). They divided into two main clusters, improved *indica* and tropical/temperate *japonica*. This cluster analysis made it possible to identify a core collection of 18 accessions with the most diverse genetic backgrounds for use in future crosses (Table 3).

SIGNIFICANCE OF FINDINGS

Determining the haplotype of the working germplasm collection at specific trait-linked loci and developing the core collection of the most diverse genotypes from this genotyping data were made possible with the utilization of marker technology. This information enables the breeders to develop novel strategies to accommodate new challenges to crop success within the field environment and changing market demands. By enhancing traditionally acceptable breeding methods, DNA marker technology can be a vital tool to make all stages of the breeding process more successful.

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Table 1. Survey of 1,291 lines of 56 different F_3 populations.

Cross no.	Lines	Keep	Discard	% discard
040494	18	5	13	72.2
040495	325	181	144	42.9
040500	53	18	35	66.0
040501	92	48	44	47.8
040505	29	8	21	72.4
040506	13	8	5	38.5
040515	10	5	5	50.0
040516	26	3	23	88.5
040517	5	2	3	60.0
040519	56	6	50	89.3
040521	5	0	5	100.0
040522	13	6	7	53.8
040523	47	16	31	66.0
040526	7	4	3	42.9
040527	8	6	2	25.0
040528	50	3	47	94.0
040533	9	2	7	77.8
040537	10	0	10	100.0
040541	5	2	3	60.0
040543	21	2	19	90.5
040544	58	15	43	74.1
040545	5	1	4	80.0
040561	4	0	4	100.0
040562	4	0	4	100.0
040564	22	13	9	40.9
040567	28	4	24	85.7
040569	2	2	0	0.0
040571	20	3	17	85.0
040573	30	20	10	33.3
040575	4	2	2	50.0
040582	13	9	4	30.8
040583	16	6	10	62.5
040584	22	12	10	45.5
040586	7	2	5	71.4
040587	17	7	10	58.8
040589	9	4	5	55.6
040590	8	1	7	87.5
040591	9	0	9	100.0
040592	12	9	3	25.0
040595	17	17	0	0.0
040601	15	4	11	73.3
040608	4	1	3	75.0
040610	4	2	2	50.0
040617	7	0	7	100.0
040626	27	26	1	3.7
040627	4	1	3	75.0
040631	9	1	8	88.9
040633	8	2	6	75.0
050643	9	4	5	55.6
050682	17	11	6	35.3
050683	8	6	2	25.0

continued

Table 1. Continued.

Cross no.	Lines	Keep	Discard	% discard
050684	17	1	16	94.1
050706	13	0	13	100.0
050724	18	2	16	88.9
050727	16	12	4	25.0
050728	6	0	6	100.0
Totals	**1291**	**525**	**766**	**64.1**

Table 2. Cooking quality genotype compared with phenotype.

RM 190 (CT) Repeat	*Waxy* Exon 1	Ave. amylose	*Alk* gene	Gel temp
		(%)		(C°)
8	“G”-int-high	25.2	med-high	69.3
10	“G”-int-high	26.4	low gel	59.6
11	“G”-int-high	25.4	Mixed	64.3
14	“G”-int-high	22.7	med-high	68.9
17	Mixed	18.4	Mixed	66.4
18	“T”-low	16.7	low gel	63.7
19	“T”-low	16.0	low gel	64.2
20	“G”-int-high	22.9	med-high	67.2

Table 3. Working core collection.

No.	Acc. no.	Cultivar
1	84	UA99-128
2	40	PI 574663
3	75	Taipei 309
4	85	UA99-134
5	23	PI 248521
6	29	PI 414679
7	100	UA99-95
8	42	PI 584696
9	79	UA99-114
10	90	UA99-154
11	35	PI 560235
12	117	UA99-98
13	27	PI 350298
14	34	PI 431481
15	47	PI 584716
16	25	PI 319703
17	70	Mars
18	8	Earl

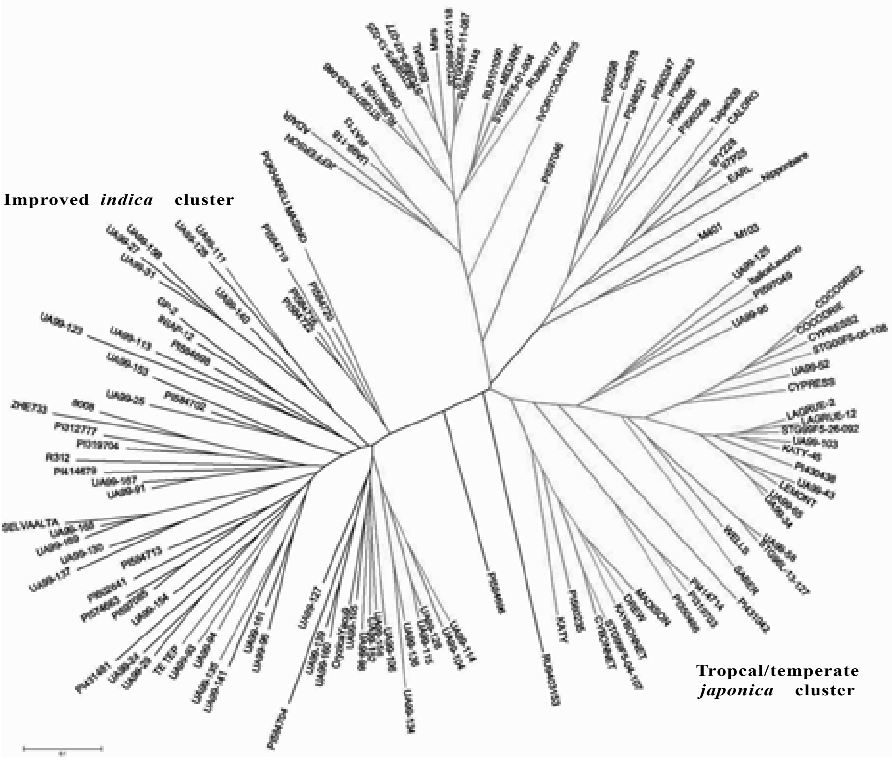

Fig. 1. Nei 1983 neighbor-joining tree with
135 accessions of the working germplasm collection.

BREEDING, GENETICS, AND PHYSIOLOGY

Screening of the Rice Breeder Germplasm (URRN's, ARTP's, and PRELIMS) to Seven Races of the Rice Blast Pathogen, *Pyricularia grisea*

E.J. Boza, J.C. Correll, F.N. Lee, K.A.K. Moldenhauer, and J.W. Gibbons

ABSTRACT

The rice blast pathogen *P. grisea* was used to screen about 1200 breeding lines from the rice breeder germplasm collection for resistance to blast. The germplasm was screened against nine isolates, representing seven physiological races of the pathogen, in a large-scale inoculation format. The isolates (and races) used were 49D (IB-49), 24 (IG-l), A264 (IC-17), ZN46 (IC-l), A598 (IB-49), TM-2 (race k), A119 (IB-49), ZN15 (IB-l), and ZN-7 (IE-I). The isolates represented several MGR586 DNA fingerprint groups as well as the two most commonly encountered races, IC-17 and IB-49, that predominate throughout Arkansas. Qualitative resistance was evaluated based on disease reactions in a standardized inoculation test after one infection period (approximately 7 days). A wide range of disease reactions was observed among the genotypes examined. The susceptible cultivar M201 had a range of disease reactions in the various tests of 6-8. Among the tests evaluated, 36 genotypes were ranked as highly resistant, 154 as resistant, 158 as moderately resistant, 124 as moderately susceptible, 144 as susceptible, and 210 as highly susceptible. Overall, isolate TM2 (race k, MGR586 Group *BNCG* US-02) was the most aggressive isolate used followed by 49D (race IB-49, MGR586 Group E/VCG US-93) isolate. A total of 98 of the most resistant genotypes were identified and tested in several additional tests to confirm resistance. The disease reactions observed should assist rice breeders in selecting advanced germplasm with blast resistance and should help in the development of rice cultivars with improved rice blast resistance.

INTRODUCTION

Rice *(Oryza sativa)* is second only to wheat in total acreage in the world and is grown on approximately 300 million acres annually (Rice Almanac, 2002; Ou, 1985). It is consumed by about 60% of the world population and it is expected that the global rice requirement will rise 1.7% annually between 1990 and 2025 (Zeigler et al., 1994). Rice blast *(Pyricularia grisea)* is a major disease and problem in all rice-growing regions of the United States. Host resistance to *P. grisea* can be among the most effective and economical management practices to reduce the impact of rice blast (Correll et al., 2000; Lee, 1994). However, as with most plant diseases, the durability of resistance to blast has been less than desirable (Lee, 1994; Marchetti, 1994).

Two *P. grisea* races, IB-49 and IC-17, predominate in the contemporary rice blast population in Arkansas (Correll and Lee, 1996). However, other races have been identified in the state and the great variability in pathogenicity among isolates has increased the difficulties of breeding resistant cultivars (Correll et al., 2000). Therefore, the potential for explosive and extensive blast damage still exists because of the reliance on a few major resistance genes for rice blast control (Lee, 1994; Marchetti, 1994). Thus, identifying major and minor resistance genes in the Rice Research and Extension Center (RREC) germplasm collection to races of the blast pathogen will assist our efforts to continue to develop rice cultivars with improved resistance to rice blast. Furthermore, greenhouse assays will assist in our efforts to develop molecular marker-assisted selection to enhance our knowledge of resistance genes in rice.

The objectives of this effort were a) to evaluate and characterize the breeder germplasm to the spectrum of genetic diversity of the rice blast pathogen with regard to virulence under greenhouse conditions in Arkansas; and b) to conduct additional pathogenicity tests to reevaluate and confirm resistance from the most resistant genotypes selected from the breeder germplasm.

MATERIALS AND METHODS

Germplasm used for disease screening was obtained from the Rice Research and Extension Center (RREC), University of Arkansas, Stuttgart, Ark. About 1200 genotypes from the Uniform Regional Rice Nursery (URRN), Preliminary tests (PRELIMS) and the Arkansas Rice Performance Trials (ARPT) were examined in a large-scale inoculation format. A subsequent pathogenicity test was performed to re-evaluate and to confirm the most resistant genotypes against all races evaluated. Seeds were seeded in a mixture of 2:1 local soil and Ready Earth® potting mix in a 50.8 x 35.5 x 6.9 cm Dyna-Flat™ (Hummert International) plastic tray in a 40-cell/tray format and grown in a greenhouse with temperatures of 28 to 30°C. Trays were fertilized with iron sulphate at a rate of 8 to 10 g per tray 1 to 2 days after planting. Fertilization with 20-20-20 (N, P, K/Peters) was applied at a rate of approximately 1 g/L 7 to 10 days after planting and a second time at the 1- to 2-leaf-stage. Plants were grown until the 3- to 4-leaf-stage (approximately 2 to 3 weeks) prior to inoculation. The cultivar M201 was included in all inoculations as a susceptible control.

Briefly, the isolates used for inoculation 49D (IB-49), 24 (IG-l), A264 (IC-17), ZN46 (IC-l), A598 (IB-49), TM2 (race k), A119 (IB-49), ZN15 (IB-l), and ZN7 (IE-I), were grown on rice bran agar for 8 to 10 days (Table 1). Seedlings at the 3- to 4-leaf stage were then inoculated with the rice blast pathogen at 2.0 x $l0^5$ spores/ml to which 0.5 to 1.0 ml of 2% Tween 20 was added to 50 to 100 ml of inoculum as a sticking agent. After inoculation, the plants were placed into a dew chamber at 100% relative humidity (RH) at approximately 21 to 22°C for 24 hours. The plants were then placed back into the greenhouse at approximately 28 to 30°C for 6 to 7 days and scored for disease reaction using a qualitative and quantitative standard rating scale from 0 to 9. A disease reaction of 0 to 3 was considered a resistant reaction whereas a reaction of ≥4.0 was a susceptible reaction. Controls included plants sprayed with water.

All the entries were ranked as highly resistant (HR) if the entry was resistant to all isolates examined; resistant (R) if resistant to all but 1 isolate; moderately resistant (MR) if resistant to 5 or 7 isolates; moderately susceptible (MS) if susceptible to 5 or 7 isolates; susceptible (S) if susceptible to all but 1 isolate; or highly susceptible (HS) if susceptible to all isolates examined.

RESULTS AND DISCUSSION

The contemporary rice pathogen population in Arkansas is composed of four distinct DNA fingerprints groups (A, B, C, and D) (Boza et al., 2003; Correll et al., 2000; Xia et al., 2000). A wide range of disease reactions was observed among the rice genotypes examined over this period but a consistently high susceptibility on cultivar M201, used as control, was observed. Eighty-nine genotypes were evaluated in the URRN 2001. Based on the ranking scale used to classify resistance, in the URRN 2001 there were 18 HR genotypes (Table 3), 23 were R, and there were 6, 20, 8, and 14 genotypes MR, MS, S, and HS, respectively. In the same test, isolate TM2 (race k) was the most aggressive with 51 S and 37 R of the genotypes evaluated followed by ZN46 (IC-l), A119 (IB-49), and 49D (IB-49) with 45, 42, and 41 S and 44, 47, and 47 R, respectively. Isolate 24 (IG-l) was the least aggressive with 16 S and 71 R. Isolates A264 (IC17), ZN15(IB-l) and ZN7 (IE-I) showed similar intermediate reaction among them.

One hundred and ninety-nine genotypes were evaluated in the URRN 2002. There were one and 10 genotypes HR (Table 3) and R, respectively, in the URRN 2002. On the other hand, 39, 23, 35, and 91 genotypes were MR, MS, S, and HS, respectively. Again, isolate TM2 was the most virulent with 185 S genotypes and 13 R; followed by ZN7 and 49D with 169 and 159 S genotypes and 30 and 40 R genotypes of the total entries examined in the URRN 2002. Isolate 24 was the least aggressive with 119 S genotypes and 80 R. A second test was conducted to reevaluate and confirm the most resistant genotypes in the URRN 2002. A total of 38 genotypes that were either HR, R, or with a circle-four reaction (borderline between Rand S) in the primary test were reevaluated to confirm their resistance to the nine isolates tested.

In the URRN 2003, 199 genotypes were evaluated. There were 6 (Table 3) and 31 genotypes with HR and R, respectively; 54, 26, 37, and 45 genotypes were MR, MS, S, and HS, respectively. Isolate 49D was the most virulent with 181 S genotypes and 18 R; followed by TM2 and ZN46 with 143 S and 56 R genotypes and 141 S and 57 R, respectively. The less aggressive isolate was A264 with 67 S genotypes and 132 R; followed by ZN7, Al19, ZN15, and isolate # 24 with 94, 97, 104, and 103 S genotypes and 105, 102, 96, and 95 R, respectively. A total of 31 genotypes were reevaluated and confirmed HR in a second pathogenicity assay against the same set of isolates used in the primary evaluation tests.

Two hundred genotypes were evaluated in the URRN 2004 with 6 (Table 3) and 64 genotypes classified as HR and R. Also, 32, 29, 45, and 24 genotypes were grouped as MR, MS, S, and HS, respectively. The most virulent isolates were 49D and TM2 with 157 and 119 S genotypes and 43 and 81 R, respectively. They were followed by ZN46, ZN15, A119, A598, A262, and ZN7, with 106, 101, 95, 91, 87, and 86 S genotypes and 92, 99, 105, 109, 112, and 114 R, respectively. Isolate # 24 was the least virulent with 39 S and 161 R. Twenty-nine genotypes were confirmed HR, R, or MR in an additional pathogenicity assay.

One hundred and three genotypes were examined for virulence reaction from the ARPT 2001. Two (Table 3) and 17 genotypes were classified as either HR or R, respectively; and 20, 17, 12, and 35 genotypes were grouped as MR, MS, S, and HS, respectively. The most aggressive isolates were TM2, ZN46, A119, 49D, and A598 with 87, 71, 69, 68, and 68 S genotypes and 15, 31, 33, 34, and 34 R genotypes, respectively. Isolates ZNI5, ZN7, A264, and 24 produced 65, 57, 49, and 42 S genotypes and 37, 45, 53, and 60 R genotypes, respectively.

We also evaluated the PRELIMS from 2001 and 2002 with totals of 36 and 360 genotypes, respectively. The PRELIMS 2001 generated 3 and 9 HR and R genotypes, respectively. Seven, nine, seven, and one genotypes were classified as MR, MS, S, and HS, respectively. The most aggressive isolates were TM2, A598, ZNI5, and 49D with 22, 21, 20, and 21 S genotypes and 11, 12, 13, and 14 R, respectively. Isolates A119, ZN46, 24, A264, and ZN7 produced 14, 20, 4, 14, and 12 S genotypes and 15, 15, 22, 22, and 23 R, respectively. In this test there were a number of genotypes that had poor germination and these genotypes were not evaluated in the test. The PRELIMS 2002 were evaluated against two races IB-49 (49D) and race k (TM2) only. When looking at the virulence reaction, 29 genotypes were R to both races. Additionally 85, 1, and 238 genotypes were R/S (R to IB-49/S to race k), *SIR* (S to *IB-49/R* to race k), and S (S to IB-49/S to race k), respectively. There were seven entries missed that were not tested in the pathogenicity assay. Moreover, isolate TM2 generated 320 S genotype and 33 R genotypes and isolate 49D produced 238 S and 115 R.

Overall, the resistant genotypes presented very similar levels of disease reaction against the composite group of isolates that represent seven different biological races that may possibly cause a threat to the rice industry especially in the southern states of the U.S. The vast majority of the HR and R genotypes were confirmed resistant in a second virulence test. About 100 genotypes from the breeder germplasm were confirmed as resistant to all races evaluated in this effort, indicating a broad genetic base for cultivar development.

SIGNIFICANCE OF FINDINGS

Efforts have been underway to characterize the breeder germplasms to new and potentially damaging races of the *P. grisea* pathogen and to effectively quantify minor gene resistance. Large scale, standardized inoculations have made it easier to directly compare genotypes for disease resistance and thereby reduce the inherent variability associated with disease screening with rice blast. A wide range of disease reactions was observed among the rice genotypes examined. Cultivar M201 showed a consistent very susceptible reaction. Overall, genotypes were classified as resistant (disease rating 0 to 3) and susceptible (disease rating 4 to 9). Additionally, the grouping of genotypes based on resistance and susceptibility to a determined number of isolates used in the screening effort helps to convey more meaningful ranking for rice breeders. A group of genotypes that have been ranked either HR or R over these tests offers a good genetic background for the development of future cultivars. In addition, many genotypes that rated 4 to 5 in the 0 to 9 rating scale may have some minor genes for resistance and be worthy of further examination under multiple inoculation tests in the greenhouse and under field epidemics to determine if resistance can be quantified.

Disease screening for blast resistance should continue to identify major and minor genes for disease resistance to common races in Arkansas. Efforts in the future should be to monitor and characterize molecular and virulence diversity of *P. grisea* in Arkansas under greenhouse and in field-screening tests to more effectively quantify minor gene resistance. The data presented indicate that developing a more complete knowledge of resistance genes in rice germplasm through the use of greenhouse studies continues to be a critical step in evaluating and utilizing both major and minor resistance genes in rice. Identifying germplasm with both major and minor (quantitative) resistance to the two common races in Arkansas, namely IB-49 and IC-17, will continue to allow plant breeders to improve yield and quality in rice cultivars by incorporating additional sources of resistance.

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Table 1. Isolates of *P. grisea* representing race diversity in Arkansas used to screen the rice breeder germplasm.

Isolate	MGR586 group[z]	VCG[y]	Race	Year	Origin
ZN15	A	US-01	IB-1	1996	TX
ZN46	A	US-01	IC-1	1996	FL
A598	A	US-01	IB-49	1992	AR
ZN7	B	US-02	IE-1	1995	TX
A264	B	US-02	IC-17	1993	AR
24	B	US-02	IG-1	1992	AR
TM2	B	US-02	race k	---	TX
A119	C	US-03	IB-49	1992	AR
49D	E	US-03	IB-49	1985	AR

[z] MGR586 DNA fingerprint group.

[y] Vegetative Compatibility Group.

Table 2. Summary of disease ranking of rice breeder germplasm evaluated against nine isolates of *P. grisea* in Arkansas.

Ranking[z]	2001 URRN[y]	2002 URRN	2003 URRN	2004 URRN	2001 ARPT[x]	2001 PRELIMS[w]
HR	18	1	6	6	2	3
R	23	10	31	64	17	9
MR	6	39	54	32	20	7
MS	20	23	26	29	17	9
S	8	35	37	45	12	7
HS	14	91	45	24	35	1
TOTAL	89	199	199	200	103	36

[z] According to the number of resistant or susceptible isolates. HR = Highly Resistant, R = Resistant, MR = Moderately Resistant, MS = Moderately Susceptible, S = Susceptible, HS = Highly Susceptible.

[y] Uniform Regional Rice Nursery.

[x] Arkansas Rice Performance Trials.

[w] Preliminary tests.

Table 3. Disease reaction of the most highly resistant genotypes from the URRN's, ARTP, and PRELIMS germplasms to nine isolates of *P. grisea* in Arkansas.

		MGR586 group (isolate) "race"									
No[z]	Variety	E (49D) "IB-49"	B (24) "IG-1"	B (A264) "IC-17"	A (ZN46) "IC-1"	A (A598) "IB-49"	B (TM2) "race k"	C (A119) "IB-49"	A (ZN15) "IB-1"	B (ZN7) "IE-1"	Rank
URRN 2001											
12	RU9503012	2	0	1	1	1	1	1	1	1	HR[y]
13	RU0001124	1	0	1	0	1	3	0	1	1	HR
18	RU9502008	3	1	2	2	1	3	3	1	3	HR
23	RU9903181	3	1	1	1	1	1	2	1	3	HR
29	RU0103029	3	1	1	3	1	1	3	1	1	HR
33	RU0004033	3	1	1	3	1	1	1	1	1	HR
37	RU9602074	3	2	1	2	2	2	1	2	2	HR
43	RU0103043	3	1	1	2	1	1	1	1	3	HR
46	RU9803181	3	0	2	2	2	1	1	1	1	HR
47	RU0001121	3	0	3	0	1	1	3	1	3	HR
64	RU9901164	2	1	1	0	1	1	1	1	1	HR
108	RU0101108	1	0	0	0	1	3	0	1	1	HR
121	RU0101121	3	1	0	2	1	1	1	1	0	HR
130	RU0101130	1	0	1	0	1	3	0	1	0	HR
143	RU0102143	3	1	3	3	3	3	3	3	3	HR
161	RU0101161	4	2	1	1	1	1	3	2	2	HR
176	RU0001176	1	0	1	1	1	1	1	1	1	HR
200	AB647	3	0	1	1	1	1	1	1	0	HR
URRN 2002											
22	RU0202022	1	0	0	0	0	3	0	0	3	HR
URRN 2003											
26	RU0103175	3	1	0	3	1	1	0	1	2	HR
27	RU0301027	3	0	0	0	0	1	0	0	0	HR
41	RU0301041	0	0	0	1	0	3	0	0	0	HR
42	RU0302042	3	1	0	3	0	3	0	1	1	HR
65	RU0302065	3	0	0	1	0	2	0	1	1	HR
120	PI629291	0	0	0	3	0	1	1	3	0	HR

continued

Table 3. Continued.

No^z	Variety	MGR586 group (isolate) "race" E (49D) "IB-49"	B (24) "IG-1"	B (A264) "IC-17"	A (ZN46) "IC-1"	A (A598) "IB-49"	B (TM2) "race k"	C (A119) "IB-49"	A (ZN15) "IB-1"	B (ZN7) "IE-1"	Rank
URRN 2004											
41	RU0301041	2	1	1	1	0	3	1	0	0	HR
104	RU0403104	3	0	1	1	3	1	0	0	1	HR
108	RU0401108	3	1	2	3	3	3	3	3	1	HR
120	PI629291	1	0	0	3	2	0	3	3	0	HR
182	RU0401182	1	1	1	1	0	1	0	0	1	HR
200	XL-8 Rice Tec	3	1	2	1	3	1	1	0	1	HR
ARTP 2001											
25	ZHE733	(4)^3	2	1	1	0	2	0	0	0	HR
93	RU9901164	1	0	1	0	0	3	1	0	0	HR

[z] Entry number assigned in the URRN's or ARTP's.

[y] HR= Highly Resistant.

Phenotypic Analysis of the 2006 MY2 Mapping Population in Arkansas

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S. Linscombe, J.H. Oard, and M.M. Blocker

ABSTRACT

The RiceCAP MY2 'Cypress'/'LaGrue' mapping population was evaluated in 2006 for phenotypic characteristics in Arkansas and Louisiana, as part of a coordinated effort to determine markers for milling. The population will be milled by researchers in Beaumont, Texas, at a later date. Three hundred twenty-five F_5 rice lines, parents, and six controls were planted at the Rice Research and Extension Center (RREC), Stuttgart, Ark. At germination, uniform stand was observed throughout the test. Date of first heading (HVS = Heading Variability Score) ranged from 2 to 3 (2 = all plants in rows within 2 to 5 days and 3 = all plants in rows within 6 to 10 days). A range of 22 days was observed in maturity among the progeny evaluated, ranging from 72 to 94 days. The parents were different in days to heading by only one day. Plant height ranged from 70 to 141 cm. The vast majority of the lines were harvested between 18 and 22% moisture content with a few exceptions below 18% and some that were harvested at 23 to 24% due to initial lodging. In general, a relatively later planting date in Arkansas might help to differentiate the recombinant inbreeding lines for milling quality.

INTRODUCTION

Rice (*Oryza sativa*) is one of the most important crops for the growing human population. By 2020, the world will need to produce 350 million tons more rice per year to feed an anticipated 3 billion more people than in 1992 (Rice Almanac, 2002). In addition to its economic importance, rice plays a major role as a model for cereal genomics because of its relative small genome of 440 Mbp and close relatedness to major cereals (Izawa and Shimamoto, 1996; Gale et al., 1998; Moore et al., 1995). The quest for high quality rice has been a major component in the development of improved germplasm in the U.S. Milling quality is part of a complex trait for which the genetic basis of inheritance is still under investigation (Dong et al., 2004).

The advent of DNA technology is providing new opportunities to develop elite rice germplasm with improved grain quality including milling performance, appearance, cooking, milling characteristics, and the recovery of milled head rice. Identification and mapping of genomic regions associated with controlling milling yield in rice will facilitate breeding of new rice varieties with high milling quality and therefore a better market price. The objectives of this study were to a) evaluate the MY2 mapping population in Arkansas for phenotypic characteristics and milling quality, and b) evaluate a relatively late planting that would help to differentiate the Recombinant Inbreeding Lines (RIL's) for milling quality.

MATERIALS AND METHODS

Parents and Population Development

Three hundred twenty-five F_4 lines of the MY2 Cypress/LaGrue mapping population were generated and provided to RiceCAP by Dr. Linscombe (Crowley, La.). The F_5 lines were grown in Crawley in 2005 to produce enough seed for replicated field trials at multiple locations (AR and LA) in 2006. Replicated controls that included original parents (Cypress and LaGrue), and six controls ('Trenasse', 'Madison', RT0134, 'Spring', 'Cocodrie', and MCR01277) were included in the field planting (Table 1).

Field Evaluations

During 2006, 325 F_6 rice lines, parents, and controls were planted at the Rice Research and Extension Center (RREC), Stuttgart, Ark., in a Crowley silt loam soil (fine, montmorillonitic, thermic Typic Albaqualfs) using a randomized complete block (RCB) design with two replications. Each rice line was planted in two-row plots approximately 2.5 feet long (12-in. row spacing). Quilt® fungicide at 21 oz/acre + Quadris® at 6 oz/acre, and Karate® insecticide at 2.5 oz/acre were applied at early booting and again 10 days later to prevent disease and stem borers, respectively. A third application of Karate® was needed to control stem boders. Frequency distributions, plots figures, and correlation analysis of family means were conducted using SAS 9.1 PROC FREQ, PROC PLOT, and PROC CORR (SAS Institute, N.C.).

RESULTS AND DISCUSSION

A uniform and consistent stand was observed throughout the trial at germination. The great majority (approximately 95%) of the rows had at least 1 plant every 2 in. of row length and about 5% had somewhat less (intermediate) than 1 plant every 2 in.

Parents (Cypress and LaGrue) had a normal and intermediate stand, respectively (Fig 1). Date of first heading (HVS = Heading Variability Score) ranged from 2 to 3 in a 1 to 5 scale (2 = all plants in rows start heading within 2 to 5 days and 3 = all plants in rows within 6 to 10 days) where 1 = all plants in rows start heading on the same day and 5 = all plants in rows >14 days. The first HVS was recorded 65 days after emergence (DAE) and last one 89 DAE (Fig 2).

Variability in maturity was not observed between parents. The parents were different in days to heading by only one day, but a range of 22 days was observed in maturity among the progeny evaluated ranging from 72 to 94 days, suggesting a very uniform and compact population for maturity (Fig 3). Overall, about 85% of the population was observed to head within 2 to 5 days and 15% within 6 to 10 days. No families were observed to head within 11 to 14 days or >15 days. Plant height ranged from 30 to 56 in. The parents were different in plant height by only 1 in., but a range of 26 in. was observed among the progeny evaluated, suggesting transgressive segregation for plant height (Fig 4). At harvesting, 2.99% of the lines were harvested between 110 to 114 DAE, 56.4% at 116 to 119, 26.8% at 120 to 124, 10.4% at 125 to129, 3.0% at 130 to134, and <1% at 136. The parents (Cypress and LaGrue) were harvested at 117 and 124 DAE, respectively (Fig 5). A significant achievement was to harvest about 94.0% of the families between 18 and 22% moisture content (Fig. 6). A few exceptions ertr below 18% and some that were taken out of the field at 23 to 24% moisture content due to initial lodging.

SIGNIFICANCE OF FINDINGS

Milling quality in rice is a very difficult trait to improve; however, it is of much economic importance to the rice industry. Phenotypic evaluations together with genotyping studies on the MY2 Cypress/LaGrue mapping population are very important efforts to generate an association between molecular markers and quantitative trait loci (QTLs) that control milling quality of rice. A coordinated effort with Louisiana, Texas, and Mississippi as part of the RiceCAP project is underway to conduct a full study on this population.

ACKNOWLEDGMENTS

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Table 1. Phenotypic characteristics between parents and checks in the MY2 population grown in Arkansas.

Phenotypic	Parent		Variety check					
characteristic	CPRS[z]	LGRU	TRNS	MDSN	RT0134	SPRG	CCDR	MCR01277
Stand	9.0	8.0	9.0	9.0	9.0	9.0	9.0	9.0
First heading	76.0	79.0	71.0	79.0	72.0	64.0	71.0	76.0
50% heading	78.0	83.0	74.0	82.0	76.0	66.0	73.0	80.0
Plant height	104.0	107.0	101.0	90.0	117.0	109.0	97.0	100.0
Days to harvest	117.0	124.0	116.0	121.0	116.0	111.0	116.0	119.0
Weight at harvest (g)	478.0	506.0	827.0	424.0	781.0	587.0	780.0	626.0
Moisture content at harvest (%)	19.6	20.2	21.4	18.4	20.3	17.8	19.2	24.1

[z] CPRS= Cypress; LGRU= LaGrue; TRNS= Trenasse; MDSN= Madison; RT0134= RiceTec line; SPRG= Spring; CCDR= Cocodrie; and MCR01277= LA line.

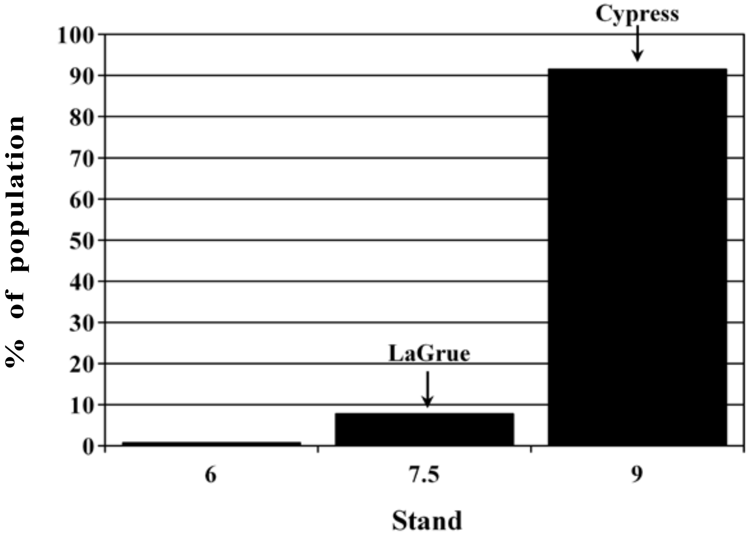

Fig. 1. Frequency distribution of rice stand using family means in the MY2 population grown in Arkansas.

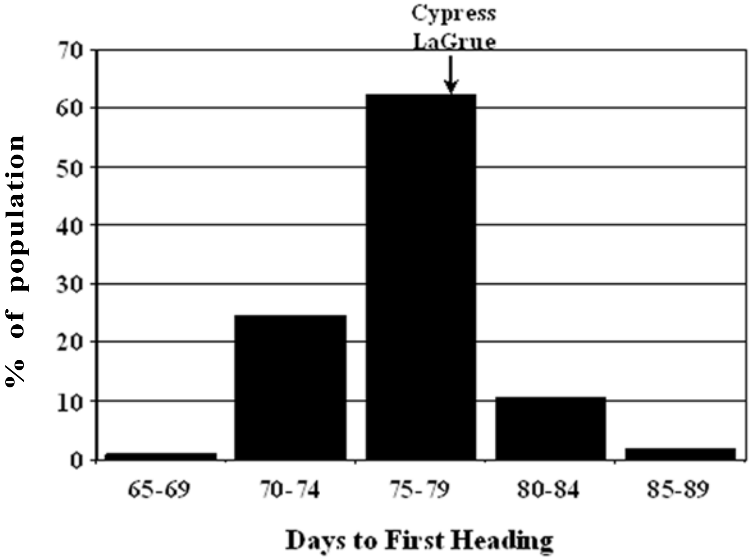

Fig. 2. Frequency distribution of days to first heading using family means in the MY2 population grown in Arkansas.

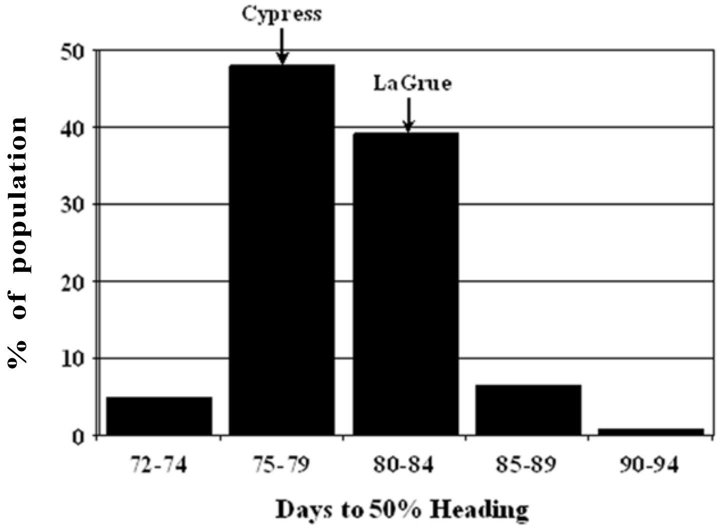

Fig. 3. Frequency distribution of days to 50% heading using family means in the MY2 population grown in Arkansas.

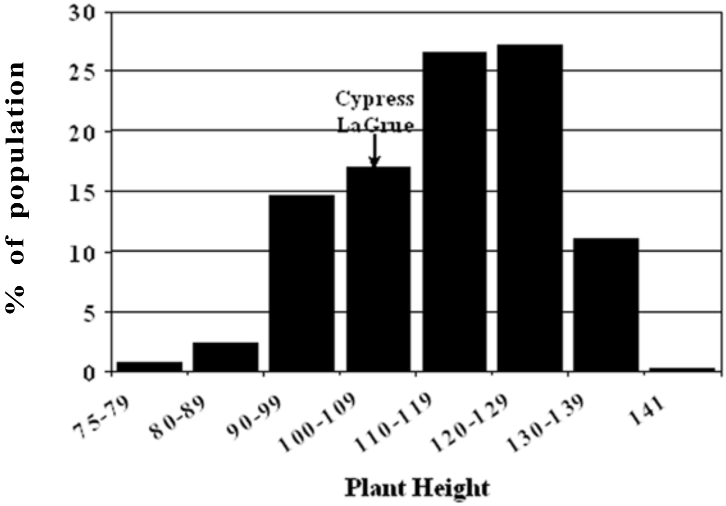

Fig. 4. Frequency distribution of plant height using family means in the MY2 population grown in Arkansas.

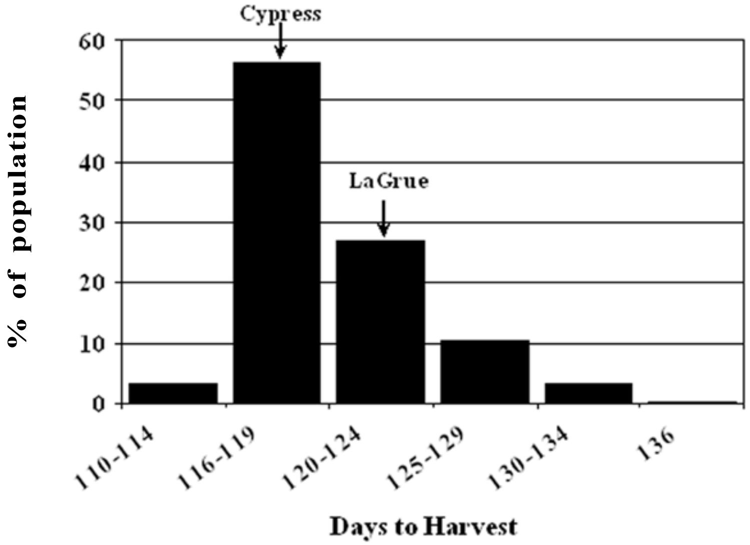

Fig. 5. Frequency distribution of days to harvesting using family means in the MY2 population grown in Arkansas.

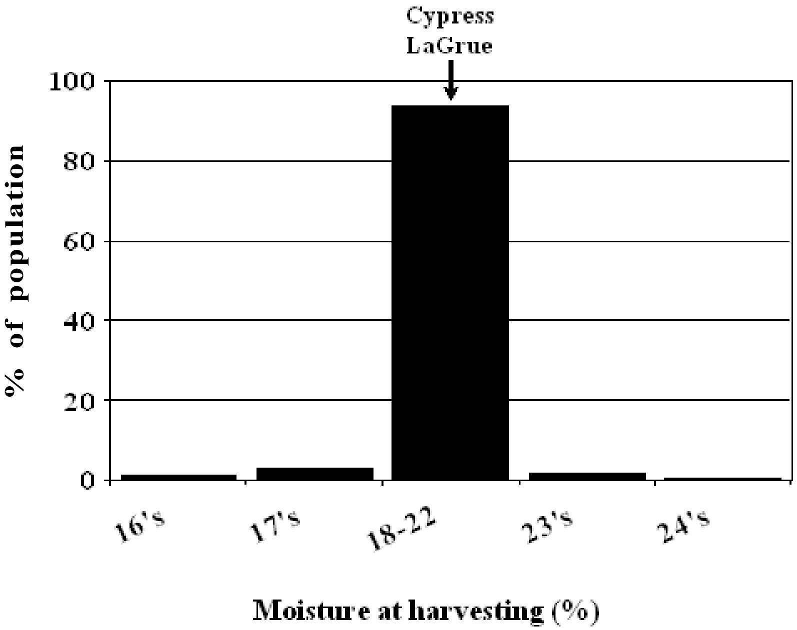

Fig. 6. Frequency distribution of percentage of moisture content at harvest using family means in the MY2 population grown in Arkansas.

BREEDING, GENETICS, AND PHYSIOLOGY

Identifying Novel Resistance Genes in Rice Wild Relatives

G.C. Eizenga, H.A. Agrama, and F.N. Lee

ABSTRACT

Rice blast and sheath blight are major fungal diseases of cultivated rice (*Oryza sativa* L.) that limit Arkansas rough rice yields and market potential. Resistance to these diseases has been found in rice wild relatives (*Oryza* spp.). A collection of these wild relatives originating from outside the United States was evaluated for resistance to blast races found in Arkansas. DNA (simple sequence repeat, SSR) markers were used to 1) determine the genetic background of these *Oryza* spp. accessions, 2) identify SSR markers associated with blast and sheath blight resistance in these *Oryza* spp. accessions, and 3) compare marker associations found in the *Oryza* spp. with those differentiated in the U.S. and international *O. sativa* accessions to identify new chromosomal regions associated with disease resistance. The *Oryza* spp. accessions included in this study were determined to have eight different genetic backgrounds or ancestries based on SSR marker analysis. Three *O. nivara* accessions containing the most blast resistance genes all share the same background, identified as K3 in this study. Sixteen chromosomal regions with associations between blast resistance (*R*-) genes and an SSR marker were identified. At least six associations were in chromosomal regions previously not reported to contain blast *R*-genes. These chromosomal regions will be characterized further in the mapping populations developed from crosses with U.S. rice cultivars. Blast resistant germplasm lines developed from these populations will be made available to U.S. rice breeders.

INTRODUCTION

Rice blast caused by *Magnaporthe oryzae* B. Couch and rice sheath blight caused by *Rhizoctonia solani* Kühn are major fungal diseases of cultivated rice (*Oryza sativa*

L.) in the United States, and irrigated rice worldwide. Wild relatives of rice, *Oryza* species (*Oryza* spp.) that are not *O. sativa*, are a potential source of several resistance (*R*-) genes to several diseases and insect pests, including blast and sheath blight (Jena and Khush 2000). Worldwide, a few of the *R*-genes identified in *Oryza* spp. have been incorporated into adapted rice cultivars. In addition, previous studies reported a few wild *Oryza* spp. accessions as being resistant to blast races found in Arkansas (Eizenga et al., 2002a).

A set of 91 newly introduced *O. sativa* accessions were identified as blast-resistant in field screening and genotyped with 176 DNA (simple sequence repeat, SSR) markers (Eizenga et al., 2006). Association mapping of these 91 accessions revealed 32 SSR markers associated with blast-resistance traits. Further analysis deciphered the genetic background (ancestry) of these accessions based on SSR markers, utilizing the software program Structure (Pritchard et al., 2000). Comparisons were made with blast genes already identified in U.S. cultivars to identify possible new genes.

The objectives of this research were to 1) determine the genetic background of 67 *Oryza* spp. accessions based on SSR markers, 2) identify SSR marker-disease trait associations in the *Oryza* spp. accessions, and 3) compare marker associations found in the *Oryza* spp., with those differentiated in the U.S. and international *O. sativa* accessions to identify new chromosomal regions associated with disease resistance.

PROCEDURES

Genomic DNA was extracted from leaf tissue, 176 SSR markers (Fig. 1) were visualized by fluorescent-labeled products, processed by an ABI Prism 3700 DNA Analyzer (ABI, Foster City, Calif.), and data analyzed with GeneScan 3.6/Genotyper 2.6 software (Eizenga et al., 2006). Genetic ancestry of the 67 *Oryza* spp. accessions based on SSR markers was determined using the program Structure (Pritchard et al., 2000).

Blast disease ratings for the *Oryza* spp. were determined according to Eizenga et al. (2002a). Blast and sheath blight ratings for the 39 *O. sativa* accessions from international sources were previously reported by Eizenga et al. (2006). *O. sativa* blast and sheath blight ratings for the 37 U.S. rice cultivars were summarized from variety release articles (http://www.ars-grin.gov/npgs/) and URRN (Uniform Regional Rice Nursery) pathology reports. The blast inoculation method used for the *Orzya* spp. was the same as that used to screen the *O. sativa* accessions. However, due to the limited seed availability and the fact that most *Oryza* spp. cannot be grown in the field, sheath blight ratings were obtained using a toothpick method developed for greenhouse inoculations of individual plants (Eizenga et al., 2002b). This method is different than that used to evaluate field plots of the *O. sativa* accessions.

Associations between the aforementioned SSR markers and the disease traits, namely blast and sheath blight, were calculated for the 62 *Oryza* spp. and 76 *O. sativa* accessions using the mixed linear model in the TASSEL software (available at http://www.maizegenetics.net). Marker-trait associations were selected as significant for the wild *Oryza* spp. with an $R^2 \geq 0.6$ ($p \leq 0.1$) and for the *O. sativa* accessions at $R^2 \geq 0.2$

($p \leq 0.1$). (Note that the highest R^2 for the *O. sativa* accessions was 0.4 vs. 0.75 for the wild *Oryza* spp. accessions.)

RESULTS AND DISCUSSION

The genetic background of the 67 *Orzya* spp. accessions examined in this study is shown in Fig. 2. These 67 accessions represent eight different genetic backgrounds or ancestries. The close relationship between the wild species, *O. nivara* and *O. rufipogon*, as the ancestral species of cultivated rice, *O. sativa*, (Jena and Khush, 2000) is highlighted by the STRUCTURE analysis of the SSR marker data placing hybrids with *O. sativa* and some accessions of these species in the same genetic background (K4). Jena and Khush (2000) also report that *O. barthii* is the ancestral parent of African rice, *O. glaberrima,* which explains the shared K5 genetic background for many of these accessions. The three *O. nivara* accessions that had the best blast resistance were all from the same K3 genetic background.

Table 1 summarizes the range of blast and sheath-blight ratings for 62 of the 67 *Oryza* spp. that were genotyped with DNA markers. In order to identify possible new resistance genes, associations between the SSR markers and resistance to blast races in the wild *Oryza* spp. accessions were determined. Seventeen SSR markers were associated with individual blast races and three markers associated with sheath-blight resistance were found within the wild *Oryza* spp. (Fig. 1). As a comparison, SSR marker-disease trait associations for a group of *O. sativa* accessions consisting of 37 U.S. rice cultivars and 39 international *O. sativa* accessions (Eizenga, et al., 2006) also were determined. Thirteen markers associated with resistance to blast races and one marker associated with sheath-blight resistance were identified within the *O. sativa* accessions (Fig. 1). The marker-trait associations for both the wild *Oryza* spp. and *O. sativa* accessions represented 22 different regions of the rice genome. Three regions were identified that were common to both the *Oryza* spp. and *O. sativa* accessions. No blast *R*-genes have been reported (Monosi et al., 2004) in at least six of the chromosomal regions that were identified as associated with blast resistance in this study. SSR markers on chromosome 1 (RM9, RM488), chromosome 2 (RM154), chromosome 3 (RM251), chromosome 7 (RM2, RM418, RM11, RM248), chromosome 9 (RM245), and chromosome 10 (RM228, RM333), are located in regions where blast-resistance genes have not been identified and may represent novel *R*-genes. In addition, new alleles for blast resistance, providing resistance to a different spectra of blast races, could be located in the chromosomal regions where blast *R*-genes previously have been identified.

In conclusion, *Oryza* spp. accessions offer promise in identifying new genes for resistance to blast and sheath-blight diseases. Mapping populations using some of these *Oryza* spp. accessions are being developed to confirm the existence of these novel blast *R*-genes. From this research, germplasm will be developed that possesses novel blast- and sheath-blight-resistant genes and this germplasm will be made available to rice breeding programs.

SIGNIFICANCE OF FINDINGS

DNA marker technology is being used to determine the genetic background of wild species of rice and identify novel blast-resistance genes that can be used to supplement those found in the cultivated rice (*O. sativa*). A crossing project is in progress to incorporate the resistance identified in the wild relatives (*Oryza* spp.) into rice varieties found in the United States and Arkansas.

ACKNOWLEDGMENTS

Funds for this research from the Arkansas Rice Research and Promotion Board included the financial support of post-doctoral associate, Dr. Hesham A. Agrama. Excellent contributions of Ms. Quynh P. Ho, DB NRRC, with the *Oryza* spp. disease ratings and DNA preparation are recognized. Contributions of Melissa H. Jia, geneticist, with the DB NRRC Genomics Core facility also are acknowledged.

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Table 1. Mean and range of blast leaf-lesion severity on the *Oryza* spp. accessions, rice (*O. sativa*) accessions from international sources, and U.S. rice cultivars inoculated with nine different isolates of blast (*Magnaportha oryzae*). Lesion severity rating was on a 0 (no disease) to 9 (dead) scale. Also, plants were rated for sheath blight disease severity on a 0 to 9 scale.

		M. oryzae race resistance rating									Sheath
Group	No.	IB-1	IB-33	IB-49	IB-54	IC-17	IE-1	IE-1K	IG-1	IH-1	blight
Wild *Oryza* spp.	62	3.8	4.3	4.9	4.4	5	1.8	4.1	2.8	2.2	4.6
		(0.0-9.0)	(0.0-7.5)	(0.0-9.0)	(0.0-9.0)	(0.0-9.0)	(0.0-6.0)	(0.0-9.0)	(0.0-8.7)	(0.0-8.0)	(2.3-8.0)
International	39	0.3	3.7	0.3	--	0.2	0.1	0.2	0.3	0.5	5.6
O. sativa lines[z]		(0.0-4.3)	(0.0-8.0)	(0.0-6.3)		(0.0-2.0)	(0.0-1.0)	(0.0-1.8)	(0.0-3.5)	(0.0-6.3)	(4.0-7.3)
U.S. rice cultivars[y]	37	4.3	6.2	5.6	2	4.8	3.9	5.2	2.8	2	6.4
		(1.0-8.3)	(0.0-9.0)	(1.0-8.0)	(0.0-8.0)	(0.0-8.0)	(0.0-8.0)	(0.0-8.0)	(0.0-8.0)	(0.0-7.6)	(4.0-8.1)

[z] Data taken from Eizenga et al. (2006).

[y] Ratings from variety release articles (http://www.ars-grin.gov/npgs/) and the URRN pathology reports.

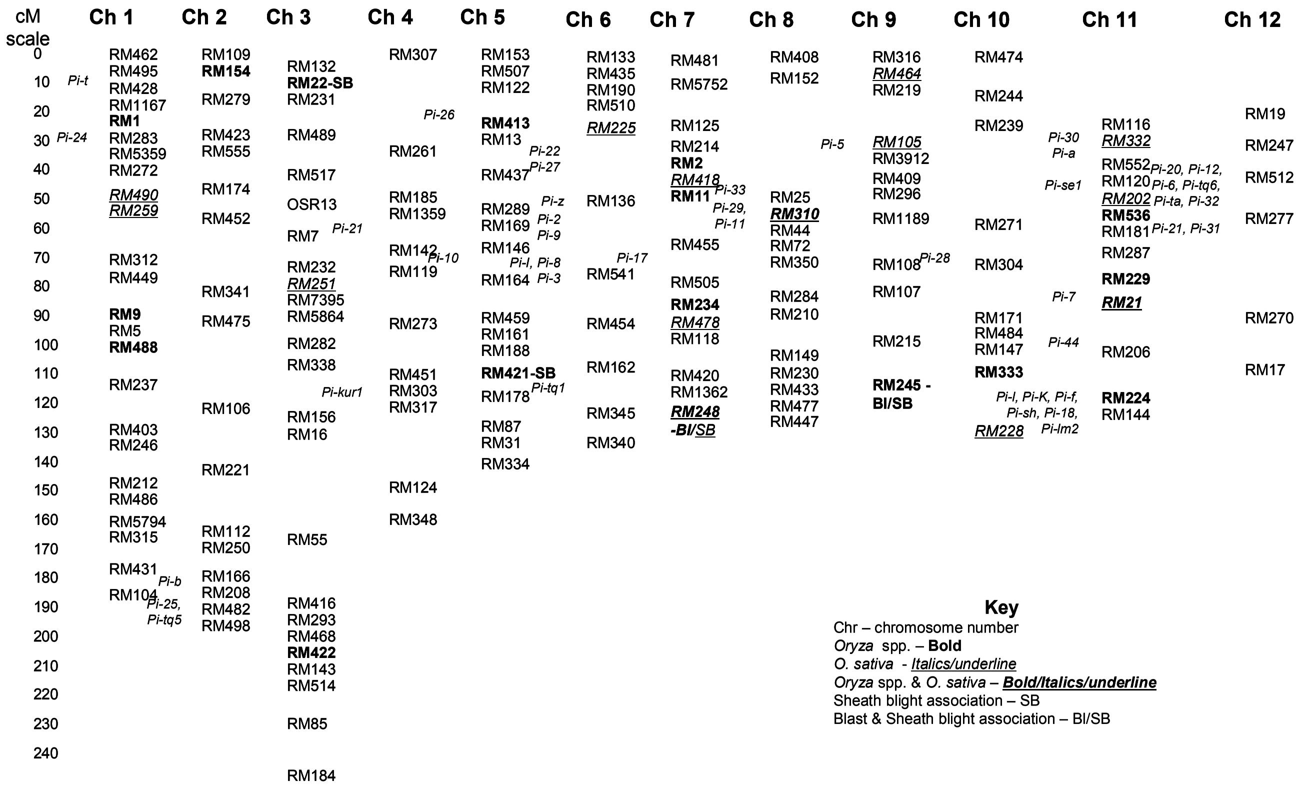

Fig. 1. MapChart diagram (Voorrips, 2002) of the rice genome illustrating the chromosomal location of the 176 SSR markers used in these studies. Those markers identified as associated with blast and sheath blight (SB) *R*-genes in the *Oryza* spp. accessions are in bold and those associated with the *O. sativa* accessions are in italics and underlined. Approximate positions of blast (*Pi-*) genes are after Monosi et al. (2004).

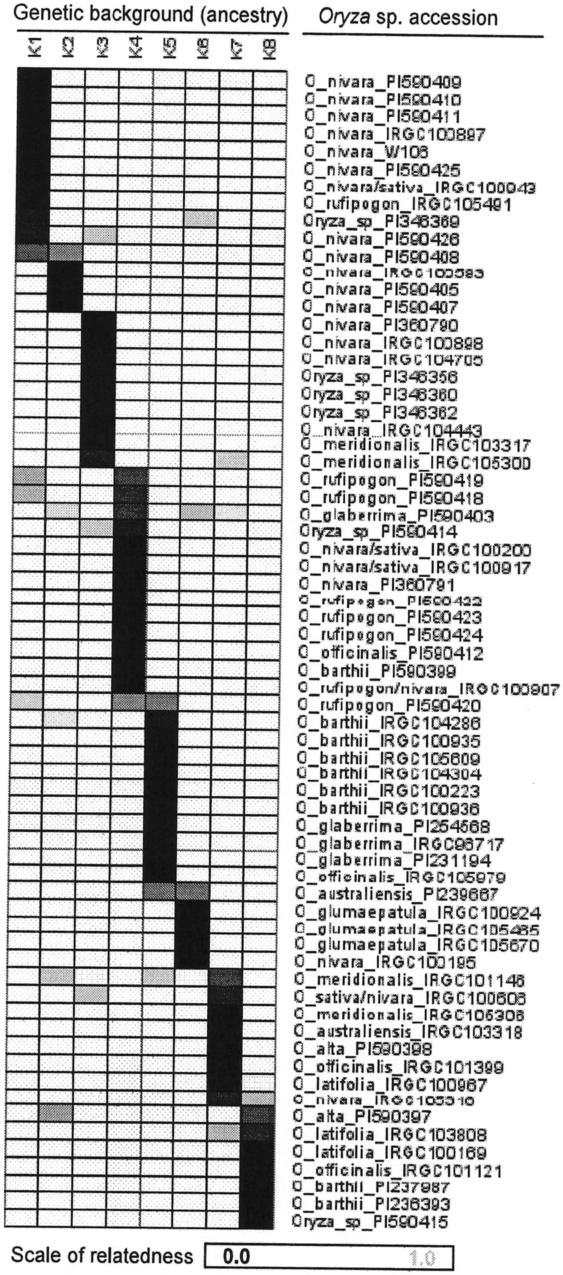

Fig. 2. The genetic background of 67 rice wild relatives (*Oryza* spp.) accessions separated into eight ancestries (K-values) based on SSR marker analysis using the software Structure (Pritchard et al., 2000). The dark squares represent a relatedness of near 100% while the white squares represent no relationship.

Population-Structure Analysis of Red Rice in Arkansas: DNA Marker Evidence for Gene Flow between Rice and Red Rice

D.R. Gealy, H. Agrama, C.E. Wilson, Jr., and L.E. Estorninos, Jr.

ABSTRACT

Red rice is a troublesome weed problem in Arkansas rice fields and numerous biotypes are present. Outcrossing between rice and red rice occurs at low rates, resulting in unusual plant types, and can complicate weed management efforts. STRUCTURE (STR) analysis of DNA SSR marker data is useful to infer population structure, to assign individuals to different populations, and to identify hybrids. Thus, this procedure was used to evaluate the genetic backgrounds of numerous red rice types that, based on visual traits, apparently had developed from natural outcrossing with rice. STR analysis of suspected red rice crosses obtained from a multi-county, multi-state area yielded little evidence that genetic markers initially associated with rice were retained in red rice populations at high levels over time. Additional studies involving a larger number of markers or markers specifically associated with rice cultivars (e.g. semidwarfism or herbicide resistance) may be necessary to confirm these preliminary findings. In contrast to the aforementioned results, STR analysis clearly showed that a group of red rice plants obtained from Mississippi Co., Ark., partially shared a genetic background with both long-grain commercial rice and red rice. They probably resulted from a recent cross between the two plant types. These studies demonstrate that STR analysis can be used to identify and characterize red rice crosses in some cases, and that it could be useful as a diagnostic tool.

INTRODUCTION

Rice and red rice belong to the same species (*Oryza sativa*) and they can intercross at low rates. Outcrossing can occur with either plant type serving as pollen donor (Chen et al., 2004; Gealy and Estorninos, 2007; Zhang et al., 2003). Hybrids can differ in coloration and plant type, depending on the red rice parent (Gealy et al., 2006). Gealy and Estorninos (2007) recently used SSR analysis to confirm that reciprocal outcrossing rates between U.S. red rice and commercial long-grain rice in controlled field plots over a five-year period averaged 0.26% with red rice as pollen donor and 0.056% with rice as pollen donor. Results from related studies have demonstrated that red rice accessions that appeared to have been derived from crosses between red rice and long grain rice were, in fact, such crosses (Estorninos et al., 2006; Gealy et al., 2005). However, the extent to which progeny of such crosses can introgress into red rice populations and remain there is not well understood.

A model-based Bayesian cluster analysis (STRUCTURE; STR) (Pritchard et al., 2000) of SSR DNA marker data from rice and red rice can be used to evaluate the genetic backgrounds of red rice populations of interest. Such analyses can be used to infer population structure, assign individuals to sub populations, and to study hybrid populations. Thus, the goal of this research was to employ STR to discern parental backgrounds of numerous red rice populations that, based on physical traits, were presumed to be rice x red rice crosses.

PROCEDURES

Multi-County/Multi-State Study

In order to evaluate the evidence of long-term gene flow/introgression between commercial rice and red rice in Arkansas, seeds from more than 400 red rice accessions were obtained from farm samples and grown at Stuttgart, Ark., as described previously (Estorninos et al., 2006). In one or more field studies (unpublished data), a small fraction of these red rice types exhibited traits consistent with progeny of known hybrids (e.g. as in Gealy et al., 2006). Thus, four such subgroups, consisting of at least 10 individuals each (Table 1), were chosen for DNA analysis. These were 1) plants that were unusually short (Lhts; ~100 to116 cm) compared to normal red rice plants (typically 130 to167 cm); 2) plants with brief heading periods (Lhds; ~3 to 5 days from initiation of heading to completion) that are common in commercial rice cultivars and of shorter duration than those of typical red rice types (~6 to 12 days); 3) plants with very short awns (Sawn; ~0.5 to 1 cm) that are typical of certain hybrid progeny; and 4) plants with various combinations (Comb) of the traits described above. Red rice accessions chosen at random (Rndm) as being representative of ordinary red rice types, and several long-grain commercial rice cultivars, were included for comparison as standards.

DNA extraction and SSR marker analysis generally were performed as described previously (Estorninos et al., 2006). Amplified PCR products from 19 SSR markers that were distributed among all 12 chromosomes were visualized on an ABI 3730 (or an ABI 3700) automated DNA sequencer using DNA isolated from leaf tissues and analyzed in Genemapper software. The markers were RM5, RM154, RM234, RM124, RM210, RM174, RM231, RM232, RM512, RM206, RM215, RM488, RM283, RM484, RM317, RM408, RM146, RM133, and RM253. To determine the population structure of these suspected crosses, a model-based Bayesian cluster analysis was performed using all red rice accessions and rice cultivars (Pritchard et al., 2000). STR software can identify true crosses as having a shared genetic background (i.e., subpopulations) with one or more red rice types and rice cultivars.

Mississippi Co., Ark., Study

A group of 15 accessions, obtained from Mississippi Co., Ark., in 2005 that consisted of variable red rice-like plant types that apparently represented a segregating population derived from a cross between red rice and rice (Estorninos et al., 2006), was included in these studies as an example of a population recently developed from outcrossing. Plant types included MS-1, pink-purple stem, rough leaf, pink awn; MS-2, purple stem, rough-smooth leaf, short green awn; MS-3, purple stem, rough leaf, short awn; MS-4, green stem, smooth leaf, awnless; MS-5, purple stem, rough leaf, pink awn; MS-6, purple stem, rough leaf, very short-awn/awnless; MS-7, green stem, smooth leaf, very short-awn/awnless; MS-8, green stem, smooth leaf, awnless; MS-9, green stem, smooth leaf, green awn; MS-10, purple stem, rough leaf, pink awn; MS-11, purple stem, rough leaf, pink awn; MS-12, purple stem, smooth leaf, green awn; MS-13, purple stem, rough leaf, pink awn; MS-14, purple stem, rough leaf, pink awn; MS-15, purple stem, rough-smooth leaf, green awn. Plant types also varied with respect to heading date and seed coat color (not shown). Overall, this combination of traits is indicative of a segregating population (F_2 or later generation) derived from a rice x red rice cross (Gealy et al., 2006). STR analysis was performed generally as described above except that nine SSR markers were used. They were RM167, RM253, RM219, RM234, RM180, RM215, RM224, RM206, and RM220.

RESULTS AND DISCUSSION

Multi-County/Multi-State Study

Five independent runs in the STR software using *k* values (hypothetical number of subpopulations) from 3 to 6 showed the highest number of accessions assigned to a specific cluster with a probability higher than 80% was obtained with *k* = 6, thus indicating the presence of complex relationships among accessions. Using the clustering diagrams with *k* = 6, the subpopulations identified by STR largely corresponded to pools originating from commercial rice, and red rice with normal-length awns, very short awns, or without awns (Fig. 1).

Known hybrids (e.g., ‘RT XL8’, ‘CL 161’ x red rice, and ‘Kaybonnet’ (KBNT) x STGS) showed the expected shared genetic background encompassing alleles from both parents in a first-generation cross (Fig. 1). There was essentially no evidence of a shared genetic background between any of the four groups of putative rice x red rice crosses or the standard red rice types and the long-grain cultivars tested (Fig. 1). However, red rice accession 1022_02 Lhds (Fig. 1; 4th entry from bottom) may share a subpopulation (*k*5) with the commercial rice, STBN (Starbonnet; no longer grown). There also was no evidence of significantly shared genetic backgrounds between these red rice accessions and a group of cultivars historically grown in the southern U.S., such as long-grains (‘Rexoro’, ‘Newbonnet’, ‘Lemont’, ‘LaGrue’, ‘Gulfmont’, ‘Drew’, ‘Dawn’, ‘Cypress’, ‘Bluebonnet’, and ‘Carolina Gold’), medium-grains (‘Zenith’, ‘Saturn’, ‘Nato’, ‘Mars’, and ‘Bengal’), as well as several japonica cultivars (‘M-204’ and ‘Koshihikari’) (Lu et al., 2005; data not shown). However, the red rice groups appeared to share common alleles with indica rice germplasm (e.g., ‘TeQing’, data not shown).

It is possible that the unusual red rice phenotypes that were tested in these studies may have arisen from preexisting genetic diversity within the red rice populations. It is also possible that rice alleles, which may have been transferred to red rice plants through intercrossing, were subsequently lost from these populations due to selection pressure. Analysis of numerous additional markers, including those specifically associated with commercial rice cultivars (e.g., markers for the SD-1 semidwarfing gene), may be more informative than the markers used in this test, and are being investigated.

Mississippi Co., Ark., Study

Using the clustering diagrams with *k* = 4, the subpopulations identified by STR largely corresponded to pools originating from commercial rice (*k* = 1 and 2), black-hull awned red rice standards such as TX4 and redrice_8 (*k* = 3), and the awnless red rice standard StgS (*k* = 4) (Fig. 2). However, all of the red rice standards, particularly 11D_RR, shared subpopulations to some degree with the commercial rice standards. As would be expected in a segregating population derived from a red rice x rice cross, some red rice accessions were composed of subpopulations more indicative of rice (e.g., MS-12, 13, and 14), others were more indicative of red rice (e.g., MS-8, 9, 10, and 11), and others were indicative of both rice and red rice (e.g., MS-2, 6, and 7). Thus, STR analysis in combination with physical traits suggests that these Mississippi Co. plants had been derived from a cross between long-grain rice and an awned red rice similar to 11D_RR, TX4std, or redrice_8 (Fig. 2). More than one initial cross or involvement of an awnless red rice similar to StgS is also possible.

SIGNIFICANCE OF FINDINGS

These results have confirmed the effectiveness and efficiency of STR analysis in the evaluation and interpretation of DNA markers for the purpose of identification and subsequent management of rice x red rice crosses in farm fields. Results from these analyses suggest that, in combination with physical traits, STR could be highly useful in monitoring outcrossing and gene flow dynamics between red rice and rice. STR revealed little evidence of the presence of rice DNA markers in red rice accessions that were hypothesized to have been derived from outcrossing events far in the past. This suggests either that the accessions in question were not actually crosses, or that a large portion of the rice DNA originally present in the cross had been lost over time so that it was not easily detected by the small number of markers used.

ACKNOWLEDGMENTS

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Table 1. Phenotypic and geographic descriptions of the red rice accessions obtained from a multi-county, multi-state area, as compared to rice and red rice standards.^{z,y,x}

Sample name (Rice or red rice)	Awns	Hull color	Leaf texture	County	Spread	Height	Emg-head	Phenotypic grouping
					(days)	(cm)	(days)	
1013_01	N	S	R	Jackson	8.3	104	70.0	Lhts
1064_01	N	S	R	Independence	9.0	114	95.7	Lhts
1092_01	N	S	R	Randolph	5.5	116	82.5	Lhts
1151_01	N	S	R	Poinsett	6.7	107	95.7	Lhts
1156_01	N	S	R	Woodruff	7.3	107	96.7	Lhts
1167_01	Y	B	R	Faulkner	6.0	115	104.3	Lhts
1176_01	Y	B	R	Faulkner	6.0	116	103.3	Lhts
1226_02	N	S	R	Clay	7.3	108	95.3	Lhts
1287_02	Y	B	R	Lee	8.0	112	103.7	Lhts
1290_02	N	S	R	Randolph	9.0	101	90.0	Lhts
1043_01	Y-SHR	S	R	Lincoln	4.7	124	83.0	Sawn
1099_02	Y-SHR	Br	R	Phillips	6.0	121	85.0	Sawn
1111_01	Y-SHR	S	R	Woodruff	7.7	130	88.7	Sawn
1124_01	Y-SHR	S	R	White	5.3	132	83.7	Sawn
1147_02	Y-SHR	S	R	Prairie	8.5	132	88.0	Sawn
1183_01	Y-SHR	S	R	Chicot	12.3	130	88.3	Sawn
1202_02	Y-SHR	Br	R	Jefferson	4.7	146	79.7	Sawn
1218_02	Y-SHR	S	R	St Francis	6.3	131	89.0	Sawn
1254_02	Y-SHR	S	R	Jefferson	4.7	146	79.7	Sawn
1300_02	Y-SHR	Br	R	Dunklin, Mo.	4.7	132	85.0	Sawn
1312_02	Y-SHR	S	R	Morehouse, La.	8.7	133	87.0	Sawn
1022_02	Y	B	R	White	5.0	141	88.7	Lhds
1052_02	Y	B	R	Lee	3.3	160	93.0	Lhds
1078_01	Y	B	R	Jackson	4.0	114	103.3	Lhds
1096_01	Y	B	R	Arkansas	3.3	118	101.7	Lhds
1131_01	N	S	R	Cross	4.0	143	87.0	Lhds
1148_02	Y-SHR	S	R	Prairie	3.3	126	82.3	Lhds
1157_02	Y-SHR	S	R	Desha	3.7	127	83.7	Lhds
1186_01	Y-SHR	S	R	Drew	3.7	136	84.3	Lhds

continued

Table 1. Continued

Sample name (Rice or red rice)	Awns	Hull color	Leaf texture	County	Spread	Height	Emg-head	Phenotypic grouping
					(days)	(cm)	(days)	
1271_02	Y-SHR	Br	R	Lincoln	2.7	115	83.7	Lhds
1406_02	Y-SHR	S	R	Woodruff	3.0	125	84.0	Lhds
1430_02	Y-SHR	S	R	Coahoma, Miss.	3.7	126	85.3	Lhds
1034_01	Y	B	R	St Francis	4.3	167	94.3	Comb
1042_01	Y	S	R	Jefferson	4.3	153	95.7	Comb
1043_02	Y	B	R	Monroe	5.0	159	94.0	Comb
1060_01	Y	B	R	Craighead	4.7	161	94.3	Comb
1111_02	N	S	R	Desha	5.0	128	94.3	Comb
1115_01	Y	B	R	Lawrence	4.3	160	94.7	Comb
1142_01	Y	B	R	Lonoke	5.0	122	102.3	Comb
1160_01	N	S	R	Morehouse, La.	4.3	142	92.3	Comb
1194_01	Y	B	R	Faulkner	4.7	127	105.0	Comb
1243_02	N	S	R	Morehouse, La.	5.0	142	92.0	Comb
1349_02	Y	B	R	Arkansas	5.0	135	103.0	Comb
1418_02	N	S	R	Jefferson	5.0	150	91.7	Comb
1431_02	Y	Br	R	East Carroll, La.	4.3	151	96.7	Comb
1039_02	N	S	R	St Francis	10.3	141	85.0	Rndm
1046_02	N	S	R	Phillips	8.0	139	86.0	Rndm
1061_01	Y	B	R	Butler	6.0	152	91.0	Rndm
1105_02	N	S	I	East Carroll, La.	9.0	148	83.3	Rndm
1132_01	N	S	R	Yell	9.7	146	84.7	Rndm
1154_01	Y	B	R	Desha	7.3	152	90.0	Rndm
1187_01	N	S	R	Ripley	9.0	145	85.7	Rndm
1263_02	N	S	R	Stoddard, Mo.	8.3	132	86.7	Rndm
1288_02	N	S	R	White	10.7	140	80.3	Rndm
1358_02	N	S	R	Craighead	8.7	154	84.0	Rndm
CL161 x RR	N	S	R	---	---	---	---	StdRxRR hyb
Kaybonnet x LA3	Y	S	R	---	---	---	---	StdRxRR hyb
Kaybonnet x StgS	N	S	R	---	---	---	---	StdRxRR hyb
RR x CL121	N	S	R	---	---	---	---	StdRxRR hyb

continued

Table 1. Continued.

Sample name (Rice or red rice)	Awns	Hull color	Leaf texture	County	Spread	Height	Emg-head	Phenotypic grouping
					(days)	(cm)	(days)	
11D	Y	S	R	Arkansas	---	---	---	StdAwnedRR
LA3	Y	S	R	LA	6.7	158	99.0	StdAwnedRR
StgB	Y	B	R	Arkansas	7.0	165	104.7	StdAwnedRR
StgS	N	S	R	Arkansas	11.0	144	89.0	StdAwnlessRR
CL121	N	S	S	---	---	---	---	StdRice
CL161	N	S	S	---	---	---	---	StdRice
Cypress	N	S	S	---	3.7	104	90.0	StdRice
Kaybonnet	N	S	S	---	2.7	119	91.3	StdRice
RTXL8	N	S	R	---	---	---	---	StdRice Hyb
Starbonnet	N	S	S	---	5.3	125	96.3	StdRice
Wells	N	S	S	---	---	---	---	StdRice

[z] Key to terms: Awns: Y = long awn, N = no awn, Y-Shr = very short awn (< 0.5 cm). Hull Color: S = strawhull, B = blackhull, Br = brownhull. Leaf Texture: R = rough, S= smooth, I = intermediate. County of Origin (State of Arkansas unless otherwise noted). Spread=number of days from first heading to final heading; Height=plant height; Emg-Head = average number of days from emergence to heading. Phenotypic grouping: Lhts=very short plants, Lhds=low heading spread [i.e., all heading occurs within a few days], Sawn=short awns, Comb=combination of various plant types as defined for Lhds and/or Lhts, Rndm=randomly selected red rice standards included for comparison, StdRxRR hyb=standard hand-crossed rice x red rice hybrid, StdAwnedRR=standard awned red rice type, StdAwnlessRR=standard awnless red rice type, StdRice=standard long-grain rice cultivar, StdRice Hyb=standard commercial rice hybrid.

[y] Max. / min. values from all red rice accessions in field nursery averaged over 3 reps were 12.3 / 3.0 days spread, 167 / 101 cm height, and 105 / 70 days emergence to heading.

[c] --- Indicates data not available.

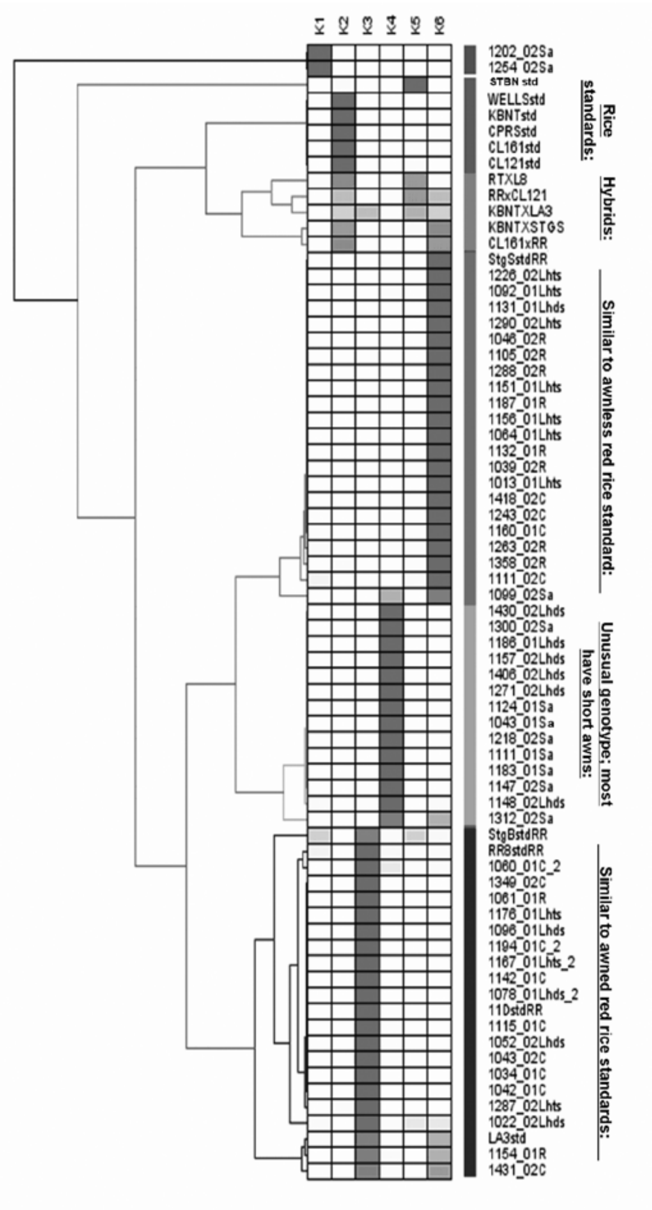

Fig. 1. Population structure of genotypes from a multi-county, multi-state collection of red rice accessions based on 19 SSR markers. More than one shaded box within a row indicates that the accession or cultivar consists of more than one genetic subpopulation (*k* value). Those with only one shaded box consist of a single identifiable subpopulation. Accessions or cultivars that are shaded in the same columns share the same subpopulation. Groupings of genotypes were based on six possible genetic backgrounds (*k*1-6) using model-based clustering analysis.

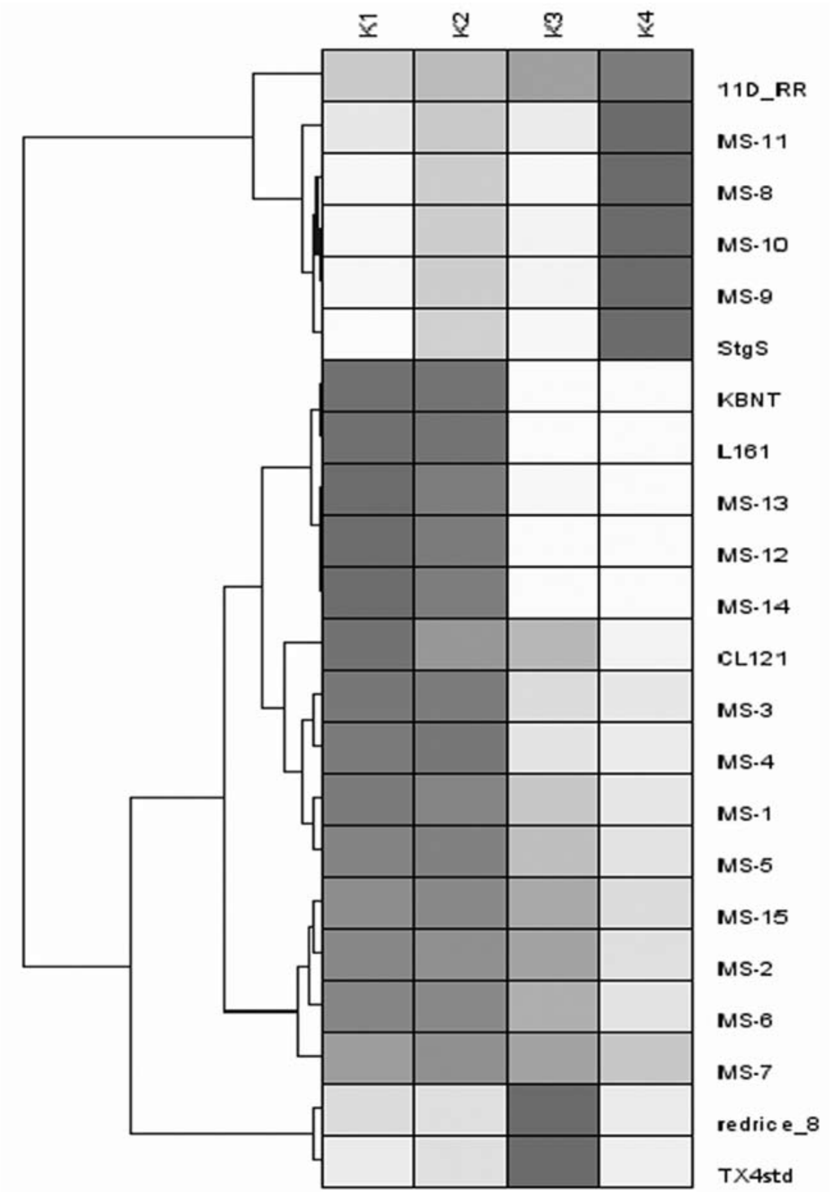

Fig. 2. Population structure of a red rice collection from Mississippi Co., Ark., thought to have resulted from a recent cross between rice and red rice. Groupings of genotypes were based on four possible genetic backgrounds (*k*1-4) using model-based clustering analysis. Rice cultivars: KBNT, Kaybonnet; L161, CL 161; and CL 121. Red rice standards: 11D_RR, AR awned red rice; StgS, Stuttgart awnless red rice; redrice_8, AR awned red rice #8; and TX4std, TX awned red rice. Mississippi Co. red rice types: MS-1 to MS-15.

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 new techniques such as molecular-aided selection are utilized to efficiently identify disease and quality genes in segregating populations. Continued exchange and utilization of new germplasm is valuable to Arkansas rice improvement. Lines with diverse genetic origins exhibit high yields, good disease and stress tolerance, and acceptable grain quality under Arkansas growing conditions. A furrow-irrigated rice trial was planted in 2006. Results showed reduced yield and milling quality under this system, and continued breeding efforts to identify suitable cultivars are needed.

INTRODUCTION

Since the release of ‘Lemont’ in the mid 1980’s, semidwarf rice cultivars have been grown in Arkansas. ‘Cocodrie’, and ‘Bengal’ are long- and medium-grain semidwarfs that occupy a large proportion of the current 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 Arkansas 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 and blast. 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 quality that tolerate the common stresses and pests found in Arkansas rice fields.

PROCEDURES

Potential parents for the breeding program were evaluated for the desired objectives. Cross combinations were programmed that combine desired characteristics to fulfill the breeding objectives. Use of parents of diverse genetic backgrounds was emphasized. Segregating populations were planted at Stuttgart and the winter nursery at Lajas, Puerto Rico. Selection was based on grain and plant type, spikelet fertility, field and greenhouse disease reaction, and grain quality. Yield evaluations began with the preliminary yield trial, the Stuttgart Initial Test (SIT) at two locations, the Arkansas rice performance trials (ARPT) at six locations in the state, 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." In 2006, we established three furrow-irrigated rice yield trials on two farmers' fields (Locations A and B) and at the RREC (Location C), all in Arkansas County. Five cultivars, four conventional Arkansas cultivars, 'Wells', Cybonnet, 'Spring', and 'CL 131', and one hybrid, 'XP 723', were replicated 5 times in a Latin Square design. Management was performed by the farmers and with accepted practices at RREC. Planting dates were 5 May for Site A, 17 May for Site B, and 22 May for Site C.

RESULTS AND DISCUSSION

About 120 cross combinations were made in 2006. Emphasis was placed on triple crosses with parents selected for tolerance to straighthead disorder, blast and panicle blight disease as well as yield and grain quality. Over 500 F_1 single-plant triple crosses were selected in 2006 and will be space-planted at Stuttgart in 2007 (Table 1). Over 2000 F_2 single plants were selected during the year. Several of these crosses were made with cold-tolerant parents. Panicles from these plants were sent to the winter nursery for generation advancement. About 2000 single panicles from early flowering lines were harvested and replanted at Puerto Rico so that 2 generations will be gained from the winter nursery in 2006. The remainder of selected lines will be planted as F_4 rows at Stuttgart in 2007. Plants with known sources of the blast gene *Pi-ta*, and diverse cooking-quality alleles were evaluated using molecular-aided selection (MAS) allowing for a significant increase in efficiency of selection at Puerto Rico. Over 700 F_4 rows were selected in 2006 from about 3800 rows planted at Stuttgart to advance to F_5 in 2007. From over 1500 rows planted, about 150 F_5 and F_6 lines were selected based on plant type, grain quality, earliness, and disease reaction to advance to preliminary yield trials in 2007.

Yields of selected semidwarf lines from the preliminary yield trial are shown in Table 2. Medium-grain lines from the crosses RU9901127/97Y228//STG02P-01-015 and 97Y228/PI 560265//STG97F5-01-004 showed improved blast resistance and similar yield to Medark, but had reduced milling quality. RU9901127, STG02P-01-015, and STG97F5-010-004 are Arkansas medium-grain breeding lines while 97Y228 and PI 560265 are cold-tolerant introductions from California and Colombia, South America, respectively. These latter two lines are examples of newly introduced germplasm accessions that are being incorporated into the very narrow medium-grain germplasm base. Long-grain entries 1122 and 1295 yielded more than Wells and were superior in either blast reaction or milling quality. The entry 1295 is from the cross Cocodrie/ZHE733//WC 285. Cocodrie is a popular Louisiana semidwarf, japonica type while ZHE733 and WC 285 are indica introductions from China and South America, respectively. These lines will be further advanced to replicated trials for 2007. 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 2007 more experimental lines, including F_2 populations, will be tested under similar conditions at Pine Tree.

Average grain yields from the furrow-irrigated trial (Table 3) were low. Location B produced the highest average yield across cultivars with 160 bu/acre, followed by 91 bu/acre at location A and 75 bu/acre at location C. Late planting affected yields at all locations and weed competition was intense at Location C. The hybrid XP 723 performed best at all locations ranging from 108 bu/acre at location C to 252 bu/acre at location B. The hybrids' ability to produce biomass under stress conditions contributed to the high yields under furrow irrigation. Wells and Cybonnet yielded an average of 107 bu/acre across the three locations while Spring and CL 131 were 79 bu/acre and 78 bu/acre, respectively. Late harvest at location A resulted in very low total and head-rice milling yields for all entries. XP 123 had the highest head-rice yield at that location followed by CL 131 and Cybonnet. At location B, milling yields were acceptable, ranging from 55% head rice for XP 723 and Cybonnet to 52% for Spring. Average plant height varied from 32 in. at location C to 36 in. at location B. Between locations, XP 123 varied most in height while Cybonnet and CL 131 had the least difference in height between locations. Furrow-irrigated rice is being used by farmers for various reasons including reduced labor costs, ease of pesticide application, and water-use efficiency. Cultivars adapted to this modified upland rice ecosystem must have early seedling vigor, good tillering ability, and rapid leaf cover to help compete with weeds. Disease resistance especially for rice blast will be essential for successful use of the furrow-irrigated system. Breeding efforts will continue to identify cultivars adapted to furrow-irrigated rice.

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. Furrow-irrigated rice requires cultivars with improved early vigor, rapid biomass production, and improved disease and pest resistance. 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 2006.

	Number of lines	
Evaluation phase	Planted	Selected
F_1 transplants	6840	509
F_2 space plants	294,900	2028
F_4 panicle rows	3849	709
F_5 & F_6 panicle rows	1521	190

Table 2. Data from the 2006 Preliminary Semidwarf Rice Yield Trial for experimental lines and check cultivars. SEREC, Rowher, Ark.

	Grain	Disease[z]				50%		
Entry	type	NB	ShB	Vigor[y]	Height[x]	HD	Yield	Milling
					(in.)		(bu/acre)	(HR:TOT)
Medark	M	4	7	3	39	103	228	67:70
1059[w]	M	3	7	2	36	96	203	52:63
1056	M	2	7	3	38	89	200	61:66
1122	L	9	7	2	35	95	250	35:66
1295	L	0	6	3	36	93	243	41:68
Wells	L	8	6	2	38	98	229	34:68

[z] Disease scores from field evaluation: Neck Blast (LB) at Pine Tree Experiment Station where 0 = no blast and 9 means blank panicles and Sheath Blight (ShB) at Rice Branch where 0 = no infection and 9 = plants dead.

[y] Vigor taken preflood on scale of 1 to 4 with 1 = poor and 4 = excellent vigor.

[x] Vigor, height, days to 50% heading, yield, and milling data are from Rohwer.

[w] 1059 is from the cross RU9901127/97Y228//STG02P-01-015 and1056 is from the cross97Y228 /PI 560265//STG97F5-01-004. 1122 is from RU9901133/Jefferson and 1295 is from Cocodrie/ZHE733/WC 285.

Table 3. Data from the 2006 furrow-irrigated trial at three locations for selected rice cultivars and hybrids.

Cultivar	Yield[z]			Total milling			Head rice			Height		
or hybrid	Loc A	Loc B	Loc C	Loc A	Loc B	Loc C	Loc A	Loc B	Loc C	Loc A	Loc B	Loc C
	(bu/acre)			(%)						(in.)		
Wells	88	153	79	62	71	70	7	53	50	38	40	35
Cybonnet	120	131	71	65	70	69	22	55	55	30	32	29
Spring	32	145	59	63	70	67	13	52	50	37	38	34
CL 131	57	118	59	65	70	68	27	53	52	27	28	25
XP 723	158	252	108	67	68	68	36	55	53	38	42	36
Mean	91	160	75	64	70	68	21	54	52	34	36	32
$LSD_{(0.05)}$	20.2	21.1	21.3	1.5	1.0	1.2	3.9	1.6	2.7			

[z] The furrow-irrigated trial was conducted at 3 locations: Loc A and B were on farmers' fields and Loc C was at the RREC. Yield, total milling, head rice, and height are means of 5 replications at each location.

Update on Molecular Analysis of Rice Blast Disease on Cultivar Banks

Y. Jia, J.C. Correll, F.N. Lee, and R.D. Cartwright

ABSTRACT

Rice cultivar 'Banks' was found to be susceptible to rice blast disease in fields in Corning, Ark., in 2004. Molecular analysis was undertaken to understand the molecular mechanisms of the susceptibility to rice blast disease in Banks cultivar grown in commercial rice fields. The standard blast resistance *Pi-ta* gene was confirmed as present in the cultivar Banks. Expression of *Pi-ta* resistance was confirmed by inoculating Banks with blast races such as IB-49 and IC-17 that contain the avirulence gene *AVR-Pita*. However, the structure of the *AVR-Pita* allele in isolates from Banks was determined to be significantly different from the known *AVR-Pita* fungal gene found in race IB-49 previously occurring in Arkansas. A stable transposable Pot3 was found to reside in the important structure domain of the putative *AVR-Pita* protein in one isolate from Banks. This *AVR-Pita* allele was not detected in other blast isolates from Banks using allele-specific DNA technology. We suggest the Banks cultivar expresses the standard *Pi-ta* resistance gene and that blast isolates obtained from Banks had adapted to defeat resistance gene *Pi-ta.* Our molecular analysis of isolates from the Banks variety indicates the blast fungus adapted to defeat the resistance standard *Pi-ta* resistance gene present in Banks cultivar, and incited the severe blast observed in the Banks cultivar near Corning, Ark., during 2004.

INTRODUCTION

Blast disease challenges rice (*Oryza sativa* L.) production in Arkansas and worldwide. Advancements in cultural practices and breeding resistant varieties have accounted for the effectiveness of disease control in Arkansas for many years. However, blast disease is commonly observed throughout Arkansas.

Rice cultivar Banks, (semidwarf RU0001188), was released by the Arkansas Agricultural Experiment Station in 2004. Banks is a very high-yielding, midseason, long-grain rice cultivar. It originated from the backcross 'LaGrue'//'Lemont'/ RA73/3/ LaGrue/4/LaGrue (cross no.19951166). LaGrue is a high-yielding long-grain rice while Lemont is a long-grain semidwarf rice. RA73 is an induced mutant selection from Bonnet 73 irradiated with a Fission Neutron rate of 1800 R (line # STG74MU429) (Moldenhauer et al., 2004).

Banks is known to possess the *Pi-ta* blast-resistance gene based upon molecular marker analysis and reaction to specific isolates. It was known that the *Pi-ta* gene specifically confers resistance to specific blast pathogen *Magnaporthe oryzae* (formerly *Magnaporthe grisea*) races that contain the corresponding fungal avirulence gene *AVR-Pita*. The question being addressed by this research is why severe blast disease occurred in the Banks field at Corning, assuming the *Pi-ta* gene was functioning in preventing blast. Analysis of the structure and function of the *Pi-ta* gene should allow us to predict the effectiveness of the *Pi-ta* gene in the rice plant. The investigation of the structure of the *AVR-Pita* allele should provide some answers to why blast disease occurred in cultivar Banks.

The objectives of this study were to determine the structure and function of the *Pi-ta* gene in Banks, and the structure of the *M. oryzae* avirulence gene *AVR-Pita*.

PROCEDURES

Standard methods were used for DNA preparation, amplification of the *Pi-ta* gene using gene specific primers, and sequencing for this study. Seeds of Banks and blast isolates were collected from a diseased Banks field found near Corning, Ark., in 2004.

RESULTS AND DISCUSSION

The complete *Pi-ta* allele in Banks was sequenced and determined to be molecularly identical to the *Pi-ta* allele in cultivar 'Katy' (Jia et al., 2004; K. Moldenhauer, personal communication). Reverse transcriptase-mediated PCR (RT-PCR) is the technique routinely used to analyze gene expression. Results from RT-PCR analysis indicate that the *Pi-ta* allele in Banks was expressed as expected.

The fungal *AVR-Pita* gene is known to trigger the *Pi-ta* gene-mediated defense response in the plant (Orbach et al., 2000). When expression of *AVR-Pita* is altered, cultivars that contain *Pi-ta* are susceptible to the blast pathogen. A total of 39 isolates including 8 virulent isolates from Banks were analyzed using an *AVR-Pita*-specific primer. The presence of the PCR product correlates with resistance in two cultivars that contain *Pi-ta* (Katy and 'Drew') and the absence of the PCR product correlates with the susceptibility in two cultivars ('M202' and 'C101A51') that do not contain *Pi-ta* alleles (Table 1). The failed PCR amplification of the *AVR-Pita* allele suggests that the structure of the *AVR-Pita* allele in blast isolates obtained from Banks is significantly altered (Table 1). These results suggest that the *Pi-ta* gene does not recognize *AVR-Pita* and effective resistance is not triggered. Moreover, a 2.6 kb fragment was amplified from one virulent isolate, B2. Sequence analysis of the 2.6 kb fragment revealed a virus-like transposon Pot3 at the conserved region of the *AVR-Pita* allele in B2. This finding suggests that the insertion of Pot3 altered the expression of the *AVR-Pita* allele. The insertion of Pot3 transposon at the promoter region was previously found in a laboratory strain (Kang et al., 2001). However, Pot3 could not be amplified from all other isolates (which are virulent on Banks in greenhouse tests). It is possible that other genetic changes occurred, altering the expression of the *AVR-Pita* gene so that the fungus can bypass cultivars containing the *Pi-ta* gene such as Banks. To confirm that there are several different virulent alleles, Rep-PCR is another technique that can be used to predict the genetic diversity of the rice blast fungus (George et al., 1998). Using Rep-PCR with primers Pot2-1 and Pot2-2, eight of 12 different classes of isolates were detected in 16 virulent isolates (Fig. 1). These results suggest that the genomes of these virulent isolates are distinctly different from each other. Further studies on molecular mechanisms of susceptibility and frequencies of the occurrence of these virulent isolates will shed insight into evolutional adaptation of the rice blast pathogen. Resulting knowledge will be very useful for controlling blast disease in Arkansas and worldwide.

SIGNIFICANCE OF FINDINGS

Our data indicate the blast fungus “has defeated” a resistance gene *Pi-ta* in rice through deletion and transposition of the avirulence gene *AVR-Pita* in the pathogen in a commercial rice field. This knowledge is important for developing practical, integrated disease-management strategies for grower use. It also provides the scientific basis for the importance of stacking resistance genes with overlapping resistance spectra to defeat different races of rice blast.

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Table 1. Summary of disease reactions of rice cultivars to isolates of *Magnaporthe oryzae* and the presence of the *AVR-Pita* allele.

		Origin		MGR586 fingerprint	Isolate	Isolate	Disease reactions^v				*AVR-Pita* (YL169/YL149)
Isolate	Race^z	State	Year	group^y	phenotype^x	reference^w	M202	C101A51	Katy	Drew	Amplicon^u
A598	IB49	AR	1992	A	WT	1,2,3	S	S	R	R	+
A264	IC17	AR	1993	B	WT	1,2,3	S	S	R	R	+
A119	IB49	AR	1992	C	WT	1,2,3	S	S	R	R	+
A347	IC17	AR	1992	D	WT	1,2,3	S	S	R	R	+
75A49	IG1	AR	1975	B	WT	1,2,3	S	S	R	R	+
75A49/3	IG1			B	nit	1	S	S	R	R	+
K60	IG1-RS			B	WT-RS	2,3	S	S	S	S	-
18	IC17	AR	1992	B	WT	2,3	S	S	R	R	+
18/1	IC17			B	sul		S	S	R	R	+
18/1-2	K			B	sul-RS		S	S	S	S	-
18/1N	IC17			B	nit		S	S	R	R	+
18/1N-13	K			B	nit-RS		S	S	S	S	-
24/1	IG1	AR	1992	B	nit	1,2,3	S	S	R	R	+
24/1-2	K			B	nit-RS		S	S	S	S	-
25	IC17	AR	1992	B	WT	2,3	S	S	R	R	+
25/104	IC17			B	nit		S	S	R	R	+
25/104-16	K			B	nit-RS		S	S	S	S	-
60	IC17	AR	1992	D	WT	2,3	S	S	R	R	+
60/1	IC17			D	nit		S	S	R	R	+
60/1-5	K			D	nit-RS		S	S	S	S	+
S-1	K	AR	1994	B	WT		S	S	S	S	-
94071A		AR	1994	B	WT	1	S	S	S	S	-
ZN4	IE1	TX	1995	C	WT	3	S	S	R	R	+
TM2	K	TX		B	WT	1,3	S	S	S	S	-
IB1							S	S	R	R	+
IB33		AR			WT-RS		S	S	S	S	-
ZN61	IB49	AR	1992	C	WT	3	S	S	R	R	+
ZN57	IC17	AR	1992	B	WT	3	S	S	R	R	+
B-C/3-1							S	S	S	S	-
1188R		AR	2004	B	WT		S	S	S	S	-

continued

Table 1. Continued.

		Origin		MGR586 fingerprint	Isolate	Isolate	Disease reactions[v]				*AVR-Pita* (YL169/YL149)
Isolate	Race[z]	State	Year	group[y]	phenotype[x]	reference[w]	M202	C101A51	Katy	Drew	Amplicon[u]
1188S		AR	2004	B	WT		S	S	S	S	-
B1	K	AR	2004	B	WT		S	S	S	S	-
B2	K	AR	2004	B	WT		S	S	S	S	-
B3	K	AR	2004	B	WT		S	S	S	S	-
B4	K	AR	2004	B	WT		S	S	S	S	-
B5	K	AR	2004	B	WT		S	S	S	S	-
B6	K	AR	2004	B	WT		S	S	S	S	-
B7	K	AR	2004	B	WT		S	S	S	S	-
B8	K	AR	2004	B	WT		S	S	S	S	-

[z] The race designation was determined either in the current study or as part of concurrent studies (Correll et al., 2000a, b; Xia et al., 2000). The race K designation was originally used to indicate virulence on the previously resistant cultivar Katy. In this study, race K designates virulence on *Pi-ta* containing cultivars Katy and Drew.

[y] The MGR586 fingerprint group was previously determined (Correll et a.l, 2000a,b; Xia et al., 2000) .

[x] Isolate phenotypes include wild-type (WT) field isolates; race-shift (RS) isolates, which were virulent on *Pi-ta*-containing cultivars and were originally recovered from the susceptible lesions on Katy after being inoculated with a parental isolate that was avirulent on Katy (Correll et al., 2000a); and nitrate (nit) and sulfate (sul) non-utilizing mutants that were used as marked strains to confirm that the race-shift isolate originated from the avirulent parental isolate (Correll et al., 2000b). Isolate IB-33 was recovered as a race-shift isolate from rice cultivar Katy grown in a greenhouse. Isolates 1188R and 1188S as well as the isolates with a "B" prefix were collected from the cultivar Banks from several counties in Arkansas during severe rice blast epidemics in commercial fields in 2004 (Clay=Clay County, Ark., USA; Law.=Lawrence County, Ark.).

[w] 1 = Correll et al., 2000a; 2 = Correll et al., 2000b; 3 = Xia et al., 2000.

[v] Cultivars Katy and Drew have the resistant *Pi-ta* allele, and cultivars C101A51 and M202 have the susceptible *pi-ta* allele (Jia et al., 2003); Mean disease reactions of 0 to 2 on the 0 to 5 scale or 0 to 3 on the 0 to 9 scale were considered as resistant reactions ("R"), whereas reactions of 3 to 5 or 4 to 9 were considered as susceptible reactions ("S").

[u] The presence (+) or absence (-) of a PCR amplicon with primers YL169 and YL149. The amplicon produced was 1086 bp.

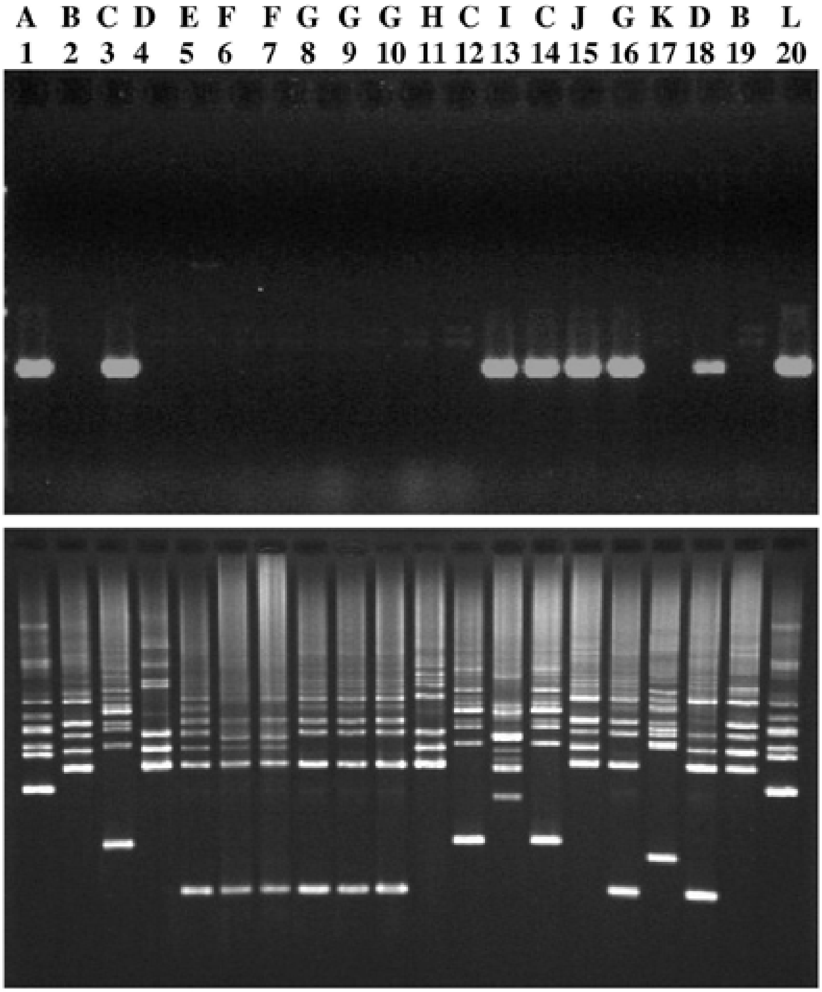

Fig. 1. Genetic diversity of *M. oryzae* field isolates as revealed by *AVR-Pita* specific primer YL168 and telomere specific primer Tel 3 (upper panel) and by rep-PCR with primers Pot2-1 and Pot2-2 (bottom panel). PCR products were separated by agarose gel electrophoresis and visualized with ethidium bromide. Lanes (left to right) contain the products: 1. ZN4 (IE-1), 2. TM2 (IE-1K), 3. 1188R, 4. B1, 5. B2, 6. B3, 7. B4, 8. B5, 9. B6, 10. B7, 11. B8, 12. ZN15 (IB-1), 13. IB-33, 14. IB-49, 15. ZN57 (IC-17), 16. B-C/3-1, 17. 60/1-5, 18. 94071A, 19. TM2 (IE-1K), 20. ZN61 (IB-49). ZN61 (IB-49), ZN57 (IC-17), ZN15 (IB-1), and ZN4 (IE-1) are wild type (avirulent) isolates, and the others are race-shift (virulent) isolates. Race designations are indicated in parentheses.

Characterization of a Recombinant Inbred Line Population of Rice Using SSR Markers

G. Liu, J.L. Bernhardt, M.H. Jia, Y.A. Wamishe, and Y. Jia

ABSTRACT

A population of 269 F_{10-11} recombinant inbred lines (RILs), from a cross between 'Kaybonnet' *low phytic acid* 1-1 (KBNT*lpa*) and 'Zhe733', was molecularly characterized using simple sequence repeat (SSR) markers. One hundred and seven markers were mapped on 12 rice chromosomes, representing a total of 1016.3 c*M* of genetic distance. The average frequencies of overall genome heterozygous and non-parental alleles per RIL were 1.3% and 0.4%, respectively. Thirteen heterozygous RILs at ≥5 marker loci and nine RILs with ≥5 non-parental alleles were identified, representing 5.1% and 3.5% of the 255 RILs population. Two hundred and thirty-eight RILs were clustered as 10 sub-groups based on Nei's (1972) genetic distance. Sixty-nine RILs were selected for field evaluation of rice water-weevil resistance based on the similarities of their genetic background. This linkage map would facilitate developing DNA markers to tag genes resistant to rice pests, agronomically important traits, and also for marker-assisted selection.

INTRODUCTION

Kaybonnet *low phytic acid* 1-1 (KBNT*lpa*) is an irradiation-induced mutant of a tropical japonica cultivar Kaybonnet with the phytic acid portion of seed phosphorus reduced from 71% to 39%. KBNT*lpa* possesses a single recessive gene, *lpa*1-1, for low phytic acid and resistance genes to several U.S.-predominant races of rice blast (*Magnaporthe grisea*) such as IB-1, IB-49, IC-17, and IG-1 (Rutger et al., 2004). Zhe733 from China is a high-yielding, early-maturing indica rice cultivar and also resistant to *M. grisea* (Yan and Cai, 1991) and to straighthead, a physiological disorder of rice in the

U.S. (Yan et al., 2005). Using these parental cultivars, Rutger and Tai (2005) developed the $F_{10\text{-}11}$ generation of recombinant inbred lines (RIL) population of KBNT*lpa*×Zhe733, which is used in this study.

RIL populations have been extensively used for constructing molecular marker-based genetic linkage maps using SSR markers in many crops. Similarly, rice RILs also have been used in mapping qualitative and quantitative traits. Therefore, molecular characterization of KBNT*lpa*×Zhe733 RILs population is useful in mapping of rice blast resistance genes, the genes associated with low phytic acid composition, and other agronomically important traits or difficult traits such as reaction to rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel. The objectives of this study were to evaluate heterozygosity in this RIL population using SSR markers, to construct an SSR-based genetic linkage map, and to cluster and select the RILs according to their SSR genotypes.

PROCEDURES

The KBNT*lpa*×Zhe733 population (Rutger and Tai, 2005) of 269 $F_{10\text{-}11}$ RILs was used in this study. The KBNT*lpa*×Zhe733 RILs (KZRILs) were planted in plastic pots. DNA extraction was performed based on the method by Tai and Tanksley (1990). DNA samples were qualitatively determined, quantified and normalized to 5 ng/µL prior to DNA amplification. One hundred and sixty SSR markers were tested on the parents and 109 polymorphic markers were used to test KZRILs population. PCR amplification was performed following the standard procedure. The samples were run on an ABI Prism 3700 DNA analyzer according to the manufacturer's instructions. SSR fragment sizing was performed using the software GeneScan® and Genotyper®. Alleles were binned manually.

Data analysis for all marker loci was based on successful marker amplification and DNA product analysis on the DNA analyzer. All loci used in this study were polymorphic with a frequency of less than 0.94. Genetic linkage analysis of SSR markers was performed using the software JoinMap®. Loci were assigned to linkage groups by the program default settings with likelihood-odds-ratio (LOD) scores equal to or higher than 3.0. The "fixed order" command was used to identify the most probable marker order within a linkage group. Genetic distance and cluster analysis were conducted using the software PowerMarker (http://statgen.ncsu.edu/powermarker). Nei's (1972) genetic distance was used to calculate pair-wise genetic distance among all the KZRILs. Unweighted pair-group method using arithmetic average (UPGMA) method was used for cluster analysis. Cluster tree was constructed using the program Mega (http://www.megasoftware.net). The KZRILs in cluster sub-groups representing genetic diversity of the KZRIL population were selected using the function of "Line Selection" of PowerMarker and the selected KZRILs were re-clustered.

RESULTS AND DISCUSSION

Of 255 KZRILs detected by 109 markers, 172 KZRILs (67.5%) were homozygous; 42 KZRILs (16.4%) were heterozygous at a highest marker loci of 42; 30 KZRILs (11.8%) had up to 9 non-parental alleles; and 11 KZRILs (4.3%) were heterozygous and had non-parental alleles. A KZRIL detected as having heterozygosity or non-parental alleles at more than 5 marker loci was defined as a heterozygous KZRIL or a non-parental KZRIL. Thus, 13 heterozygous KZRILs and 9 non-parental KZRILs were found, representing 5.1% and 3.5% of the 255 KZRILs population, respectively. The average frequencies of overall genome heterozygosity and non-parental alleles per KZRIL were 1.3% and 0.4%, respectively. Theoretically, the average frequencies of heterozygous loci in a F_{10} and F_{11} RIL population should be 0.2% and 0.1%, respectively. Even though the frequency of heterozygous loci in this study (1.3%) was higher than the theoretical values, it is still obviously lower than the average frequencies of 3.6% by Xiao et al. (1996) and Cho et al. (1998).

A genetic linkage map of 107 marker loci was constructed based on the analysis of 109 SSR markers (Fig. 1). RM1 and RM408 were not linked to other markers in the linkage map. The mapped markers covered 12 rice chromosomes in 1016.3 c*M* of genetic distance with an average of 9.3 c*M* between two markers. This is shorter than the genetic distance of 1565.9 c*M* for the same number of SSR markers from the database of "Cornell2001" in Gramene (http://www.gramene.org). The total genetic distance in this population was 64.9% of Cornell map (2001). Similarly, He et al. (2001) reported that the genetic distance of each chromosome in an RIL population was shorter than that in a double haploid (DH) population. The total genetic distance in the RIL population of ZYQ8/JX17 (*indica/japonica*) was 70.5% of that in the DH population derived from the same rice cross. The order of the markers on chromosomes 1, 2, and 4-11 agreed with Cornell2001. However, there were some disagreements on marker order with Cornell2001 in this study. The high percentage of skewed markers towards Zhe733 on chromosome 3 and the relatively small number of markers on chromosome 12 might result in these disagreements.

Excluding heterozygous and non-parental KZRILs, cluster analysis was applied to 238 KZRILs using UPGMA method. The dendrogram showed a clear separation of the KZRILs into 10 sub-groups (Fig. 2). Clustering of KZRILs is particularly useful to select representative RILs of the whole population for mapping RWW resistance. Reducing the number of RILs by means of line selection is necessary to study such a trait that is so difficult to evaluate. Screening for resistance to RWW in the greenhouse has not been possible due to the difficulty in culturing RWW in an environment-controlled condition (Zhang et al., 2004). However, field evaluation of RWW resistance is feasible with a small number of test entries. For this purpose, 69 representative KZRILs were selected based on the similarities of their genetic background for field phenotyping RWW resistance (Fig. 3).

SIGNIFICANCE OF FINDINGS

Clustering and selection of KZRILs are essential steps towards phenotyping difficult traits such as RWW resistance. The KBNT*lpa*/Zhe733 RIL population has been confirmed as an excellent mapping population. The genetic linkage map generated in this study will be useful for mapping and cloning genes of agronomic interest and for marker-assisted selection in rice improvement.

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The authors would like to thank Dr. J.N. Rutger and Ms. L. Bernhardt for providing rice seeds of KBNT*lpa*/Zhe733 RIL population, and Dr. H.A. Agrama for his help in data analysis. This research was funded by the Arkansas Rice Research and Promotion Board. China National Natural Science Foundation (30370970, 30471177) partially supported G. Liu's work at the University of Arkansas.

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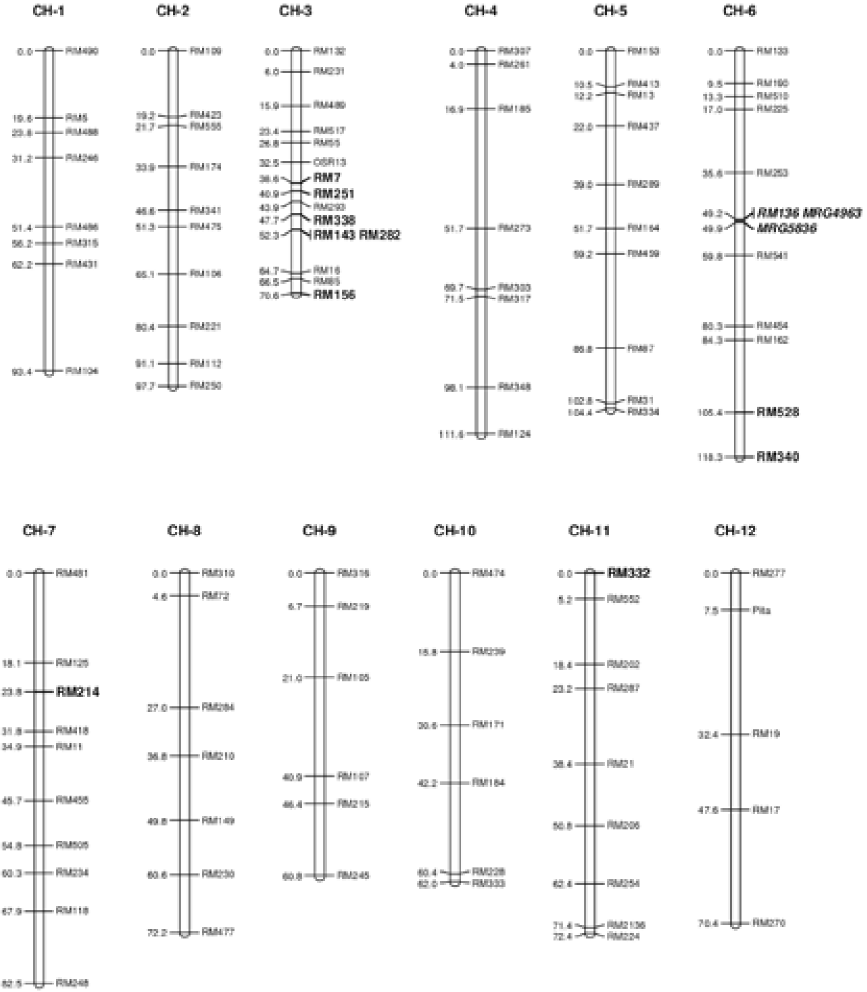

Fig. 1. A genetic linkage map of 107 SSR markers on 12 rice chromosomes based on 269 RILs of KBNT*lpa*/Zhe733 population. ***The genetic distances of SSR markerss in cM were shown on the left side of each chromosome.***

Fig. 2. Clustering of 238 RILs of KBNT*lpa*/Zhe733 population using UPGMA method based on Nei's (1972) genetic distance. *The RILs indicated with the symbol of "●" were the representative RILs selected for further field evaluation for rice water weevil resistance.*

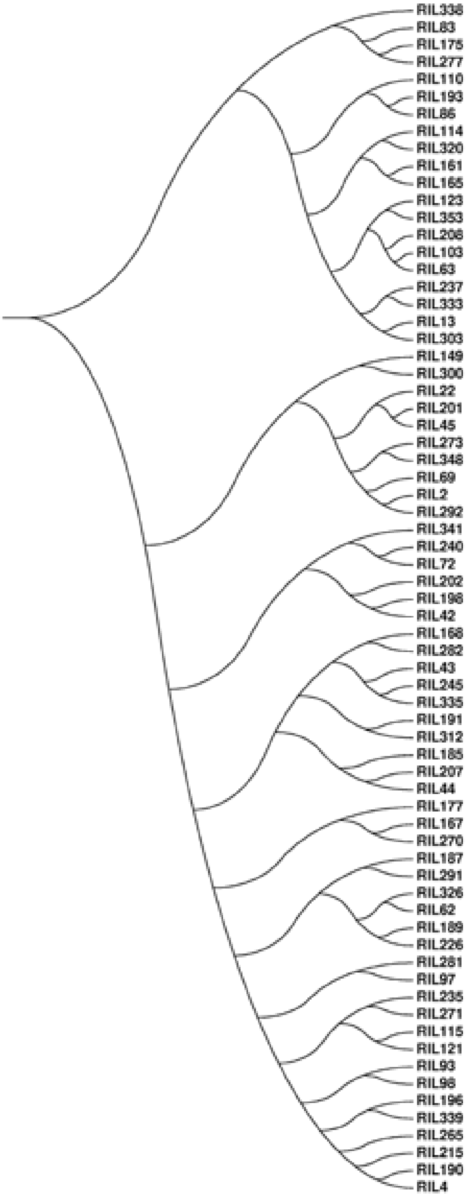

Fig. 3. Clustering of the selected representative RILs in the KBNT*lpa*/Zhe733 population using the UPGMA method.

‘CL171-AR’, the First Arkansas Clearfield Variety

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ABSTRACT

‘CL171-AR’ rice (*Oryza sativa* L.), is a high-yielding, midseason, long-grain Clearfield rice cultivar developed by the agricultural experiment stations of Arkansas and Louisiana. Clearfield technology denotes resistance in the rice cultivar to the herbicide Newpath. CL171-AR originated from the cross ‘Wells’/‘CL161’ made at the Rice Research Station at Crowley, La., in collaboration with Dr. Tim Croughan in 1999. CL171-AR was approved for release to BASF for further testing during 2006. It has good rough-rice yields with good milling yields similar to CL161. CL171-AR has lodging resistance like that of ‘LaGrue’, rating moderately susceptible, and its maturity is similar to ‘Cypress’. The grain weight and kernel size of CL171-AR are similar to that of LaGrue. CL171-AR rates susceptible to rice blast in Arkansas conditions, susceptible to moderately susceptible to sheath blight, and susceptible to kernel smut. CL171-AR is similar to the parent CL161 for grain and milling yields and has typical southern U.S. long-grain cooking quality. The major advantage of the cultivar over the other Clearfield lines is its improved disease package.

INTRODUCTION

CL171-AR is a high-yielding, midseason, long-grain Clearfield rice cultivar developed by the agricultural experiment stations of Arkansas and Louisiana. CL171-AR was approved for release to BASF for further testing in 2006. CL171-AR has resistance to Newpath, an imazethapyr herbicide, and has an improved disease package compared to the other Clearfield rice cultivars on the market. CL171-AR is very similar to the CL161 parent for rough-rice grain and milling yields. CL171-AR was developed with funding from BASF and through the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

CL171-AR is a high-yielding, midseason, long-grain Clearfield rice cultivar developed by the Agricultural Experiment Stations of Arkansas and Louisiana. CL171-AR originated from the cross Wells/CL161 made at the Rice Research Station at Crowley, La., in collaboration with Tim Croughan in 1999. Wells is a high-yielding long-grain rice described by Moldenhauer et al. (1999). CL161 is a Clearfield rice variety released by Louisana State University and BASF Corporation. It is a mutation line from Cypress. The experimental designation for early evaluation of CL171-AR was STG03IMI261-177, starting with a bulk of F_4 seed from the 2002 panicle row IMI261-177. CL171-AR was tested in the Arkansas Rice Performance Trials (ARPT) 2004-2005 as entry STG03IMI261-177.

In 2005, the ARPT was conducted at five locations in Arkansas: Rice Research and Extension Center (RREC), Stuttgart, Ark.; Pine Tree Experiment Station (PTES), Colt, Ark.; Northeast Research and Extension Center (NEREC), Keiser Ark.; Jackson Co. Farmer Field, Newport, Ark. (JCFF); and a Clay Co. Farmer Field, Corning, Ark. (CLC). In 2006, the ARPT was grown at the RREC, PTES, NEREC, JCFF, CLC, and the Southeast Research and Extension Center (SEREC), Rowher, Ark. Each year the tests had three replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. Data collected from these tests included plant height, maturity, lodging, kernel weight, percent head rice, percent total rice, grain yield adjusted to 12% moisture, and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas Division of Agriculture Cooperative Extension Service Rice Production Handbook MP192 (CES, 2001). Agronomic and milling data are presented in Table 1. 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 Spring and other very-short season cultivars grown in the ARPT. Rough rice grain yields of CL171-AR are very similar to Cypress, CL161, and CL131 in the Arkansas Rice Performance Trials (ARPT).

In 11 ARPT tests (2005-2006), CL171-AR, CL161, 'CL131', 'Francis', Wells, 'Cocodrie', 'Cheniere', and 'Cybonnet' averaged yields of 182, 181, 182, 209, 205, 177, 190, and 194 lb/acre, respectively. Milling yields (whole kernel:total milled rice) at 12% moisture from the same tests averaged 60:71, 62:70, 60:71, 60:70, 56:71, 62:71, 60:70, and 62:71 for CL171-AR, CL161, CL131, Francis, Wells, Cocodrie, Cheniere, and Cybonnet, respectively.

CL171-AR is similar in maturity to Cypress. CL171-AR, like Francis and Wells, had greater straw strength, an indicator of lodging resistance, than Drew. On a relative straw-strength scale (0 = very strong straw, 9 = very weak straw) CL171-AR, Francis, Wells, Drew, CL161, and Cocodrie rated 3, 3, 3, 5, 2, and 2, respectively. CL171-AR is 97 cm in plant height, which is between its parents Wells and CL161.

CL171-AR, like Wells, Francis, and CL161, is susceptible to common rice blast [*Pyricularia grisea* (Cooke) Sacc.]. They all rate an S under Arkansas conditions, using the standard disease ratings R = resistant, MR = moderately resistant, MS = moderately suceptible, and S = suceptible to disease. CL171-AR is rated S to sheath blight (*Rhizoctonia solani* Kühn), which compares with Francis (MS), Ahrent (MS), Wells (S), Cypress (VS), CL161 (VS), and CL131 (VS). CL171-AR is rated MS to kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.], which compares to Francis (VS), Wells(MR), CL161 (S), CL131 (S), Cypress (VS), and Drew (MS). CL171-AR is rated S to stem rot; MR to leaf smut (*Entyloma oryzae* Syd. & P. Syd.); S to false smut [*Ustilaginoidea virens* (Cooke) Takah]; and R to brown spot [*Cochliobolus miyabeanus* (Ito & Kuribayashi in Ito) Drechs. ex Dastur]. CL171-AR, like Wells, is MS to crown (black) sheath rot [*Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *graminis*]. CL171-AR is rated S to bacterial panicle blight in Arkansas. It has an MS reaction to straighthead, this compares to CL161 (S), CL131 (VS), Cocodrie (VS), Wells (MS), and Francis (MS).

Plants of CL171-AR have erect culms, green erect leaves like CL161, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw-colored with both colorless and purple apiculi, and some short-tip awns on the lemma at maturity. Kernels are similar in size to those of Cocodrie and Cybonnet. Individual milled kernel weights of CL171-AR, CL161, CL131, Francis, Wells, Drew, Cheniere, Cocodrie, and Cybonnet, averaged 17.6,16.5, 16.8, 16.8, 18.9, 16.8, 17.6, 16.6, and 17.7, respectively, in the ARPT, 2005-2006.

The endosperm of CL171-AR is nonglutinous, nonaromatic, and covered by a light-brown pericarp. Rice quality parameters indicate that CL171-AR has typical southern U.S. long-grain rice cooking quality characteristics, as described by Webb et al. (1985). CL171-AR has an average apparent starch amylose content of 22.3 g kg^{-1} and an intermediate gelatinization temperature (70 to 75°C), as indicated by an average alkali (17 g kg^{-1} KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

The release of CL171-AR offers producers the first Arkansas Clearfield cultivar with good rough-rice grain and milling yields similar to CL161. CL171-AR also offers producers a Clearfield line with an improved disease package especially for sheath blight where it rates susceptible.

ACKNOWLEDGMENTS

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Table 1. Three-year average agronomic data from the 2005 to 2006 Arkansas Rice Performance Trials for CL171-AR and other cultivars.

Cultivar	Grain type[z]	Yield 2005	Yield 2006	Yield Mean[y]	Height	50% heading	Kernel weight	Milling[x]
		(bu/acre)	(bu/acre)	(bu/acre)	(in.)	(days)	(mg)	(HR:TOT)
CL171-AR	L	194	173	182	39	91	17.6	60:71
CL161	L	187	176	181	39	91	16.5	62:70
CL131	L	193	172	182	33	89	16.8	60:71
Francis	L	210	208	209	40	90	16.8	60:70
Wells	L	213	198	205	41	91	18.9	56:71
Cocodrie	L	195	162	177	37	90	17.6	62:71
Cheniere	L	197	185	190	37	90	16.6	60:70
Cybonnet	L	202	186	194	38	90	17.7	62:71

[z] Grain type: L = long-grain, M = medium-grain, and S = short-grain.

[y] 2005 consisted of five locations, Rice Research and Extension Center (RREC), Stuttgart, Ark.; Pine Tree Experiment Station (PTES),Colt, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Jackson Co. Farmer Field (JCFF), Newport, Ark.; and Farmers Field in Clay County (CLC); and in 2006 at the RREC, PTES, NEREC, JCFF, CLC, and Southeast Research and Extension Center Rohwer Branch Station (SEREC), Rowher, Ark.

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

Functional Characterization of *OsLti6a* Using Yeast Heterologous Expression

M.R. Morsy and J.McD. Stewart

ABSTRACT

OsLti6 genes are related to an evolutionary, conserved abiotic stress-related gene family encoding low-molecular-weight hydrophobic proteins. A high expression level of OsLti6 in a chilling-tolerant rice genotype suggests a role in stress tolerance. Also, stress tolerance and high expression of OsLti6 associated with low electrolyte leakage indicated a possible role of OsLti6 in membrane stability. To study the role of OsLti6 in chilling-stress tolerance, expression effects were tested in a heterologous yeast system. Expression of OsLti6a in yeast allowed higher survival and growth rates when grown under chilling stress compared to the same yeast strain transformed with a control plasmid. Tolerance to other abiotic stresses in the heterologous system, as measured by electrolyte leakage and cell viability, implies a role for OsLti6 in membrane stability during stress.

INTRODUCTION

Sub-optimal environmental conditions cause damage to many plant species including rice. To neutralize the damaging effects of stress conditions, plants have developed complex molecular and biochemical mechanisms (Seki et al., 2003). In *Arabidopsis*, two genes were isolated from a cDNA library using a subtracted cDNA probe enriched in chilling-induced transcripts (Capel et al., 1997). Functional characterization of the *Arabidopsis RCI2A* gene in a yeast mutant defective in the *RCI2* homologous yeast gene was able to correct the salt-sensitive phenotype of the *SNA1* deletion mutant (Nylander et al., 2001). Two homologous rice genes induced by chilling stress, *OsLti6a* and *OsLti6b*, were isolated from a subtracted cDNA library (Morsy et al., 2005). Based on hydropathy plots and subcellular localization in the membrane fraction, OsLti6 proteins are thought to have a role in increasing membrane integrity during stress (Morsy et al., 2005).

Over-expression of stress-responsive genes in a model system may be used to confirm their role in the biology of stress tolerance. The yeast heterologous expression system is a rapid, highly reproducible tool that provides tentative answers concerning the biological function of stress-related genes (Stanasila et al., 1998). Functional characterization of *OsLti6* by heterologous expression should provide information for or against the hypothesis of its role in stress tolerance. This paper describes the effects of heterologous expression of *OsLti6a* in a yeast system.

PROCEDURES

Survival and Growth Rates

Stress tolerance of the *S. cerevisiae* strain expressing OsLti6 (YRG2-OsLti) was tested under stress conditions and compared to control yeast transformed with the null vector (YRG2-BD). YRG2-OsLti and YRG2-BD yeast strains were grown for 2 to 3 days on SD media lacking tryptophan. One colony of each strain was inoculated into 1 ml YPAD medium, vortexed and transferred into 50 ml YPAD medium. Overnight cultures were collected by centrifugation then resuspended in 1X TE buffer to a final OD_{600} of 1.0 ($5x10^7$cell/ml). The yeast suspensions were further diluted by adding 100 µl of each into 50 ml of TE buffer. A 200 µl aliquot of each was spread on YPAD plates (5 plates) to determine the survival rates under various stresses. For chilling treatment, cells were grown for 4 to 5 days at 12°C. For salt and mannitol treatments, YPAD media were prepared with 0.25, 0.5, 0.75, 1, 1.2, or 1.4 M NaCl and 0.5, 0.75, 1, 1.2, or 1.4 M mannitol, and the yeast cultures grown on these media at 30°C for 2 to 3 days. For controls yeast strains were grown on YPAD media without additive at 30°C. For the growth rate of yeast strains, 100 µl of cell suspension with an OD_{600} of 1.0 of each cell strain were added to YPAD broth and grown at 12°C with shaking for 48 hours for chilling treatments. For salt and osmotic stress treatments, liquid medium containing 0.75 M NaCl or 1 M mannitol was used, respectively. Control yeast strains were grown on liquid YPAD medium and kept at 30°C with shaking.

Yeast Viability Test

One colony each of YRG2-OsLti and YRG2-BD yeast were grown separately to late log phase in YPAD broth. Subsequently, 50 µl of culture were added to 1 ml of sterile water containing 2% D (+) glucose and 10mM Na-HEPES (pH 7.2) in a microfuge tube, centrifuged for 5 minutes at 1000xg and then resuspended in 1 ml of the same mix. Yeast suspensions were combined with 20 µM of FUN-1 cell viability stain (Molecular Probe, Eugene, Ore.), mixed, and incubated at 30°C in the dark for 30 minutes. Number of cells in 5 µl of stained yeast were determined by a hemocytometer slide under an Axioskop 2 Plus fluorescent microscope (Carl Zeiss, Thornwood, N.Y.)

equipped with a fluorescein filter set with excitation at 480 nm and emission at 530 nm. Five squares of the hemocytometer were counted, and an average number of cells in 1 ml was estimated to be 22 X10^6 for each yeast strain per treatment. The stained cells were analyzed with Auto Montage Pro software and scored for dead and living cells and percentage of dead cells was calculated.

Electrolyte Leakage

A similar colony of each yeast strain was grown on YPAD liquid media for 24 hours. Cells were collected and the OD_{600} of each was adjusted to 1.0 with TE buffer as described previously. One hundred µl of each strain were inoculated into 25 ml liquid YPAD medium and grown for another 24 hours at 30°C. For the chilling treatment, cultures were moved to 12°C with shaking for 12 hours. For salt and osmotic stress, cells were collected, supernatant was discarded, and new 25 ml medium with salt (0.75 M NaCl) or mannitol (1M mannitol) was added. The cells were gently resuspended and grown for 12 hours at 30°C. Control yeast strains were grown at 30°C in standard YPAD medium. The electrical conductivity (EC) of the cell suspensions was measured at the start and at the end of the 12 hours' incubation period. Total electrolyte from each treatment was measured after boiling for 30 minutes. The control values from medium containing no yeast were subtracted from the initial and total conductivity before calculation of the percentage of electrolyte leakage. Percent electrolyte leakage (EL) due to stress was expressed as EC before boiling divided by EC after boiling × 100. Ten cultures were measured for each treatment, and the whole experiment was conducted twice.

Statistical Analysis

Environmental stress treatments are reported as the average of five separate replications for each strain-treatment. ANOVA and Student-t tests were used to determine differences among treatments and yeast strains.

RESULTS AND DISCUSSION

OsLti6 belongs to the UPF007 protein family that is present in many organisms, including animals, fungi, and plants, and may share common function. We previously proposed that OsLti6 proteins contribute to the biochemical processes involved in preserving the structural and functional integrity of the plasma membrane during chilling stress in rice seedlings (Morsy et al., 2005). In this paper, we test the hypothesis by inducing over-expression of OsLti6a in yeasts and subjecting these to abiotic stress.

Survival of yeast strains YRG2-OsLti and YRG2-BD was similar (measured as number of colonies) at 30°C (Fig. 1a). Exposure of these strains to low-temperature stress (12°C) decreased survival significantly compared to growth at 30°C. However, after exposure to chilling temperatures, survival of control yeast with the null plasmid was only about half that of YRG2-OsLti (Fig. 1a). YRG2-OsLti yeast grown on medium containing mannitol up to 1 M or 0.25 M NaCl was able to maintain survival at the control level (Fig 1b, 1c). These results are supported by the report of Navarre and Goffeau (2000) that the *OsLti6* homolog *RCI2* from *Arabidopsis* could functionally complement a yeast mutation in *Pmp3p,* which is sensitive to salt stress. The YRG2-BD yeast experienced a reduction in survival when grown on medium containing as low as 0.5 M mannitol. Increases in mannitol concentration beyond 1 M or NaCl over 0.25 M led to reductions in survival of both strains, although survival of YRG2-OsLti was higher (Fig. 1b, 1c). At 1.4 M NaCl, the highest concentration used, some YRG2-OsLti cells survived whereas the control yeast had zero survival at this concentration (Fig. 1c). Similar results were reported by Imai et al. (2006) where they found that the OsLti6 homolog from wheat can partially complement a NaCl-sensitive mutant.

A reduction in growth (measured by OD_{600}) occurred under chilling stress in both yeast strains, but after 48 hours the growth of YRG2-OsLti reached nearly the level of cells grown at 30°C. Although the YRG2-BD began growth after 3 hours of chilling, the growth was slow and by 48 hours the OD of the colonies was only 60% of the same strain grown at 30°C (Fig. 2).

YRG2-OsLti and YRG2-BD strain had significant reductions in growth within the first 3 hours of osmotic (1 M mannitol) or salt (0.75 M NaCl) stress (Fig. 2c, 2d). Both strains reached the exponential growth phase within 6 to 12 hours while control yeast grown at 30°C began this phase after 3 hours (Fig. 2a). In medium containing 1 M mannitol, the growth of YRG2-OsLti was consistently higher than that of YRG2-BD (Fig 2c). On the other hand, there was little difference in the growth of the two strains in medium containing 0.75M salt (Fig. 2d).

To evaluate the effect of over-expression of the OsLti6a protein on membrane stability during stress, the percentages of electrolyte leakage (EL) and cell viability were measured for YRG2-OsLti and YRG2-BD cell suspensions. The FUN-1 viability stain provided a quantitative visualization of the effect of stress on viability and membrane integrity. The percentages of EL and dead cells for both strains under control conditions were similar, however, the YRG2-OsLti strain showed lower EL and dead cells under stress conditions compared to YRG2-BD (Fig. 3).

Over-expression of OsLti6a fusion protein in yeast increased survival and growth under chilling stress. Moreover, the OsLti6a fusion protein decreased electrolyte leakage and increased cell viability compared to the yeast strain expressing BD without OsLti6. These results provide indirect evidence of enhanced membrane integrity, and suggest that OsLti6a has a role in stress tolerance.

Reports (Dunn et al., 1994; Capel et al., 1997) indicate that *OsLti6a* and its homolog are induced by chilling, salt- and water-deficit stresses in rice and other plants, suggesting a role in each of these stresses. Previously (Morsy et al., 2005), the induction pattern of the *OsLti6* gene family in a chilling-tolerant rice genotype was compared to that in a chilling-sensitive genotype, and electrolyte leakage from leaves and tolerance to chilling were correlated. The expression pattern and electrolyte leakage data in rice suggested a role of the OsLti6a protein in protecting the cellular membrane from damage in the early stages of stress. Interestingly, over-expression of the OsLti6a protein in yeast increased the survival, growth, and regrowth of the yeast strain not only under chilling stress but also under osmotic stress. We used FUN-1 stain, a dye that provided an indication of membrane permeability in yeast (Roth et al., 1995), to identify the effect of the OsLti6a protein on plasma membrane integrity. The percentage of cells with intact cellular membrane was higher in yeast expressing the OsLti6a-BD fusion protein compared to yeast expressing only BD. These results provide indirect evidence that OsLti6a enhances membrane integrity during stress. Further confirmation was obtained by measurement of membrane leakiness of suspension cultures of yeast expressing OsLti6a and control-yeast strains. Expression of OsLti6a was inversely correlated with the level of membrane injury, as measured by electrolyte leakage, compared to yeast expressing the BD protein only. Cell viability, as measured with FUN1, and decreased electrolyte leakage of suspension cultures of yeast, suggest that OsLti6a increases membrane integrity during stress.

SIGNIFICANCE OF FINDINGS

In view of the correlation between OsLti6 gene expression and decreased membrane leakiness in rice and in yeast in this study, it is reasonable to hypothesize that OsLti6 is important in increasing membrane integrity during stress. Moreover, considering the increased expression of OsLti6 genes in a chilling-tolerant rice genotype compared to a chilling-intolerant rice genotype, as well as increased survival and growth rate during chilling stress, it seems that OsLti6 genes are intimately involved in the mechanisms that protect plants from chilling stress. The OsLti6 proteins seem to play a role in the protective machinery of chilling tolerance, and to some extent in osmotic stress tolerance, but their role in salt tolerance is minimal. The OsLts6 may be an excellent candidate for selection in a molecular breeding program to enhance chilling tolerance.

ACKNOWLEDGMENT

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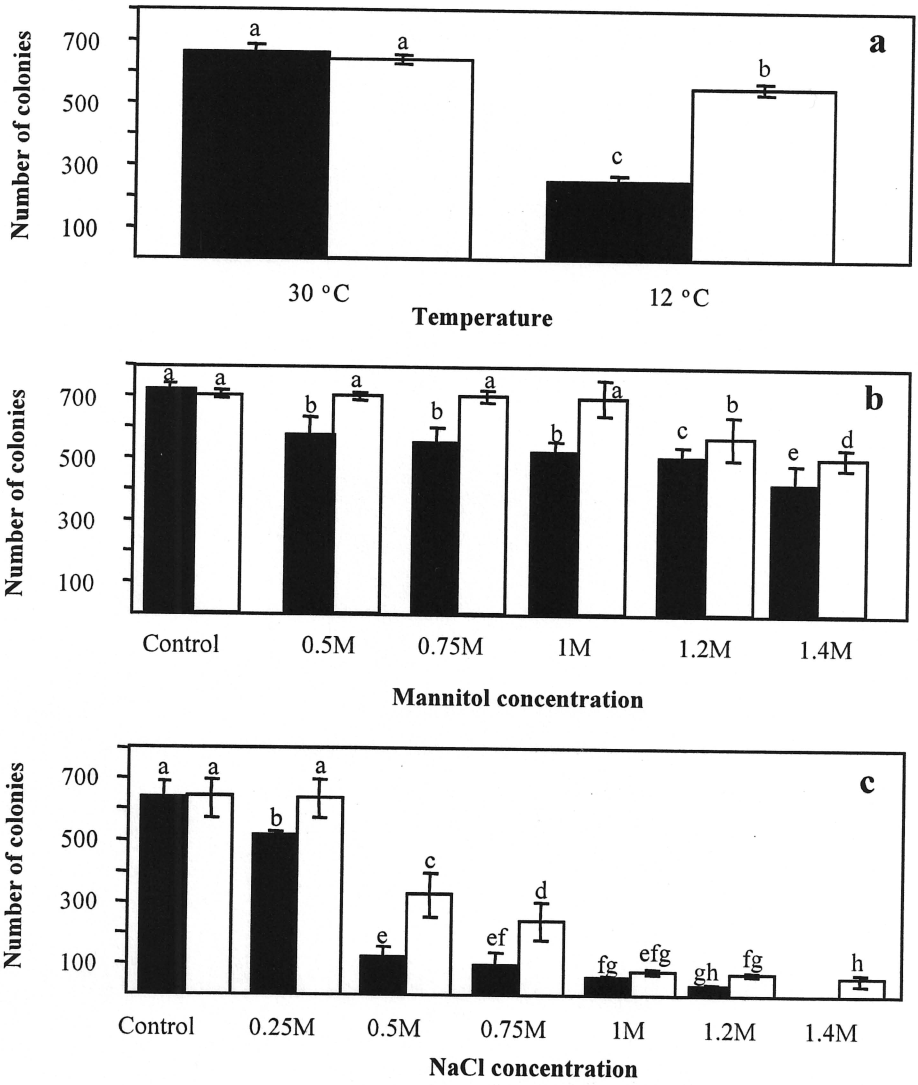

Fig. 1. Survival of YRG2-OsLti (open bars) compared to YRG2-BD (solid bars) yeast cells under different stresses. Survival was measured as number of colonies that grew under chilling stress, or in media containing NaCl for salt stress, or mannitol for osmotic stress. (a) The effect of 12°C on the survival of yeast strains compared to those grown at 30°C. (b) The effect of osmotic stress induced by different concentrations of mannitol added to the media on yeast strains grown at 30°C. (c) The effect of salt stress as NaCl at different concentrations on yeast strains grown under 30°C. Different letters indicate significantly different means between treatments or strains (n = 5; α≤ 0.05).

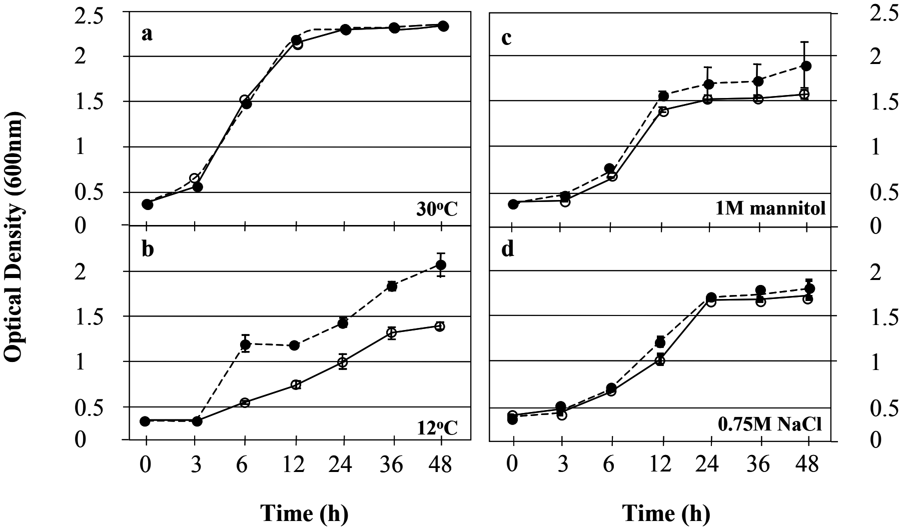

Fig. 2. Growth rate of YRG2-OsLti (dashed line, closed circles) compared to YRG2-BD (solid line, open circles) under different stresses. Growth rate was measured as optical density of cell suspension at OD_{600} under chilling stress; media contained NaCl for salt stress or mannitol for osmotic stress. (a) Yeast strains grown at 30°C in optimum medium. (b) The effect of 12°C temperature on the growth of yeast cells. (c) The effect of osmotic stress (1 M mannitol) on yeast cells grown at 30°C. (d) The effect of salt stress (0.75 M NaCl) on yeast cells grown at 30°C.

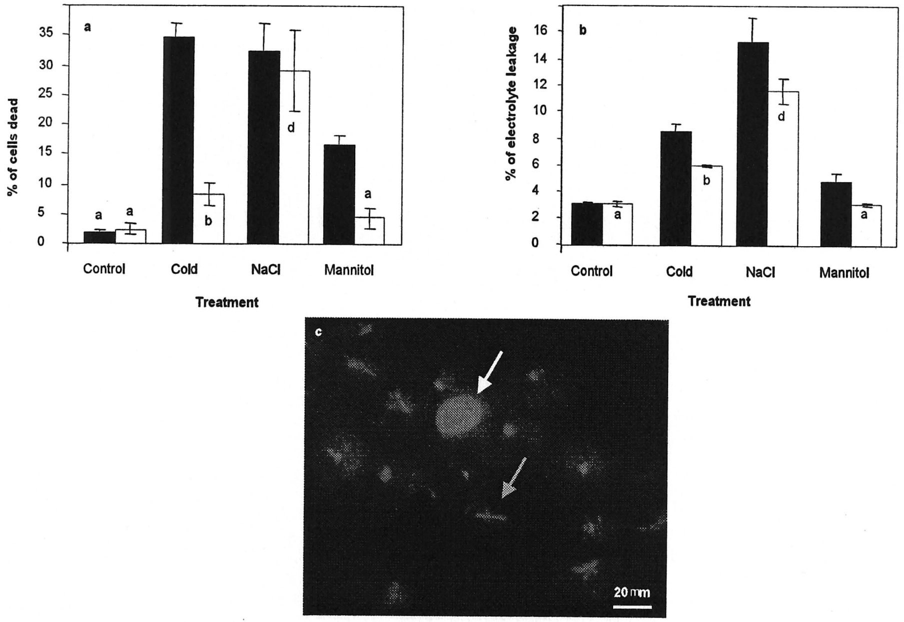

Fig. 3. Percentage of dead cells and electrolyte leakage of *S. cerevisiae* YRG2-OsLti and YRG2-BD. (a) Percentage of dead cells stained with FUN-1 and observed with a fluorescence microscope equipped with a long-pass filter set with excitation emission of 530 nm for visualization of fluorescein. (b) Percentage of electrolyte leakage in cell suspension cultures grown under stress conditions. White bars represent yeast expressing OsLti6 fusion protein and black bars represent control yeast. (c) Microscopic field illustrating the appearance of live and dead yeast cells stained with FUN-1. The cylindrical intravacuolar structures (CIVS) appear as rod-shaped inclusions indicating viable cells with functional membranes (arrows) while the dead yeast cells have very bright fluorescence and do not contain discrete fluorescent structures (arrowheads).

OsLti6a Protein-Protein Interaction Is Not Detected by the GAL4 Yeast Two-Hybrid System

M.R. Morsy and J.McD. Stewart

ABSTRACT

Low-temperature stress is a major limiting factor in rice production especially during the early seedling development stages. Two related cold-induced genes, *OsLti6a* and *OsLti6b*, were isolated from developing seedlings of a chilling-tolerant rice (*Oryza sativa* L.) cultivar CT6748. The OsLti6a protein (6.0 kDa) is highly hydrophobic with two possible membrane-spanning domains. Concurrence of tolerance to cold stress and decreased membrane damage in rice seedlings with higher expression level of the *OsLti6* genes indicated a possible role of these genes in increased membrane stability. To test this hypothesis and determine the functional role of the *OsLti6* gene family in cold-stress tolerance, interaction between OsLti6a and other rice proteins was studied. No interaction was detected by the GAL4 yeast two-hybrid assay between OsLti6a and other rice proteins represented in high titer in a rice cDNA library. OsLti6a appears to have minimum interaction with other proteins. Since changes in protein/lipid ratio are related to changes in membrane fluidity and integrity, we propose that OsLti6 may increase membrane stability by changing this ratio in response to cold stress.

INTRODUCTION

The functions of many stress-responsive genes remain unknown, and identification of the function of these genes is a challenge facing molecular biologists. One method to help understand the function of an unknown protein is to identify its interacting proteins. Fields and Song (1989) described the first yeast two-hybrid system used to identify protein-protein interaction. This system is based on the fact that eukaryotic transcription factors have discrete and separable DNA-binding and transcriptional activation domains. In this system, fusing one test protein to the DNA-binding domain of the yeast GAL4 transcription factor, and fusing a second protein to the GAL4 activation domain allows protein-protein interactions to be tested. The fusion proteins are expressed in a suitable yeast strain and the interaction detected by assaying for expression of a GAL4-responsive reporter gene.

Thus far, the properties of *OsLti6* genes and their homologs are hypothetical, but based on their hydropathy plots (hydrophobic nature of the protein) and subcellular localization in the membrane fraction, they are thought to have a possible role in increasing membrane integrity during stress. This paper reports the results of research to identify possible interacting protein partners of OsLti6 using the yeast two-hybrid system.

PROCEDURES

Construction of Expression cDNA Library

An RNeasy kit (Qiagen, Valencia, Calif.) was used to isolate total RNA from 2-leaf stage rice seedlings of chilling-tolerant CT6748 grown under a 10/13°C regime for 4 days. The mRNA was isolated from total RNA with a PolyA-Tract kit (Promega, Madison, Wis.) following the recommendations of the manufacturer. A yeast expression cDNA library was made according to the HybriZAP2.1 two-hybrid system (Stratagene, La Jolla, Calif.). The initial titer of the HybriZAP-2.1 cDNA library was 4.12×10^6 cfu/ml transformants with average insert size of 1.2 kb.

Plasmid Construction

OsLti6a was amplified with specific primers containing over-hangings for the *Eco*RI and *Xho*I restriction sequences at the 5' and 3'ends, respectively, for further directional cloning in the pBD-GAL4 Cam vector. The *OsLti6a* template on the pBluescript vector was added to a PCR reaction and amplified using the primers: 5' GGAATTCCAAGCAGAAGAATGGCGGACAGC 3' (F) and 5' CCGCTCGAGCTACTTGGTGACCCAG 3' (R). After amplification, *OsLti6a* was cloned into pBD-GAL4 Cam vector and transformed into *E. coli* DH5α. Positive clones were sequenced to confirm that transformed colonies contained the pBD-GAL4 Cam vector with *OsLti6a* insert in the correct orientation.

Yeast Transformation

Competent yeast (*Saccharomyces cerevisiae* strain YRG-2) cells were prepared and transformed according to Gietz et al. (1992). Briefly, 100 ng of pBD/OsLti6a construct, null pBD-GAL4 Cam vector or control plasmids were placed in 50 ml tubes followed by the addition of 1 ml of competent yeast cells, 100 μg denatured salmon sperm, and 600 μl of TE–LiAc–PEG solution. The tubes were vortexed and incubated at 30°C for 30 minutes with shaking at 200 rpm. Each tube received 70 µl of DMSO, was mixed gently, and heat-shocked for 15 minutes at 42°C. Transformed cells were pelleted and resuspended in 1 ml of 1X TE buffer. One hundred µl of transformed cells were spread on synthetic dropout (SD) agar plates lacking leucine, or leucine and tryptophan, or tryptophan only, depending on the plasmid used as suggested by Stratagene, and incubated at 30°C for 2 to 4 days until colonies appeared.

Yeast Protein Isolation and Western Blot

Expression of OsLti6a protein was verified by western blot analysis after isolation of yeast total proteins. Yeast clones expressing the pBD/OsLti6a and control yeast containing the null pBD-GAL4 Cam were grown separately in selective SD broth lacking tryptophan overnight at 30°C. Cells were pelleted by centrifugation, washed with 1 ml ice-cold ddH2O, and again recovered by centrifugation. One ml ice-cold ddH2O containing 100 µg/ml phenyl methyl sulfonyl fluoride (PMSF) was added followed by 150 µl ice cold 2N NaOH + 8% β-mercaptoethanol (ME) (for 1 ml, 400 µl 5N NaOH + 600 µl ddH2O + 80 µl β ME). The tubes were mixed by inverting several times, incubated on ice for 10 min, and then 150 µl ice cold 50% tricholoroacetic acid (TCA) were added. The contents were again mixed by inverting the tubes several times, and the tubes were incubated on ice for 10 min. After centrifugation for 2 minutes, cells were washed with 1 ml ice-cold acetone and repelleted for 2 minutes. The pellet was dried and resuspended in 100 µl sample buffer (500 µl 3X sample buffer pH6.8 + 500 µl ddH2O + 12.5 µl β-ME + 25 µl 1M Tris base + 100 µg PMSF + a drop of bromphenol blue). Proteins were denatured at 95°C for 5 min, then 10 µl were loaded on a gel for SDS-PAGE. Immunodetection of the OsLti proteins on a western blot was performed with the ECL Plus western blotting reagent and detection system (Amersham, Piscataway, N.J.) using a polyclonal antibody raised against OsLti6a protein as described by Morsy et al. (2005).

Yeast Two-Hybrid Screening

Ten control plasmids (separate or in pairwise combination) transformed into YRG-2 were tested for interaction by *lacZ* expression assay before proceeding with the library transformation strain. The transformation results of these control plasmids identified no interaction, so transformation of YRG2-*OsLti6* with the expression library followed. One hundred µg of plasmid DNA from the HybriZAP2.1 cDNA library and 3 mg of salmon-sperm carrier DNA were transformed into YRG2-*OsLti* by the lithium acetate method described above. The transformation mixture was plated on SD medium lacking histidine, tryptophan, and leucine. For further selection of positive interactions, the *lacZ* reporter gene activity was assayed by the filter-lift assay according to Stratagene recommendations.

RESULTS AND DISCUSSION

A class of stress-induced genes coding for small hydrophobic proteins is found in many organisms, including animals, plants, fungi, and bacteria, suggesting that these genes have a roll in stress tolerance. We isolated two closely related genes, *OsLti6a* and *OsLti6b*, and proposed that they contribute to the biochemical processes involved in preserving the structural and functional integrity of the plasma membrane during cold stress in rice seedlings (Morsy et al., 2005).

In an attempt to determine how OsLti6 proteins function, we checked the ability of OsLti protein to interact with other rice proteins. Full-length *OsLti6a,* fused to the GAL4 DNA-binding domain vector (pBD/*OsLti6a*), was introduced into the YRG-2 yeast strain and was tested for activation of the *HIS3* selectable marker and the *LacZ* reporter. The resulting YRG2-OsLti strain did not activate the transcription of the *HIS3* selectable marker or the *LacZ*, thus demonstrating the absence of transcriptional activation in the pBD/*OsLti6a*. Expression of the OsLti6a fusion protein was confirmed by western blot analysis where a band with molecular weight of ~23 kDa was observed in the YRG2-OsLti yeast strain but not in the YRG2-BD containing the null vector (Fig. 1). Therefore, we proceeded to introduce the cDNA expression library into the yeast bait strain. Controls for both positive and negative interaction gave the expected results, demonstrating that the yeast two-hybrid system was functioning properly (Fig. 2 a to f). A total of $4.12x10^6$ transformants were screened for their ability to grow on a medium lacking histidine, tryptophan, and leucine. This initial screening yielded only a few, small positive clones after 14 days of incubation (Fig. 2h). Subsequent screening for *lacZ* expression showed no activation (Fig. 2g). This experiment was repeated 4 times, with new transformation events from the expression library, with the same results. These results suggest that OsLti6a has very weak, if any, interaction with other rice proteins represented in the library used for screening.

Investigation of protein-protein interaction between OsLti6a and the rice proteins, using the yeast two-hybrid system, showed no interaction between OsLti6a and other proteins represented in the screened library. One possible explanation for the positive effect of the OsLti6a fusion protein on survival, growth rate, and membrane leakiness in rice is that OsLti6a, as a small membrane protein, may cause changes in the protein/lipid ratio and thereby alter membrane fluidity. We propose that OsLti6 may enhance cellular membrane protection against stress via several mechanisms. These mechanisms may include alteration of the lipid/protein ratio and/or lipid mobility or via production of conformational changes to the lipid bilayer leading to more flexible membranes during cold stress. Lipid mobility is related to chilling sensitivity in plant thylakoid membranes via its effect on membrane fluidity (Gang et al., 1990) and membrane protection (Kota et al., 2002). The overall lipid mobility of the membranes depends to a certain extent on lipid-protein interactions, which are determined by the lipid/protein ratio.

SIGNIFICANCE OF FINDINGS

The correlation between the *OsLti6* expression and decreased membrane leakiness in rice and increased survival with higher expression of *OsLti* without obvious interacting partners indicates that this protein is important in abiotic stress tolerance. A reasonable hypothesis is that OsLti6 increases membrane integrity during stress via alteration of the lipid/protein ratio and/or lipid mobility.

ACKNOWLEDGMENTS

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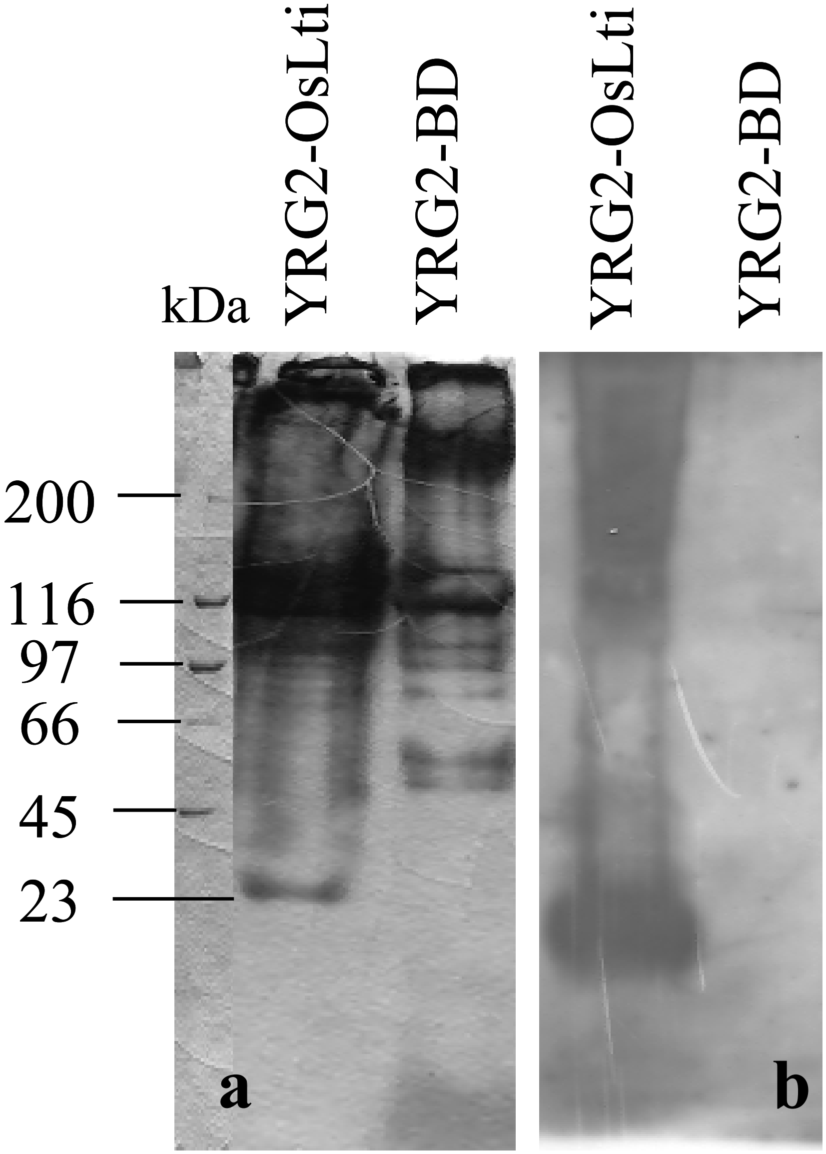

Fig. 1. Conformation of OsLti expression in yeast. (a) SDS-PAGE profile showing the accumulation of a ~6.2 kDa polypeptide in the protein extract of YRG2-*OsLti* yeast strain compared to YRG@BD yeast strain. (b) Western blot showing ~6.2 kDa polypeptide detected by the OsLti antibody in the YRG2-*OsLti* yeast strain protein extract. The high-molecular-weight proteins binding the OsLti6 antibody are unknown but may result from low-stringency binding to other proteins or to aggregates of the fusion protein.

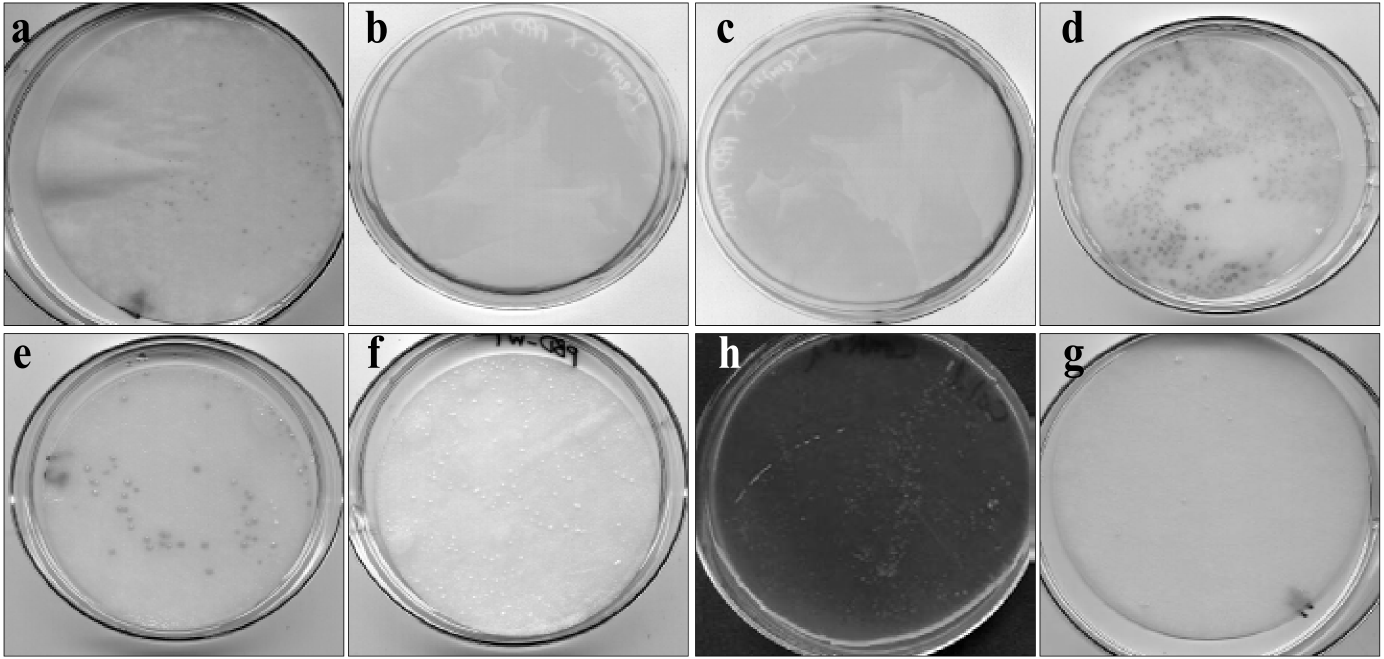

Fig. 2. Results of yeast two-hybrid screening and positive and negative control transformations. a = Positive control LacZ pGAL4, b = Negative interaction pLamin C & pAD-MUT, c = Negative interaction pLamin C & pAD-WT, d = Positive interaction pBD-WT & pAD-WT, e = Positive interaction pBD Mut, pAD Mut, f = Negative control LacZ pBD WT, h = colonies grown on selective media after transformation of the YRG2-OsLti with rice GAL4-AD expression library, and g = selection for activation of *LacZ* reporter gene in positive clones.

Development of Two Early-Flowering Indica Germplasms of Rice

J.N. Rutger and R.J. Bryant

ABSTRACT

Two early-flowering indica mutant germplasms of rice (*Oryza sativa* L.), indica-14 (PI 645478) and indica-15 (PI 645479), were induced from two International Rice Research Institute (IRRI) germplasm lines. The IRRI lines approach U.S. grain quality standards, but are too late in maturity for U.S. conditions. Indica-14 and -15 are 23 and 11 days earlier than their indica parents, and are 9 and 26 days later than a prominent japonica check cultivar. They have grain shape and amylose contents similar to U.S. long-grain japonica cultivars. Indica-14 and -15, together with four previously released early flowering indica mutants of two other IRRI rice germplasms, provide useful sources of indica diversity for U.S. rice improvement programs.

INTRODUCTION

Indica rices, grown extensively in tropical regions, often are higher yielding than the tropical japonicas grown in the U.S., but generally are too late in maturity and do not have satisfactory grain quality for U.S. markets (Eizenga et al., 2006). A base-broadening effort to develop indica germplasm suitable for U.S. rice was initiated by crossing a very early indica cultivar from China with International Rice Research Institute (IRRI) germplasm lines that approach U.S. grain quality standards (Rutger et al., 2005). Recombinant lines received early maturity but also weak straw from the China parent. Therefore, as an alternative to the crossing program, induced mutation was used to select early maturity in the high-grain-quality IRRI germplasm background.

PROCEDURES

The lines were derived by gamma radiation of IRRI germplasm lines IR65629-67-3-3-1-1-2 and IR60864-88-1-1-1-2, abbreviated henceforth as IR65629 and IR60864, respectively, provided by G.S. Khush of IRRI (personal communication, December 20, 1995). Seeds of the two IRRI germplasms were gamma-ray mutagenized in late 2000 with 250, 300, and 350 Gy. The M1 generation was grown in the 2000/01 Puerto Rico nursery. Approximately 1000 M1 panicles were taken from the 250 and 300 Gy treatments; fewer panicles were taken from the 350 Gy treatment, which had reduced M1 plant viability. The unthreshed M1 panicles were planted in 2001 at Stuttgart, in hills about 40 cm apart in 30-cm-wide rows. Single early flowering panicles were taken from M2 hills observed to be segregating for flowering time. Twenty-one M2 selections were made from IR65629 and nineteen from IR60864. These lines were successively narrowed down and advanced in subsequent winter and summer nurseries, to the M7 generation in 2004, when they were yield tested at Stuttgart, in six-row plots, 5.1 m long and 0.3 m row width with 56 kg ha^{-1} of nitrogen fertilizer applied preflood. The two center rows were harvested. The tropical japonica long-grain cultivar 'Francis' (PI 632447) was included as a check. Agronomic data and amylose contents were collected.

RESULTS AND DISCUSSION

Check cultivar Francis flowered in 94 days after planting, was 98 cm tall, yielded 8080 kg ha^{-1}, had 664 mg g^{-1} whole-kernel milling yield, and 226 g kg^{-1} amylose in the milled rice. Brown rice length was 7.2 mm and 1000 kernel weight was 21.2 grams.

Indica-14, derived from 300 GY treatment of IR65629, flowered in 103 days, was 106 cm tall, yielded 7930 kg ha^{-1}, had 596 mg g^{-1} whole-kernel milling yield, and 232 g kg^{-1} amylose in the milled rice. Brown rice length was 7.6 mm and 1000 kernel weight was 23.3 grams. The IRRI parent was not grown in 2004, but indica-14 was 23 days earlier than its parent when both were grown in 2003, indicating successful induction of earlier maturity.

Indica-15, derived from 250 GY treatment of IR60684, flowered in 120 days, was 116 cm tall, yielded 8220 kg ha^{-1}, had 608 mg g^{-1} whole-kernel milling yield, and 224 g kg^{-1} amylose. Brown rice length was 7.9 mm and 1000 kernel weight was 24.3 grams. The IRRI parent was not grown in 2004, but indica-15 was 11 days earlier than its parent when both were grown in 2003, again indicating successful induction of earlier maturity.

Thus the two early-flowering mutants were 9 and 26 days later than the Francis check, 8 and 18 cm taller, and were competitive in yield and amylose content, but had lower whole-grain milling yield. Brown-rice grain length was longer and kernel weight was heavier than in the check cultivar. Indica-14 and -15 were not as early-flowering as the induced mutants, indica-10, -11, -12, and -13, which were only 7 to 9 days later than Francis (Rutger et al., 2007), but the current ones come from different IRRI parents so they represent additional indica diversity.

SIGNIFICANCE OF FINDINGS

Indica germplasm with suitable maturity and grain quality for U.S. markets should be useful to scientists wishing to utilize such materials in breeding and other research. Therefore, germplasm amounts of seed (≤5 grams) of the above lines may be obtained by writing to: R.J. Bryant, Dale Bumpers National Rice Research Center, USDA-ARS, 2890 Hwy. 130 East, Stuttgart, Ark. 72160. Requests from outside the U.S. must be accompanied by an import permit. Seed also will be placed in the National Small Grains Collection, USDA-ARS, 1691 South 2700 West, Aberdeen, Idaho 83210, where it is available for research purposes, including development and commercialization of new cultivars. If this germplasm contributes to the development of new cultivars, it is requested that appropriate recognition by given to the source.

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Three Early Flowering Germplasms of a Blast Disease-Resistant Indica Rice for U.S. Rice Improvement Programs

J.N. Rutger, F.N. Lee, and R.J. Bryant

ABSTRACT

USDA-ARS and the Arkansas Agricultural Experiment Station developed three indica germplasms of rice (*Oryza sativa* L.) Indica-16 to Indica-18 (PI 645480 to PI 645482, respectively). These three germplasms are induced early-flowering mutants of *Oryzica llanos* 5 (PI 584668, henceforth abbreviated as OL5) a highly blast disease [*Pyricularia grisea* (Cooke) Sacc.]-resistant cultivar from Colombia, which in itself is a month too late in maturity for the U.S. These germplasms are 24 to 36 days earlier than the parent, making them 6 to 18 days later than the southern long-grain cultivar 'Francis' (Moldenhauer et al., 2002). They retain the blast resistance of the OL5 parent. Their early maturity and blast resistance make them useful sources of indica diversity for U.S. rice improvement programs.

INTRODUCTION

Indica rices, which are grown extensively in tropical regions, typically are higher yielding than the tropical japonicas grown in the U.S. but generally mature too late when grown in the U.S. (Eizenga et al., 2006). Therefore base-broadening efforts to develop indica germplasm suitable for U.S. rice were initiated to induce early flowering mutants in indica germplasm. The present report describes three early-flowering mutants derived from the indica cultivar OL5 which is resistant to all U.S. races of the blast fungus *P. grisea*.

PROCEDURES

The lines were derived by gamma radiation of OL5 in late 1999 at rates of 270, 300, and 320 Grays (Gy). The M1 generation was grown in the 1999/00 Puerto Rico winter nursery. No panicles were taken from the 270 Gy dosage, which showed little effect from radiation. About 600 M1 panicles were taken from each of the 300 and 320 Gy dosages for one M1 panicle-to-one M2 row plantings at Stuttgart, Ark., in 2000. Early-flowering selections, each from a different M2 row to assure independent origin, were made from 12 rows of 300 Gy and 11 rows of 320 Gy. The early-flowering selections were expeditiously advanced in summer and winter nurseries. By the M9 generation at Stuttgart in 2004, the number of selections from the 300 Gy treatment had been reduced to 9, and the number from the 320 Gy treatment to 10, for a total of 19. In the 2004 M9 and 2005 M10 generations, two replicate yield tests were conducted, in six-row plots, 5.1 m long and 0.3 m row width with 56 kg ha^{-1} of nitrogen fertilizer applied preflood. The two center rows were harvested. The OL5 parent and the cultivar Francis were included as checks. Days-to-flower, height, yield, whole-kernel milling yield, kernel length, and amylose content were determined on the 2004 and 2005 crops. The 2004 crop was also assayed for 10 SSR markers: RM149, RM190, RM481, RM22, RM225, RM484, RM303, RM489, RM231, and SSS. Individual leaf-blast race reactions were determined in inoculated greenhouse tests in 2004, 2005, and 2006. Field data were collected from an inoculated blast nursery during 2005 at the Pine Tree Experiment Station (PTES), Colt, Ark. Sheath-blight data were collected from inoculated field nurseries conducted during 2005 at the Rice Research and Extension Center, Stuttgart, Ark. (UA-RREC).

RESULTS AND DISCUSSION

Although all 19 lines were earlier than the OL5 parent and retained the blast-disease resistance expressed by the OL5 parent, following the 2005 crop only 3 lines, Indica-16 and Indica-17 from the 320 Gy treatment and Indica-18 from the 300 Gy treatment, were selected for germplasm release. This decision was based on agronomic considerations and SSR marker discrepancies. Eight of the germplasms proved susceptible to the physiological disease straighthead in 2005, 4 had low grain-yield, and 4 had low whole-grain milling yield. These 16 germplasms also differed from the OL5 parent by two to five SSR markers. The remaining three germplasms had good agronomic properties, excellent blast resistance, and differed from the parent by only a single SSR marker, which was considered an acceptable level of SSR variation.

The three germplasms were 24 to 36 days earlier than the OL5 parent, 6 to 18 days later than the Francis check cultivar, and 13 to 25 cm taller than OL5 and Francis (Table 1). None differed significantly from Francis for yield; the OL5 parent matured too late to get meaningful yields, although it was possible to get mature seed in 2003 and 2004 for milling tests.

None of the germplasms had significantly lower whole-kernel milling yields than OL5 and Francis. Brown-rice grain lengths of the germplasms and the OL5 parent were longer than Francis. Apparent amylose contents of Indica-16 and Indica-17 were similar to Francis while Indica-18 had higher amylose content like the OL5 parent (Table 1). As noted above, the physiological disease straighthead occurred in 8 of the indica germplasms, in the 2005 field nursery. Trace amounts, on a 1 to 9 scale where 1= resistant and 9 = very susceptible, occurred in the present 3 germplasms and in the parent OL5 and the check cultivar Francis (Table 2). The 3 germplasms were placed in a two-replicate straighthead test in 2006 in the straighthead testing area, which had received 6.6 kg ha^{-1} of monosodium methanearsonate (MSMA). Straighthead scores in 2006 were 6.0, 2.0, and 6.5 for Indica-16, Indica-17, and Indica-18, respectively (Table 2). Neither OL5 nor Francis were included in the 2006 test, but the respective straighthead scores were 1.0 for the check cultivars 'Zhe733' (PI 692016) and 6.5 for the check cultivar 'Mars' (CI 9945), two cultivars that are known to be resistant and moderately susceptible, respectively, to straighthead. In susceptible cultivars, some of which are widely grown in Arkansas, straighthead is controlled by draining and drying the fields 10 to 14 days before internode elongation (Yan et al., 2005).

In the 2004 greenhouse blast tests, the germplasm lines tested as highly resistant to contemporary field races IB-1, IB-49, IC-17, IE-1, and IE-1k and the virulent laboratory race IB-33 (Table 2). The check cultivar Francis tested susceptible to all races. Check cultivars, 'Kaybonnet' (Gravois et al., 1995), 'Ahrent' (Moldenhauer et al., 2001), and 'Cybonnet' (Gibbons et al., 2006), were resistant to races IB-1, IB-49, IC-17, IE-1, and susceptible to races IE-1k and IB-33.

In the drought-stressed 2005 PTES blast field nursery inoculated with contemporary blast races IB-1, IB-49, IC-17, IE-1, IG-1, and IH-1, OL5 and the 19 mutants were highly resistant to rice blast. Check cultivars Ahrent and Kaybonnet were resistant to leaf blast and panicle blast. Francis was susceptible to leaf and panicle blast. All materials were susceptible to sheath-blight disease at the UA-RREC location.

In additional 2006 moisture-stressed greenhouse tests, Indica-16 and Indica-18 were resistant to historical races IB-17, IB-45, IB-54, and ID-13. While resistant to races IB-17, IB-54, and ID-13, Indica-17 tested moderately resistant to resistant to race IB-45. The parent OL5 was not included in the 2006 greenhouse tests.

SIGNIFICANCE OF FINDINGS

Indica germplasm with suitable maturity for U.S. production should be useful to scientists wishing to utilize such materials in breeding and other research. Therefore, germplasm amounts of seed (ca 5 grams) of the above lines may be obtained by writing to: R.J. Bryant, Dale Bumpers National Rice Research Center, 2890 Hwy 130 East, Stuttgart, Ark. 72160. Requests from outside the U.S. must be accompanied by an import permit. Seed also will be placed in the National Small Grains Collection, USDA-ARS, 1691 South 2700 West, Aberdeen, Idaho 83210, where it is available for research purposes, including development and commercialization of new cultivars. If this germplasm contributes to the development of new cultivars it is requested that appropriate recognition be given to the source.

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Table 1. Agronomic characteristics of three OL5 early-flowering germplasms, OL5 parent, and check cultivar Francis grown in Arkansas.

Germplasm	Days to flower from planting [z]	Height[z]	Yield[z]	Whole kernel milling yield[z]	Kernel length[z]	Apparent amylose[z]	Differing SSR marker[y]
		(cm)	(kg ha^{-1})	(mg g^{-1})	(mm)	(g kg^{-1})	
Indica-16	98	110	7929	594	7.9	214	RM190
Indica-17	100	122	8137	580	8.2	220	RM481
Indica-18	110	116	7636	610	7.6	250	RM22
OL5	134	97	-	635	7.6	242	-
Francis	92	97	8048	612	7.0	219	-
LSD$_{05}$	3	8	1070	56	0.3	22	-

[z] Average of 2004 and 2005 yield trials, except for milling yield, kernel length, and amylose of OL5 for which data were from 2003 and 2004.
[y] 2004 yield trial.

Table 2. Disease ratings of three OL5 early-flowering germplasms, OL5 parent, and Arkansas cultivars Francis, Ahrent, Cybonnet, and Kaybonnet.

	Straighthead scores[z]		2004 Summary	2005 PTES		2005 RREC	
			Greenhouse leaf	Leaf blast	Panicle blast	Sheath blight rating	
Germplasm	2005	2006	blast rating[y]	rating[y]	rating[y]	Planting one	Planting two
Iindica-16	1.5	6.0	R	R	R	S	S
Iindica-17	1.0	2.0	R	R	R	S	S
Iindica-18	1.0	6.5	R	R	R	S	S
OL5	1.0	-	R	R	R	S	S
Francis	1.0	-	S	S	S	S	S
Ahrent	-	-	S-R	R	S	S	S
Cybonnet	-	-	S-R	-	-	-	-
Kaybonnet	-	-	S-R	R	MR	S	S

[z] Straighthead scores: 1 = resistant and 9 = very susceptible.
[y] Disease ratings: R = resistant, MR = moderately resistant, S-R = mixed ratings of susceptible to resistant, and S = susceptible.

Infection of Plants of Selected Rice Cultivars by the False Smut Fungus, *Ustilaginoidea virens,* in Arkansas

M. Ditmore, J.W. Moore, and D.O. TeBeest

ABSTRACT

False smut, caused by *Ustilaginoidea virens*, has recently been found in Arkansas. Plants infected by the fungus remain symptom-free until heading and it is difficult to see spores on contaminated seeds. Field tests were conducted in 2006 to determine the effect of false-smut inoculation of rice seeds on the yields of selected rice cultivars. Seeds were inoculated by vacuum infiltration in suspensions containing one million spores per ml. Spores were obtained from mature spore balls found on panicles collected in Arkansas in 2005. Infiltrated and control seeds were planted into large pots placed in pools at the Agricultural Experiment Station at Fayetteville in a randomized complete block design with four replications for each cultivar and treatment. The data were collected at maturity and included the number of panicles set per plant per treatment and the amount of blanking found on the panicles. Tissue samples were collected for PCR analysis to determine if plants were infected. The results of these experiments show that inoculation of seeds by infiltration reduced the number of panicles produced compared to control plants. While this work must be repeated, the current data suggest that the recognizable symptoms of infection in rice plants by *U. virens* are cryptic and should perhaps be expanded to include the deleterious effect on panicle production as a symptom of infection. These preliminary data suggest that current estimates of yield reductions based on the number of spore balls formed might be inaccurate. We propose that infection, with or without spore-ball formation, is deleterious to panicle formation and directly causes increased seed blanking. Early detection of the fungus in asymptomatic plants is warranted for timely application of fungicide to minimize yield reduction through chaffing and reduced panicle formation.

INTRODUCTION

False smut of rice is caused by the fungus *Ustilaginoidea virens*. This clavicipitaceous pathogen has been in the United States for many years, but was first reported in Arkansas in 1997 (Cartwright and Lee,2006). It has been previously reported that this disease does not typically affect yield, but quality issues remain important due to production of ustiloxin, a microtubule inhibitor toxic to animals (Luduena et al., 1994; Koiso et al., 1994). More recently, the literature suggests that yields can be significantly reduced (Zhou et al., 2003).

Knowledge concerning the disease cycle and epidemiology of *U. virens* is minimal, incomplete (Lee and Gunnell, 1992), and often irreproducible. The fungus is reported to survive in soil or contaminated rice grain as spore balls produced on mature panicles (Fig. 1). Spore balls are believed to germinate late in the growing season and infect rice flowers (Cartwright and Lee, 2006). Some investigators have successfully inoculated plants by injecting boots prior to flowering or by spraying flowering panicles (Ikegami, 1963). We have reported previously that histological examinations showed that spores placed on roots germinated asynchronously over time and that all of the inoculated roots of rice plants were infected when inoculated in this manner (Schroud and TeBeest, 2005).

It has been reported that the number of spore balls found on mature panicles or the degree of blanking (= chaffing) may be related to the level of resistance in the cultivar (Cartwright et al., 2003). Smut tests conducted in Arkansas demonstrate that nearly all cultivars grown commercially in Arkansas are considered to be susceptible. The current recommendations for the control of this disease are that producers apply fungicides to plants at the heading stage in fields with a history of this disease.

The objective of this work was to determine if rice plants grown from seeds vacuum-infiltrated with spores of *U. virens* would express signs or symptoms of infection, such as chaffing and decreased panicle production, earlier in the growing season before spore balls were formed on panicles.

PROCEDURES

Five different cultivars or breeding lines, ‘Cheniere’, ‘Drew’, ‘Koshihikari’, ‘Nipponbare’, and ‘Zhe 733’, were used in field tests in 2006. Seeds were obtained from the collection at the Rice Research and Extension Center in Stuttgart, Ark. Seeds of these cultivars were stored at -20°C.

Since viable and proven cultures of *U. virens* known to be virulent to rice were not available, spores of the fungus were collected from pseudomorphs found on panicles of field-grown ‘Clearfield XL8’ harvested in 2005. Panicles and seeds containing the pseudomorphs had been stored in the laboratory at 24°C until used. Spores were suspended in water and used without additional surfactants added to the spore suspensions.

Inoculation was accomplished by infiltration of seeds for 30 min with a protocol adapted from Zhou et al. for 30 min. Spores were diluted to a concentration of 1 million spores per ml. Fifty seeds to be infiltrated were placed in 10 ml of inoculum. Controls were infiltrated with water. After infiltration, seeds were air-dried overnight at 24°C.

Seeds were germinated in Petri dishes on moistened filter paper for 72 hr before direct transplantation to the plastic pots in the field. The pots were filled with field soil and flooded before planting. Seedlings were transplanted as germinated seedlings into pots, six seedlings per pot, and one pot of each five cultivars per pool. The experiment contained four replications, with each replication a pool. Controls were transplanted in the same way but were placed in separate pools to reduce the possibility of inter-pot dispersal of spores.

All pools were fertilized with urea added to the floodwater in the pools two and four weeks after transplanting. Additional fertilization was added as needed. Pots placed in the plastic pools were maintained at a depth approximately half-full to full by frequent inspection and filling as necessary.

Panicles were harvested as they matured for each of the different cultivars used. The total number of panicles found on each of the six plants in each replication and the number of blanked heads were recorded for each of the plants in all treatments.

Three plants of each cultivar grown from infiltrated seeds were tested for the presence of DNA consistent with *U. virens*. DNA extraction was performed using the DNeasy extraction kit (Qiagen) after grinding in liquid nitrogen. PCR primers specific for *U. virens* were selected by the comparison of sequence alignments from the ITS region of isolates collected from diverse geographical origins and rice varieties (Zhou et al., 2003). Nested PCR was performed using puReTaq Ready-To-Go PCR Beads (Amersham) in a PTC-200 Gradient Thermal cycler (MJ Research). First-round amplifications contained 10 ng DNA template and 1 μmole of both primers. Second-round amplifications utilized 1 μl of the first-round amplicon and 1 μmole of both primers. Thermal cycling conditions were 96°C for 2 min followed by 30 cycles of 96°C for 20 sec, 58°C for 30 sec, 72°C for 30 sec, and a final extension cycle of 72°C for 7 min. Products were visualized by horizontal agarose-gel electrophoresis.

Data were statistically analyzed using Student t tests and analysis of variance. Treatments were compared by testing differences in the number of panicles formed and the number of filled panicles formed on all of the plants for each cultivar in each of the replications since all replications contained the same number of plants for all hybrids.

RESULTS AND DISCUSSION

Since little is known about the disease cycle, we conducted experiments to better understand this disease by examining plants, that showed no symptoms of infection, using molecular techniques. It has been reported that *Ustilago hordei* can infect barley plants from seeds without causing visible symptoms or signs of infection being expressed until heading on susceptible and resistant cultivars (Willets and Sherwood, 1999). We vacuum-infiltrated rice seeds, though it is has not been established whether seed-borne inoculum is a primary source of infection for *U. virens*.

Visible symptoms or signs of infection were not found on any of the plants grown from infested seeds at any time during the course of this experiment conducted in the field in 2006. Until recently, methods used for the detection and identification of pre-symptomatic infections by plant pathogens have generally included isolation of the pathogen on nutrient media and morphological examination of isolates. These procedures are time-consuming and not easily applicable to *U. virens* because the fungus is very difficult to isolate on agar media. Repeated PCR tests conducted in our laboratory, as adapted from Zhou et al. (2003), showed that DNA consistent with *U. virens* was found in all of the inoculated plants, but was not found in any of the control plants.

The data collected at harvest from four replications of six plants per replication per treatment indicated that the total number of panicles produced on plants grown from infested seeds was significantly reduced from the number of panicles found on control plants for all five cultivars tested (Table 1). The total number of panicles found on plants grown from infested seeds was 24.1%, 60.0%, 61.5%, 72.9%, and 73.8% of the control plants for Koshihikari, Drew, Nipponbare, Zhe 733, and Cheniere, respectively.

Similarly, the total number of panicles with filled grains was significantly different from controls for plants grown from inoculated seeds. For example, 99.3% of the panicles on control plants of Cheniere were filled, whereas only 91.3% of the panicles on plants from inoculated seeds were filled. For Drew, 99.5 % of the control panicles were completely filled while on plants grown from infested seeds, only 95% of the panicles were filled. Koshihikari had 97.7% of the panicles on control plants completely filled, while on inoculated plants only 90.5% of the panicles were completely filled. With Zhe 733, 36.9% of the panicles on the control plants were filled, but only 16.3% of the panicles on inoculated plants were filled. Nipponbare was the only cultivar whose number of filled panicles found on control plants did not significantly differ from those of treated plants. In this case, 99.5% to 99.6% of the panicles were completely filled.

Taken together, our experiments show that infection of rice plants can occur through planting of infested seeds and those plants grown from infested seed encounter a reduction of panicles produced and a reduction in filled panicles. These data are also consistent with those collected from preliminary greenhouse tests conducted in which 24 cultivars were grown from seeds infested by spores of *U. virens* (data not shown).

Our field data from 2006 and our greenhouse data from 2005 imply that the false-smut fungus is both seed-borne and seed-transmitted. However, diagnosis of the disease in the early stages, when control measures would be most efficacious, would be highly advantageous due to the absence of symptoms or pathogenic structures indicative of the disease until late-season and harvest time. The nested-PCR protocol described here can rapidly and reliably identify *U. virens* isolates in and on rice seeds, in seedlings, and in mature plants. The early identification of the pathogen may help improve the timing and efficacy of control measures as well as the selection of non-infected seed stores and identification of resistant cultivars.

SIGNIFICANCE OF FINDINGS

False smut is an emerging and increasingly significant pathogen of rice crops in Arkansas, sometimes affecting yield but was primarily considered as reducing quality. A toxin is also produced on infected plants that may further increase the presence of this disease in Arkansas. Furthermore, the data indicate that false smut causes significant yield reductions by reducing the number of panicles produced on plants and by increasing the number of panicles that are blank on plants grown from infested seeds.

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Table 1. Results of a field test conducted at Fayetteville, Ark., in 2006. The data are averages of four replications of six replications per cultivar. Plants were inoculated by infiltration of seeds with spores of *U. virens* under vacuum.

	Total no. of panicles[z]			Total no. filled		% Panicles filled	
Cultivar	Control	Inoculated	%	Control	Inoculated	Control	Inoculated
Cheniere	74.5 cd	55.0 e	73.8	74.0 c	51.5 d	99.3	91.3
Drew	93.8 b	56.3 e	60.0	93.3 ab	53.5 d	99.5	95.0
Koshihikari	109.5 a	26.3 f	24.1	107.0 a	23.8 ef	97.7	90.5
Nipponbare	91.0 b	56.0 e	61.5	90.5 b	55.8 d	99.5	99.6
ZHE 733	86.8 bc	63.3 de	72.9	32.0 e	10.3 f	36.9	16.3

[z] Means within and across treatments for each set of panicle data followed by the same letter are not significantly different ($P = <0.0001$). Data were collected from 24 plants per treatment (6 plants/rep with 4 reps). Total percentages are calculated by the equation: Inoculated/controls X 100 while the percentage of panicles filled was calculated from the equation: Total number of panicles for each treatment/total number filled X 100.

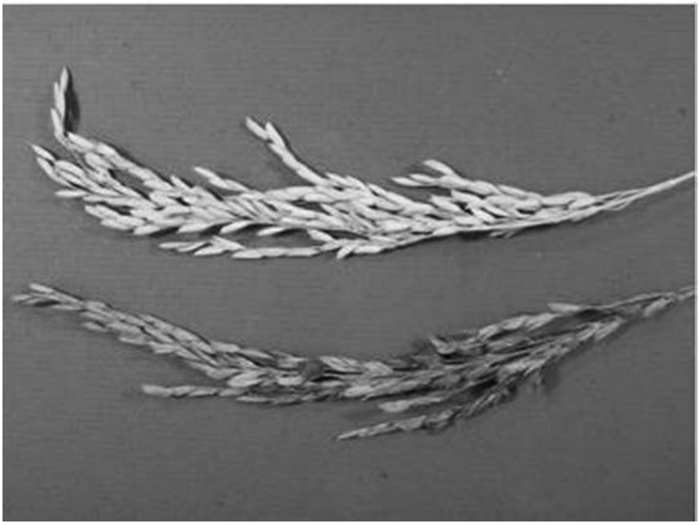

Fig. 1. The image shows a healthy rice panicle above an infected panicle, the latter displaying spore-covered seeds and pseudomorphs, the typical signs of infection by *U. virens.* The pseudomorphs were produced after exertion of the panicle from the boot.

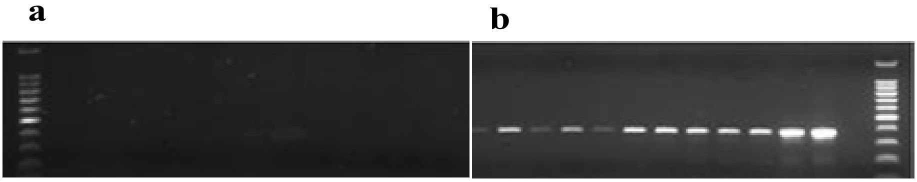

Fig. 2. Plants grown from infiltrated seed are infected by *U. virens.* PCR data showing control plants with no amplification indicating the absence of *U. virens* **DNA (a) and** *U. virens* **detection in plants grown from infiltrated seed (b).**

PEST MANAGEMENT: DISEASES

Blast Vulnerability Detected in Novel Blast-Resistant Germplasm

F.N. Lee and G.C. Eizenga

ABSTRACT

Previous research in artificially inoculated greenhouse tests and field nurseries identified new rice germplasm accessions as being resistant to the common blast (*Pyricularia grisea*) races found in Arkansas (IB-1, IB-49, IC-17, IE-1, IE-1k, IG-1, and IH-1) and eliminated those accessions with major blast-resistance genes (*Pi-b*, *Pi-ta).* currently utilized in U.S. varieties, thus identifying accessions with novel blast-resistant genes that could be incorporated into resistant varieties for Arkansas producers. Subsequent testing revealed an unanticipated blast vulnerability to archived *P. grisea* races IB-45, IB-54, and ID-13, which predominated during the 1950s and 1960s, in several of the resistant accessions. When inoculated with race ID-13, very-susceptible-type 7 to 8 leaf lesions developed in all tests of very closely related accessions 4607, 4611, 4612, 4632, 4642, 4593, 4594, 4633, and 4641(1); and R 312. Also, Guang 6ai-4, Wab450-24-3-2-P18-hb, and Wab450-I-B-P-62-hb developed susceptible-type 5 to 6 lesions in one or more tests inoculated with race ID-13. Susceptible-type 4 to 7 leaf lesions developed on all the aforementioned accessions in two of the four tests inoculated with race IB-54. A limited vulnerability to race IB-45 was also noted for all accessions and to race IB-17 for Wab450-24-3-2-P18-hb, Wab450-I-B-P-62-hb, and R 312. Most importantly, with the exception of a single IB-54 test, two accessions, 'Kechengnuo No. 4' and 'Shufeng 117', tested resistant to all the archived blast races to date.

INTRODUCTION

The University of Arkansas rice pathology research, funded in part by the Rice Research and Promotion Board (RRPB), has the overall objective of developing rice disease-control strategies. This research effort requires a dedicated search for new disease-resistant germplasm obtained from various sources world wide. Once quarantined to eliminate unknown diseases, the new accessions are thoroughly tested in inoculated greenhouse and field disease nurseries. These tests are routinely conducted at the University of Arkansas Rice Research and Extension Center (UA-RREC) Stuttgart, Ark., and at the University of Arkansas Pine Tree Experiment Station (UA-PTES) located near Colt, Ark. Through joint collaborations with the USDA-ARS Dale Bumpers National Rice Research Center (DB NRRC) scientists conducting molecular analysis for DNA markers, it is now possible to identify many known disease-resistance genes and enhance identification of new resistance sources.

The overall emphasis of the project is detection and identification of major resistance for common fungal diseases of rice occurring in the U.S., particularly rice sheath blight caused by *Rhizoctonia solani* and rice blast caused by *Pyricularia grisea*. This project recently reported the discovery of novel blast-resistant (*R*-) genes in germplasm accessions that are currently not utilized in contemporary U.S. varieties (Eizenga et al., 2004; Eizenga et al., 2006; Lee et al., 2003). These newly identified blast-resistance genes are currently being incorporated into new varieties by the UA breeding programs funded by the RRPB. This report presents data on an unexpected blast susceptibility in this very desirable germplasm to previously untested *P. grisea* races that were prevalent during the 1950s and 1960s

PROCEDURES

The germplasm accessions that tested resistant to contemporary blast races (IB-1, IB-49, IC-17, IE-1, IE-1k, IG-1, and IH-1) and lacked the major blast-resistance genes (*Pi-b*, *Pi-ta*) in previous tests were selected and evaluated in four different three-replication tests in the greenhouse facilities located at the UA-RREC. Check varieties were 'Drew', 'Wells', and 'Zhe 733'. Standardized greenhouse procedures were used to test entry reaction to archived *P. grisea* races IB-17, IB-45, IB-54, or ID-13 that predominated during the 1950s and 1960s (Marchetti, 1994). Contemporary check race IE-1k was also included. Moderately drought-stressed plants at the 4-leaf (V4) growth stage were inoculated with an atomized spore suspension (2 x10^5 spores/ml) of individual races. Test plants were immediately placed in a 100% humidity chamber for 12 to 24 hours, moved to greenhouse benches, and grown under upland conditions for approximately 7 days when leaf-lesion severity was estimated using the standard visual 0 to 9 rating scale (Lee et al., 2003). Leaf-lesion categories were: 0 = no lesions; 2 to 3 = small, closed center lesions with brown borders indicate plant-restriction lesion development; 4 = slightly larger, usually elongated susceptible lesions with ash-grey centers and reddish brown borders; 5 to 6 = elongated blast-susceptible lesions with well-developed ash-grey centers and reddish-brown borders; 7 to 8 = larger susceptible type lesions with little if any evidence of border discoloration or other plant resistance response; and 9 = very large susceptible-type lesions with no evidence of plant response to infection that typically result in rapid leaf death.

RESULTS AND DISCUSSION

An unanticipated blast susceptibility was identified in novel germplasm accessions inoculated with archived isolates (Table 1). The nine very closely related germplasm accessions 4607, 4611, 4612, 4632, 4642, 4593, 4594, 4633, and 4641(1); and the more distantly related R 312 developed very-susceptible 7 to 8-type lesions in all tests when inoculated with race ID-13. In addition, accessions Guang 6ai-4, Wab450-24-3-2-P18-hb, and Wab450-I-B-P-62-hb developed susceptible type 5 to 6 lesions from race ID-13 in one or more tests. Susceptible-type 4 to 7 lesions developed on all the aforementioned accessions in two of the four tests inoculated with race IB-54. Accessions Guang 6ai-4 and Wab450-24-3-2-P18-hb developed type 4 to 5 lesions in three of four tests inoculated with race IB-45. Although remaining accessions were more tolerant, a vulnerability to race IB-45 was noted for novel germplasm accessions 4607, 4632, 4594, 4633, 4641(1), and R 312, which exhibited type 4 to 6 ratings in individual tests. Most accessions were resistant to race IB-17 although some vulnerability was noted with Wab450-24-3-2-P18-hb, Wab450-I-B-P-62-hb, and R 312 in individual tests.

Check-entry Zhe 733 and germplasm accessions Kechengnuo No. 4 and Shufeng 117 were resistant, with the exception of a single IB-54 test, to the archived blast races tested.

The standard 0 to 9 visual evaluation of leaf lesions provides a crude assay of plant resistance to specific blast races under controlled conditions. Errors in individual tests originate with plant growth conditions, environmental conditions in the greenhouse and inoculation chambers, viability and quality of inoculum, and evaluator skill. However, data from multiple tests generally estimate varietal resistance under typical production-field conditions. Type 0 to 3 lesions usually indicate a resistant variety. Type 5 to 6 lesions are typical for varieties with good to excellent field resistance when grown under high soil moisture or flooded field conditions but subject to severe leaf and rotten neck blast if moisture stressed. Varieties with type 7 and higher lesions characteristically require intense management practices or are unacceptable for general production fields. A consistent lesion type over multiple replicated tests generally estimates varietal performance. Inconsistent susceptible rating in individual tests, such as those recorded for races IB-54 and IB-45, provide an indication of varietal vulnerability as field conditions vary from optimal to stress conditions.

If these classifications are correct, data presented in Table 1 indicate the accessions 4607, 4611, 4612, 4632, 4642, 4593, 4594, 4633 4641(1) and R 312 with type 7 to 8 lesions will be especially susceptible to race ID-13 in grower fields, comparable to known blast-susceptible varieties ‘M-201’ and ‘Frances’. Also, accessions Guang 6ai-4, Wab450-24-3-2-P18-hb, and Wab450-I-B-P-62-hb will require growers to carefully manage cultural practices in the presence of race ID-13. Cultural practices will also determine susceptibility of all test entries to races IB-45 and IB-54.

The uniformly high susceptibility to blast race ID-13 (Table 1) confirms previous molecular research (Eizenga et al., 2006) showing a close genetic relationship (Table 1) between accessions 4607, 4611, 4612, 4632, 4642, 4593, 4594, 4633, and 4641(1), which are placed in DNA cluster group 3 and have the same genetic background (K3).

In addition, this suggests these accessions share a common resistance gene. Accession R 312 also is highly susceptible to race ID-13, although placed in DNA cluster group 8, and also shares some of the same genetic background (K3). With respect to the race ID-13-susceptible accessions, it should be noted resistant accessions Shufeng 117 (DNA cluster group 8 with K3 and K7 genetic backgrounds) and Kechengnuo No. 4 (DNA cluster group 7 with genetic backgrounds in K3, K5 and K7) share the common genetic background K7, which may contain different *R*-genes.

The new germplasm identifies one or more unique blast-resistance genes not utilized in current U.S. varieties. Unfortunately, the results presented here show some accessions are also vulnerable to older blast races predominating in varieties grown during the 1950s and 1960s. Due to *P. grisea*'s inherent ability to adapt to the resistance genes present in the predominant rice varieties, re-appearance of the archived races or equally virulent races is anticipated if these new *R*-genes become widely utilized in Arkansas fields. In spite of this possibility, these new *R*-genes are extremely valuable. Although molecular markers to identify these new *R*-genes are not currently available, breeders can proactively pyramid resistance genes using greenhouse assays along with markers specific for *R*-genes such as *Pi-ta*, *Pi-b*, $Pi\text{-}k^h$, and $Pi\text{-}k^s$, which confer resistance to archived races IB-45, IB-54, and ID-13 (Eizenga et al., 2006).

SIGNIFICANCE OF FINDINGS

Rice growers depend upon proper conservation, discovery, and manipulation of resistance genes as a basic component of rice disease-control strategies. Defining disease liabilities of new blast-resistant *R*-genes provides plant breeders with information required to successfully incorporate that resistance source into modern rice varieties having higher yielding and quality characteristics. This research also alerts us to a potential problem of unexpected losses to rice blast such as those experienced with the variety 'Newbonnet' during the 1980s or more recently with 'Banks' during 2004 to 2006.

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**Table 1. Leaf lesion type observed when
archived U.S. blast races in two (IE-1k) or four
Germplasm accessions were grouped into clusters and**

	Tests of inter-									
Accession name	IB-17				IB-45				IB-	
	1	2	3	4	1	2	3	4	1	2
Shufeng 117	0	0	0	0	0	0	0	0	4	0
Kechengnuo no. 4	0	1	0	0	1	0	0	0	7	0
Guang 6ai-4	0	0	0	0	5	1	4	4	6	2
Wab450-24-3-2-P18-hb	1	0	0	4	5	2	5	3	7	4
Wab450-I-B-P-62-hb	6	0	4	1	0	0	0	0	4	0
4607	0	0	0	0	6	1	2	3	6	0
4611	0	0	0	0	0	0	3	0	6	0
4612	0	0	0	0	0	2	1	0	0	1
4632	0	0	0	0	1	2	1	4	7	0
4642	0	0	0	0	0	1	1	1	1	0
4593	0	0	0	0	0	0	1	3	0	0
4594	0	0	0	0	5	1	1	4	7	0
4633	0	0	0	0	1	0	0	4	6	0
4641(1)	0	0	0	0	5	0	3	1	6	1
R 312	0	0	5	5	5	0	1	2	6	1
DREW	8	4	6	0	0	0	0	0	7	0
WELLS	8	5	7	8	0	0	1	0	6	0
Zhe 733	0	0	0	0	0	0	0	0	0	0

^{z} Data taken from Eizenga et al (2006).

blast-resistant germplasm was inoculated with
(IB-17, IB-45, IB-54, or ID-13) different replicated tests.
the genetic background according to DNA (SSR) markers.

national blast races								DNA cluster group[z]	Genetic back-ground(s)[z]
-54		ID-13				IE-1k			
3	4	1	2	3	4	1	2		
0	1	0	0	0	0	0	0	8	K3, K7
0	0	0	0	0	0	0	0	7	K3, K5, K7
1	7	1	6	6	0	0	0	8	K5, K7
2	6	6	5	6	3	1	2	2	K6
0	1	5	1	4	1	1	0	2	K6
0	5	8	8	7	8	0	0	3	K3
0	5	8	7	7	8	0	0	3	K3
0	6	8	8	7	8	0	0	3	K3
0	5	8	8	7	7	0	0	3	K3
0	5	8	8	8	8	0	0	3	K3
1	5	8	8	8	8	0	0	3	K3
0	6	8	8	7	8	0	0	3	K3
0	4	8	8	7	8	0	0	3	K3
0	5	8	8	8	8	0	0	3	K3
1	5	7	8	8	8	1	1	8	K3, K7
0	0	0	0	0	0	8	8	1	K1
0	1	0	2	0	0	8	8	1	K1
0	0	0	0	0	0	0	0	.	.

PEST MANAGEMENT: DISEASES

Role of Soil Type in Predisposing Banks and Other *Pi-ta* Varieties to Rice Blast

F.N. Lee, Z. Gubrij, and R. Baker

ABSTRACT

The high-yield varieties ‘Banks’ and ‘Cybonnet’, released to seed growers during 2004, contain the *Pi-ta* R gene used in blast-resistant varieties for over 16 years. While Cybonnet fields were blast free, severe blast disease developed in drought-stressed Banks growing in a sandy production field in Clay County during 2004 and then again in sandy fields throughout Arkansas during 2005 and 2006. Race ‘IE-1k’, a rare but well researched minor race of the blast fungus *Magnaporthe grisea,* was isolated from diseased Banks plants. Soil samples were collected from Clay County production fields and University of Arkansas research stations near Colt and Stuttgart, Ark. *Pi-ta* and non-*Pi-ta* varieties growing in these soil samples under either drought-stressed-upland or continuous-flood treatments were inoculated with race IE-1k. Leaf blast severity was highest in drought-stressed-upland treated plants and was reduced by the continuous-flood treatment. Soil samples were ranked according to blast severity over all varieties with the highest being an unidentified UA-PTES sandy loam sample followed by an UA-RREC Dewitt silt loam sample, a Corning 2005 Bosket FSL sample, an unidentified UA-PTES silt loam and, finally, a Corning 2004 Bosket FSL sample. This soil-type severity ranking was essentially the same, with minor variations, for each variety. Although leaf blast severity was higher with plants in specific soil samples, test results do not show increased blast susceptibility in drought-stressed Banks to be associated with a specific soil type. The test data show Banks to be more susceptible to race IE-1k than are other *Pi-ta* varieties. Although susceptibility is intensified with drought stress and soil type, Banks lacks known blast-resistance genes *Pi-kh* and *Pi-ks.* These genes and/or other unidentified genes apparently confer muc of the observed blast field resistance present in other *Pi-ta* varieties. Blast field resistance, cumulative in susceptible

varieties, increases with magnitude and duration of root zone soil moisture until plants become highly resistant or immune to contemporary blast races. Field resistance, mediated by soil moisture, provides the primary rice-blast control mechanism utilized in Arkansas rice production.

INTRODUCTION

High-yielding varieties Banks and Cybonnet, released to seed growers during 2004, contain the major blast resistance gene (R gene) *Pi-ta*. In experimental tests and observation plots throughout Arkansas, Banks and Cybonnet expressed an increased rice-blast resistance over that of established high-yielding blast-susceptible varieties 'LaGrue' and 'Wells'. Thus, Banks and Cybonnet were released as resistant varieties for use in blast-prone sandy production areas such as in northeast Arkansas. Since release, Cybonnet has remained blast resistant as expected. However, the Banks variety was severely damaged by rice blast over approximately 20 acres of a sandy production field in Clay County during 2004 (Lee et al., 2005a). Blast subsequently developed on drought-stressed Banks plants growing in sandy areas of production fields during 2005 and 2006.

Fungal isolates obtained from blasted Banks plants have been characterized as being the blast fungus *Magnaporthe grisea* race IE-1k. The *Pi-ta* R gene provides variety resistance to all common blast races except IE-1k. Discovered soon after the release of *Pi-ta*-based 'Katy' in 1989, race IE-1k was recognized as a potential threat to Arkansas rice production because the *Pi-ta*-based varieties are susceptible to race IE-1k in greenhouse tests. However, IE-1k appeared to be "poorly environmentally adapted" because incidence was limited to a few random plants in research field plots and Arkansas rice production fields. Race IE-1k-susceptible *Pi-ta*-based varieties including Katy, 'Kaybonnet', 'Drew', 'Ahrent', and now Cybonnet have been widely utilized in Arkansas production areas without any observed blast damage.

This research, funded primarily by the Arkansas Rice Research and Promotion Board, was undertaken to determine specific reasons race IE-1k damages the Banks variety but does not adversely impact other *Pi-ta* varieties. Results presented here exemplify our ongoing effort to better define and utilize blast field-resistance and investigate the consistent association of drought stress in sandy soils with blast in Banks.

PROCEDURES

Field-soil samples, taken from a depth of 0 to approximately 4 in., were: 1) a Bosket FSL soil collected immediately adjacent to the 2004 Corning blast-infected field-site; 2) a comparable Bosket FSL collected near 2005 Corning blast-infected production fields; 3) a sandy-loam soil (type unknown); 4) a silt-loam (type unknown) from the University of Arkansas Pine Tree Experiment Station (UA-PTES) rice blast nursery near Colt, Ark.; and 5) a Dewitt silt-loam from the University of Arkansas Rice Research and Extension Center (UA-RREC) pathology field nursery near Stuttgart, Ark. Test varieties were: Wells, a widely grown blast-field-resistant variety that is subject to major yield reduction when drought-stressed; two well established blast-resistant *Pi-ta* varieties Drew and Ahrent; three newly released *Pi-ta* varieties Banks, Cybonnet, and 'Spring'; and 'Saber', which is moderately resistant to resistant to race IE-1k in greenhouse tests. Samples were transported to the UA-RREC during 2005 for greenhouse pathogenicity tests using type *Pi-ta*-virulent race IE-1k (Zn 19). Tests were conducted concurrently for each soil type using techniques as previously reported (Lee et al., 2004; Lee et al., 2005b) where drought-stressed-upland or continuous-flood test conditions were established in 5-(H) by 6-(W) in. plastic pots. Blast severity for each plot was determined using the standard 0 to 9 visual rating scale where 0 = no disease and 9 = maximum lesion growth.

RESULTS AND DISCUSSION

All inoculated varieties exhibited leaf symptoms with severity being highest for plants growing in the drought-stressed-upland treatment and reduced by the continuous-flood treatment. Over all varieties, leaf blast severity was highest in upland plants growing in the PTES sand loam sample followed by the UA-RREC nursery, the Corning 2005, the UA-PTES loam and, finally, the Corning 2004 sample, respectively (Fig. 1A). Using drought-stressed-upland results, a comparable soil-type-severity ranking occurred, with minor variations, for each variety. Initial stages of the flood-induced-blast-field-resistance characteristic of the non-*Pi-ta* Wells was evident in continuous flood treatment (Fig. 1B). Banks, with overall higher blast severity ratings for the continuous-flood and the upland treatments, was the most susceptible and least flood-responsive *Pi-ta* variety tested (Figs. 1C, 1D, 1E, and 1F). Differences in leaf blast severity due to soil sample were evident but did not associate the blast damage in drought-stressed Banks with a specific soil type.

The reduced leaf blast observed with the continuous-flood treatment was consistent with previous research results and provided insight into the nature of blast field resistance (Lee et al., 2004). The reduced field resistance in Banks was less obvious because data are from a single short-term greenhouse experiment which did not capture the cumulative nature of blast field resistance. Under field conditions, blast resistance increases with flood depth and duration until certain varieties become highly resistant if not immune to all blast races. Flood-mediated root-zone dissolved oxygen determines blast severity in all susceptible varieties by controlling hormone production, plant metabolism, and plant morphology (Singh et al., 2004). These internal plant processes occur independently of external disease variables such as free water on leaves and high humidity, which impact spore dispersion, viability, and infection. Additional detailed experiments that closely monitor variable soil characteristics and blast severity are necessary to better define the role of soil type in predisposing rice plants to blast.

All *Pi-ta* varieties were susceptible to race IE-1k in greenhouse tests. When compared with type IE-1k, virulence and molecular differences were detected in IE-1k isolates from Banks (Jia et al., 2006; Lee et al., 2005a). However, these differences do not explain the sudden and severe blast outbreak in drought-stressed production fields of Banks with not other stressed *Pi-ta* varieties. Although Banks was more susceptible to race IE-1k when drought-stressed, other aspects of the disease must be considered. The field-resistance phenomenon is poorly researched in rice. Perhaps the increased blast susceptibility of Banks can be explained by the absence of blast resistance genes Pi-kh and Pi-ks or other unknown minor genes essential for field-resistance development.

Regardless, new approaches must be developed to better predict and avoid events such as occurred with Banks. The immediate need is a fast, accurate assay for IE-1k severity and less reliance on the *Pi-ta* gene as a stand alone means to control rice blast. The problem is not limited to a single blast race or resistance gene however, because all current U.S. rice varieties are susceptible to one or more blast races and the blast pathogen frequently adapts to new R genes, techniques must be developed to define and utilize quantitative blast field-resistance in new varieties.

SIGNIFICANCE OF FINDINGS

Arkansas rice farmers suffer economic losses when rice varieties do not yield to their maximal capacity because of unexpected production problems such as rice blast disease. Results better define variables contributing to the blast disease in the "resistant" Banks, which contains the *Pi-ta* R gene. These data identify the need for improved field-resistance, which is the primary blast control mechanism utilized in Arkansas, and should guide researchers developing new rice varieties.

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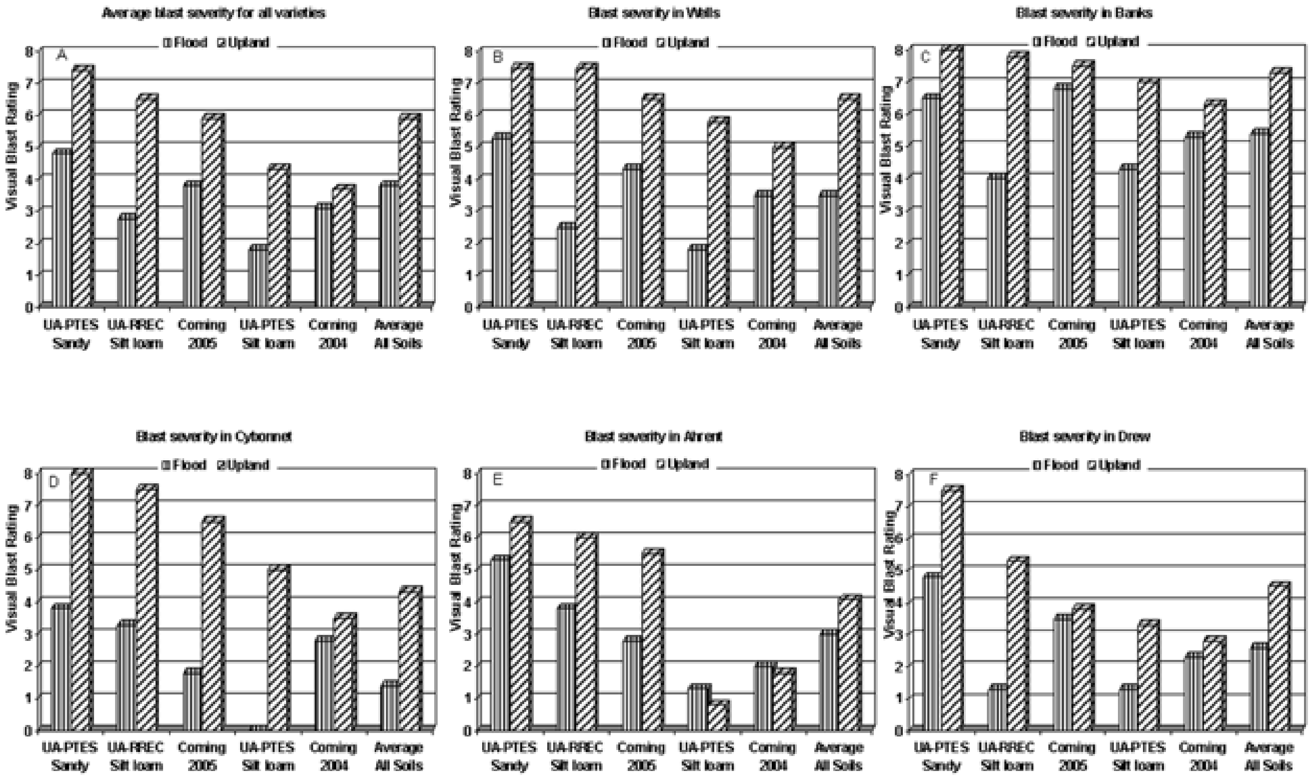

Fig. 1. Comparison of leaf blast severity for Wells, Banks, Cybonnet, Ahrent, and Drew when growing in field soil samples with either continuous-flood or drought-stressed-upland treatments. A. Ratings averaged over all varieties for each soil sample, B. Wells ratings for each soil sample, C. Banks ratings for each soil sample, D. Cybonnet ratings for each soil sample, E. Ahrent ratings for each soil sample, and F. Drew ratings for each soil sample.

PEST MANAGEMENT: DISEASES

Effect of Preventative Fungicide Application on Sheath Blight, Rice Yield, and Milling Quality of 15 Rice Cultivars

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E.A. Sutton, F.N. Lee, J. Gibbons, and C.E. Wilson

ABSTRACT

Rice cultivars ‘4484’, ‘Bengal’, ‘Cheniere’, ‘CL 131’, ‘CL 171AR’, ‘Ricetec CL XL730 Hybrid’, ‘Ricetec CL XP729 Hybrid’, ‘Cybonnet’, ‘Francis’, ‘Jupiter’, RU0501102, ‘Sierra’, ‘Trenasse’, ‘Wells’, and ‘Ricetec XL 723 Hybrid’ were planted in replicated “paired” plots, with one of the pair treated using Quadris® fungicide at 12.8 fl oz/acre shortly after panicle differentiation. All plots were inoculated at panicle initiation by applying 100 ml sodium alginate + mineral oil + *Rhizoctonia solani* AG1-1A isolate RS 407 floating pellets per plot. Results showed a significant reduction in sheath-blight severity by Quadris® treatment for all cultivars and a significantly higher yield for treated plots for Cheniere, CL 171AR, Ricetec CL XL730 Hybrid, Cybonnet, Francis, RU0501102, Sierra, Trenasse, and Wells. Cultivars 4484, Bengal, Ricetec CL XP729 Hybrid, Jupiter, and Ricetec XL 723 Hybrid did not show a significant yield response with fungicide treatment. Cultivars Cheniere, CL 131, CL 171AR, Cybonnet, and Sierra had significantly higher head and total rice milling yields when treated, while RU0501102 and Wells had significantly higher total milled rice yields when treated but head rice was not significantly different between treated and untreated plots for these two cultivars. Yield gain over the untreated control for each cultivar ranged from 1.9 to 37.4%, with gains above about 10% being significant within cultivar. This is the first year of this experiment and it will be repeated at more locations in 2007.

INTRODUCTION

Rice diseases continue to limit profitable rice production in Arkansas and the southern U.S. due to the favorable environment for fungal diseases and current high-input rice-production practices that favor disease development and survival of various pathogens. Nevertheless, rice diseases do not cause measurable loss in every field so the use of foliar fungicides in the state varies. Major diseases like sheath blight, blast, and kernel smut are routinely controlled using fungicides and about 40% of the rice crop is treated each year for these problems. While scouting is encouraged before using fungicides, certain growers routinely treat all fields regardless of cultivar or other factors, assuming fungicides always "at least pay for themselves." Fungicide applications for rice cost \$20 to \$30 per acre for the product and aerial application cost. While environment plays a huge role in the need for and effectiveness of foliar fungicides in rice, cultivar resistance is probably equally important. Since resistance to sheath blight is limited in many southern U.S. rice cultivars, and since rice cultivars change over time in the state, the impact of genetic resistance on sheath blight development with or without fungicide application should be periodically examined. This is especially true since reaction to sheath blight has primarily been determined by visual assessment of disease severity, as evidenced by vertical development of the disease through heading, and yield loss has not always been a consideration due to research expense.

The objectives of this study were to determine the effect of a preventative fungicide application on sheath blight, yield, and milling quality for a range of rice cultivars.

PROCEDURES

The rice cultivars included 4484, Bengal, Cheniere, CL 131, CL 171AR, Ricetec CL XL730 Hybrid, Ricetec CL XP729 Hybrid, Cybonnet, Francis, Jupiter, RU0501102, Sierra, Trenasse, Wells, and Ricetec XL 723 Hybrid. Plots were located on the Robert Moery farm in Lonoke County, and managed in cooperation with the grower using the latest University of Arkansas Division of Agriculture-recommended rice-production practices.

Cultivars were planted 12 April 2006 using a seeding rate of 100 lb/acre, except for Ricetec CL XL723 Hybrid, Ricetec CL XL730 Hybrid, (35 lb/acre), and Ricetec CL XP729 Hybrid (45 lb/acre), with a plot grain drill set for 7-row (on 7-in. spacing) x 25-ft long plots. Plots received 90 lb/acre N (as urea) + 50 lb/acre DAP (di-ammonium phosphate) on 18 May, followed by 45 lb/acre N (as urea) on 16 June and an additional 36 lb/acre N (as urea) on 23 June. Plots were treated with 0.5 lb/acre Facet plus 1.0 qt/acre crop oil on 27 April to control weeds.

Each pair of cultivar plots included an untreated and a fungicide-treated plot (12.8 fl oz Quadris® applied shortly after panicle differentiation for the earliest maturing cultivar), and all plots were inoculated using 100 ml calcium alginate/mineral oil floating pellets containing living mycelium of the sheath blight pathogen, *Rhizoctonia solani* AG1-1A, isolate RS 407, at panicle initiation (approximately one week prior to fungicide application) to ensure uniform disease pressure. Paired plots were arranged in a randomized complete block design with 4 replications and the fungicide was applied using a Mudmaster 4WD multi-purpose sprayer with compressed air-charged containers delivering 10 gpa (20 psi) and a spray boom fitted with 110015 flat fan spray tips.

Plots were rated for sheath blight disease when each cultivar reached 100% headed (all heads had emerged from flag leaf sheath but prior to completion of grain fill). Plots were harvested using a Hege rice-plot combine on 9 September 2006 and grain samples were dried under fans until stable grain moisture below 14% was reached. Plot yield was adjusted to 12% grain moisture and milling quality determined using an uncleaned subsample (stored dry in a paper bag), by Riceland Foods, Stuttgart, Ark. Data were analyzed using ANOVA by cultivar and location within year and mean separation was by Tukeys HSD test at P=0.05.

RESULTS AND DISCUSSION

Sheath blight was moderate in July and early August at this location, but persisted through the grain-fill period, eventually reaching the panicles and rating severe on susceptible cultivars. Quadris® reduced sheath-blight severity significantly on all 15 cultivars tested, with untreated cultivars ranging from 14% (Bengal) to 56% (4484) severity while treated-cultivar plots ranged from 0.6% (Bengal) to 15.5% (Trenasse) (Table 1). Sheath blight severity ratings ceased at 100% headed rice, a timing used in the past successfully, but the persistence of the disease under 2007 weather conditions suggested that assessments should have continued through the grain-fill period to assure collection of more accurate disease severity data. Sheath-blight severity rating data in this study may have underestimated actual disease intensity as reflected by the yield loss data.

Effect of preventative fungicide application on yield varied widely by cultivar (Table 1). Significant effect on yield by the fungicide treatment was noted for Cheniere, CL 171AR, Ricetec CL XL730 Hybrid, Cybonnet, Francis, RU0501102, Sierra, Trenasse, and Wells cultivars (Table 1). Cultivars 4484, Bengal, Ricetec CL XP729 Hybrid, Jupiter, and Ricetec XL 723 Hybrid did not show a significant yield response to fungicide treatment. Significant yield gain over the untreated control varied from 11.7 % for Francis to 37.4% for CL 131 (Table 1). Both Wells and Ricetec CL XL730 Hybrid showed unexpectedly high yield losses considering their most recent disease ratings, approximately 20% for each cultivar (Table 1). These results led to recent changes in disease reaction ratings, with Wells and Ricetec CL XL730 Hybrid changed to susceptible (S) whereas they were rated moderately susceptible (MS) previously. Sierra, previously rated MS, also had unexpectedly high yield loss (35.4%) and a very susceptible (VS) reaction, while Trenasse, rated VS in the past, had an unexpectedly low yield loss of 15.4% (Table 1). One confounding factor in this study was the erratic presence of stem rot in some of the plots. Random plants were collected and frozen from each plot, and stem-rot assessment was still being conducted at the time of writing, but this disease could have affected yield in certain plots.

The effect of fungicide treatment on milling quality also varied with cultivar (Table 1). Contrary to a commonly held belief, these results do not show consistently higher milling quality from fungicide application (Table 1). Cultivars Cheniere, CL 131, CL 171AR, Cybonnet, and Sierra had both significantly higher head- and total rice-milling yields when treated, while RU0501102 and Wells had significantly higher, total milled rice yields when treated but head rice was not significantly different between treated and untreated plots for these two cultivars (Table 1).

Results from this first-year study support the efficacy of current strobilurin fungicides for control of sheath blight and protection of yield and milling quality; however, even without known strong resistance to sheath blight, commercial rice cultivars in the southern U.S. do vary in their response to the disease and to preventative fungicide application. Semidwarf long-grain cultivars are more susceptible and thus benefit the most from fungicide application, while medium-grain and most hybrid rice cultivars benefit little, if at all, from fungicides if sheath blight is the principal disease. Yet, rice germplasm changes over time, and the recent introduction of Ricetec CL XL730 Hybrid showed that some hybrids can potentially benefit from fungicide application to control sheath blight. Climate continues to confuse the issue, with 2006 weather conditions so favorable for sheath blight persistence in the field that cultivars like Wells definitely benefited more from fungicide treatment than observed in the past. Yield-loss data with regard to sheath blight should prove a valuable addition to disease reaction ratings based primarily on visual disease severity, since these data showed the rating for Sierra to be too conservative (MS but likely should be VS) and that Trenasse may be more resistant to sheath blight damage than previously thought. Results from this study should be confirmed with additional locations in 2007.

SIGNIFICANCE OF FINDINGS

Based on these data, the disease reaction rating for additional rice cultivars to sheath blight should be changed, if confirmation data are collected during 2007. It remains clear that preventative fungicide applications do not always result in a yield or milling quality benefit to rice, even under inoculated and severe disease conditions and that most of the response to fungicides depends on the genetic resistance of the cultivar, disease pressure, and local climate.

SIGNIFICANCE OF RESULTS

Based on these results, Arkansas growers using preventative fungicide applications could save up to $30/acre by not treating cultivars resistant to sheath blight, such as Ricetec XL 723 Hybrid or Bengal. On the other hand, growers can protect up to 37% of yield and significant milling quality by treating highly susceptible cultivars like CL 131 with an appropriate and well-timed fungicide application.

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Table 1. Effect of preventative fungicide application on sheath blight, yield, and milling quality of 15 rice cultivars.

	Sheath blight		Yield			Head rice		Total milled rice	
Cultivar	Untreated	Quadris®^{z}	Untreated	Quadris®^{z}	Yield gain	Untreated	Quadris®^{z}	Untreated	Quadris®^{z}
	(% of plot height affected)		----(bu/acre 12% GM^{y}) ---		(% above unt.)	-------------------------------- (%)	--------------------------------		
4484	56.3	2.1*^{x}	135.5	140.4	3.6	57.5	57.3	64.5	64.3
Bengal	14.2	0.6*	149.6	152.5	1.9	65.5	67.0	69.0	69.8
Cheniere	33.3	0.7*	158.2	185.4*	17.2*	57.0	63.3*	63.8	69.0*
CL 131	53.1	11.8*	140.9	193.6*	37.4*	49.8	59.8*	58.8	67.5*
CL 171AR	48.8	5.3*	146.0	188.6*	29.2*	54.0	60.3*	60.7	66.0*
CL XL730	35.0	1.6*	219.9	265.0*	20.5*	60.0	61.5	70.5	71.3
CL XP729	25.0	3.3*	257.2	272.6	6.0	60.3	60.8	70.3	70.5
Cybonnet	48.9	3.5*	159.9	208.0*	30.1*	56.0	62.3*	64.5	69.3*
Francis	26.3	8.7*	182.0	203.3*	11.7*	58.5	60.0	67.0	68.8
Jupiter	39.8	5.1*	158.5	172.4	8.8	65.3	67.3	69.0	70.3
RU0501102	26.7	2.4*	169.0	220.7*	30.6*	54.5	57.5	66.5	70.0*
Sierra	50.4	6.6*	121.9	165.0*	35.4*	46.3	55.8*	60.5	66.0*
Trenasse	37.4	15.5*	170.5	196.8*	15.4*	54.5	54.5	63.0	63.0
Wells	31.0	5.0*	160.2	192.5*	20.2*	57.0	60.0	66.8	69.5*
XL 723	23.1	4.9*	269.5	279.1	3.6	61.3	62.0	70.8	70.8

[z] Quadris® applied at 12.8 fl oz/acre using a self-propelled plot sprayer calibrated to deliver 10 gpa, 7 days after panicle differentiation for Trenasse (earliest maturing cultivar)

[y] GM = grain moisture, measured using a calibrated GAC 2000 instrument (Dickey-John, Inc.)

[x] * Values within variable and cultivar (paired) were significantly different at P=0.05.

The Role of the Environment and Seedling Pathogens on Rice Stand Establishment

C.S. Rothrock, M.A. Eberle, R.L. Sealy, and R.D. Cartwright

ABSTRACT

Stand problems consistently cause significant production losses and management problems in Arkansas rice fields. These studies help to clarify the role of field history and soil characteristics on stand establishment versus the importance of environmental conditions shortly after planting. Stand response to seed treatments suggested seedling diseases and insects were important in rice stand establishment in 2006. Field and controlled environmental studies with rice field soils suggest the environment plays a large role in stand establishment. The importance of different causal agents in stand establishment is being identified by examining stand response to specific fungicides and isolation of pathogens. Results from studies in 2006 were generally in agreement with previous results that *Pythium* spp. are very important in rice stand establishment under cooler, wetter conditions after planting.

INTRODUCTION

Stand problems consistently cause significant production losses and management problems in Arkansas rice fields. *Pythium* species play an important role in stand establishment, especially under cool soil temperatures (Rothrock et al., 2004). Previous research, funded by the Rice Research and Promotion Board, has identified cold-tolerant *Pythium*-resistant genotypes (rice breeding lines) that hold the promise for more reliable stand establishment for rice in Arkansas under marginal planting environments (Rothrock et al., 2005; Rothrock et al., 2006). The objective of this project was to focus on the role of field history and environment on stand establishment in growers' fields.

In addition, this research will identify other important seedling pathogens, in addition to *Pythium* spp., and the environments that favor these pathogens.

PROCEDURES

Field Experiments

Field trials were established in seven growers' fields to examine stand establishment problems. In each of the fields, a soil temperature probe, soil moisture probe, and rain gauge were placed to monitor the weather conditions early in the growing season to help characterize the role of environment on disease and stand establishment. The cultivar 'Wells' was treated with six different seed treatments. The treatments were: Allegiance® (metalaxyl), Dynasty®/Apron XL® (azoxystrobin/mefenoxam), Dynasty®/Apron XL® + Icon® (fipronil), Vitavax®/PCNB (carboxin/PCNB), Argent® (2-(thiocyanomethylthio)benzothiazole), and none. The activity of the products included: broadspectrum fungicide (Dynasty®); *Pythium* spp. (Apron XL® or Allegiance®); *Rhizoctonia* spp. and some other fungi (Vitavax®/PCNB); *Fusarium* and other fungi (Argent®); and insecticide (Icon®). Each plot was 8 rows (7-in. spacing) by 25-ft long. Each test was a randomized complete block design with three replications. Stand counts and soil samples were taken 4 to 5 weeks after planting, with three one-meter stand counts per plot. After the stand counts were taken, approximately 25 arbitrary seedlings in the non-treated plots were dug for disease assessment and isolation of pathogens, and 12 soils samples (15 cm x 2.5 cm diameter cores) were taken along two diagonal passes per test and combined.

Controlled Environmental Experiments

Six growers' fields were selected with a history of stand establishment problems. Soils were collected by Dr. Rick Cartwright and brought to Fayetteville and refrigerated until the experiments were established. Soils were ground or screened prior to use. Two environments were used: cool/wet, and warm/dry. The warm/dry environment was conducted in the greenhouse with temperatures averaging 29°C. Soil moisture content was monitored gravimetrically and at -30 joules/kg, the pots for each soil were watered to saturation. The cool/wet environment was conducted in growth chambers with the temperature set at 15°C for 2 wk and then increased to 20°C for 2 more weeks. The soil moisture content was monitored gravimetrically and at -10 joules/kg, the pots for each soil were watered to saturation. Three cultivars were used: 'Francis', Wells, and 'Cheniere'. Seed for each cultivar had 4 different treatments: Argent®, Vitavax®/PCNB, Allegiance®, and none. Soil was placed in styrofoam cups and six seed for each cultivar and treatment were planted per cup. There were four repetitions per environment in a randomized complete block design. Stand counts were taken at 14 and 21 days in the warm environment, and at 14 and 28 days in the cool environment. Disease was assessed, after 21 days in the warm and 28 days in the cool environment, for all of the plants. Seedlings from nontreated cups were plated on water agar for isolation of pathogens as in the field experiments. The experiment was conducted twice for each environment, within 4 weeks of soil collection.

A fertility analysis was done for each site and soil. Each field study was analyzed by GLM using SAS. Each environmental study was analyzed as a factorial analysis by GLM examining stand response to field soil, cultivar, and fungicide.

RESULTS AND DISCUSSION

Stand improvements due to seed treatments were found in four of the six tests in producers' fields even though many of the treatments were not significantly greater (Table 1). The Jackson County site was lost due to heavy rainfall and the accumulation of rice debris in the test area. The combination treatment Dynasty®/Maxim®/Apron XL®/Icon® increased stands over the nontreated seed in three of six tests. In two of these three tests, this treatment had greater stands than Dynasty®/Maxim®/Apron XL® – the fungicide treatment without the insecticide. These results indicate insects are contributing to stand establishment problems in these fields. In one of six tests, Allegiance® increased stand over the nontreated seed and all other products except for Dynasty®/Maxim®/Apron XL®/Icon®, indicating *Pythium* seedling disease was limiting stands. This site had the coldest soils and most rainfall compared to the other sites (Table 2). The one site, Poinsett, with lower soil temperatures, did not have substantial rainfall during this period. These results indicate that different fields and environments have different problems and it is important to identify the causal agents causing stand losses to consistently achieve satisfactory stands.

The studies conducted in the greenhouse and growth chamber again tried to identify important causal agents responsible for seedling disease and stand losses. Using the six field soils under uniform environments, there were no interactions of soil with fungicide treatment, indicating that when placed under a uniform environment soils responded similar to seed treatment (data not shown). In other words, the same pathogens are important in all of the rice field soils examined. These results suggest that these pathogens are ubiquitous in these soils. In the cool environment, *Pythium* spp. appear to be the primary causal agent of stand establishment problems as Allegiance® was the only product that consistently improved stands over the nontreated control. For the warm environment, stands were greater than the cool environment experiments. In one of the two experiments, stands were numerically greater for all the fungicide treatments compared to the nontreated control. However, only the Vitavax®/PCNB and Argent® treatments increased stands over the nontreated control, indicating different pathogens are impacting stand under the warmer/dryer environment than the cooler/wetter environment. These results suggest that environment shortly after planting has a greater role in stand establishment than does field site for seedling diseases.

These studies help to clarify the role of field history and soil characteristics on stand establishment versus the importance of environmental conditions. Both types of studies, field and controlled environment, suggest the environment plays a large role in stand establishment. In addition, the studies indicate a diversity of organisms contribute to stand losses. The organisms isolated from seedlings from the field and controlled environmental studies are currently being identified and evaluated for pathogenicity. Results from studies in 2006 were generally in agreement with previous results that *Pythium* spp. play a large role in stand establishment problems under cool, wet conditions after planting.

SIGNIFICANCE OF FINDINGS

These studies suggest that seedling diseases and insects are important in rice stand establishment. The importance of different causal agents in stand establishment is being identified by examining stand response to specific fungicides and isolation of pathogens. The controlled environmental studies reinforced the results from the field studies that environment plays an important role in stand establishment. *Pythium* spp. were consistently associated with cool, wet conditions after planting.

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Table 1. Plant stand for different seed treatments for the cultivar Wells in growers' fields in 2006.

Seed treatment	Clark	Desha	Faulkner	Mississippi	Poinsett	Prairie
Dynasty/Maxim/ Apron XL/Icon	50.0 a[z]	31.3 a	41.0 a	43.0 ab	38.7 a	44.3 a
Dynasty/Maxim/ Apron XL	47.3 ab	26.7 b	43.3 a	32.0 c	29.7 b	50.3 a
Allegiance	41.0 bc	24.7 b	36.3 a	48.3 a	28.0 b	46.0 a
Argent	36.7 c	24.3 b	39.0 a	34.3 c	28.3 b	46.3 a
Vitavax/PCNB	43.0 abc	26.7 b	38.3 a	36.7 bc	27.0 b	50.0 a
None	41.0 bc	24.0 b	49.0 a	36.7 bc	29.0 b	45.7 a

[z] Plant stand per meter of row. Means in a column followed by the same letter are not significantly different, protected LSD (*P*=0.05).

Table 2. Soil environmental data for tests in growers' fields in 2006.

Environment[z]	Clark	Desha	Faulkner	Mississippi	Poinsett[y]	Prairie[x]
Mean soil temperature °F(°C)	69 (20.4)	67 (19.3)	.	66 (19.0)	63 (17.4)	72 (22.3)
Rainfall in. (mm)	6.3 (159)	0.8 (20)	2.3 (59)	8.7 (221)	0.2 (4)	0

[z] Environmental data collected the first 14 days after planting.

[y] Environmental data for 8 to 14 days after planting only.

[x] Environmental data for 11 to 14 days after planting only.

Table 3. Plant stands for rice field soils placed under different controlled environments.

Treatment	Cold environment (Exp. 1)	Warm environment (Exp. 2)
Allegiance	3.61 a	4.32 ab
Vitavax/PCNB	3.11 ab	4.58 a
Argent	3.06 b	4.50 a
None	2.93 b	4.08 b

[z] Plant stand out of six seed planted. Means in a column followed by the same letter are not significantly different, protected LSD (*P*=0.05).

Evaluation of Rice Germplasm for Reaction to Disease across Arkansas

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ABSTRACT

More than 200 rice breeding lines (varieties) in the Uniform Regional Rice Nursery (URRN), 100 lines in the Arkansas Rice Performance Trial (ARPT), and 27 commercial varieties or potential releases in the Rice Disease Monitoring Program (RDMP) were evaluated at different locations across Arkansas during 2006. The climate was hotter and drier than normal during the growing season. Sheath blight was moderate in intensity prior to heading, but persisted longer during the growing season, resulting in late-season damage during grain fill. Stem rot was a major problem statewide, mostly on soils suspected to be low in potassium, while blast was erratic and very localized. Narrow brown leaf spot emerged as a concern in certain areas on late-planted rice fields as did kernel smut and false smut in northeast Arkansas. Straighthead was variable, but severe on historical problem fields in the state. Several RDMP sites were evaluated and data collected on straighthead at the Clay County site; sheath blight at the Lonoke site; narrow brown leaf spot, leaf smut, and blast at the Jackson County site; and severe neck blast at the Arkansas County location. The ARPT sites in Jackson and Clay counties were evaluated and late-maturing lines in the Clay Co. ARPT were severely affected by false smut disease. Sheath blight and bacterial panicle blight (BPB) were very severe in the BPB-inoculated URRN in Lonoke County with 167 of 200 lines rated 50% or greater for sheath blight and 111 of 200 lines rated 50% or greater damage from bacterial panicle blight. The URRN at Site 2 in Lonoke County was planted late and an unusual blast epidemic occurred along with narrow brown leaf spot. Neck blast was noted on 61 of 200 lines, but commonly affected varieties were not diseased, suggesting an unusual race of the blast pathogen may have been present. Narrow brown leaf spot was noted

on 102 lines, with 45 of those rated more susceptible, but resistance was noted as well. Site 2 was inoculated with the black sheath rot pathogen, and 63 of 200 lines were rated 5 using a 0 to 9 scale. Other diseases occurred at Site 2 but were either erratic or not identified positively. Results provided new data to the rice breeding programs.

INTRODUCTION

Rice diseases remain a major problem in Arkansas, despite better control options developed as a result of grower-funded research during the past 10 years. The favorable environment and high-input management practices encourage sheath blight, the most important rice disease in the state, common in 75% of rice fields in any given year. Blast remains a major threat, especially in fields with limited irrigation, while stem rot is persistent on lighter and less fertile soils and was again a major problem in 2006. Many growers skipped potash applications to save money, a big mistake in 2006. Bacterial panicle blight damaged ‘Bengal’ again, making it difficult to grow profitably. Kernel smut and false smut were erratic, but both diseases caused local problems in northeast Arkansas on later maturing rice fields where more rainfall occurred. Straighthead was severe in plots planted in historical straighthead fields, but education programs have taught growers to avoid highly susceptible varieties, resulting in fewer commercial problems. Narrow brown leaf spot caused damage in late-maturing rice plots and fields for the first time in several years. This foliar disease has potential to become a major disease problem and 2006 conditions were apparently very favorable for development, and ‘CL 131’ was very susceptible over a large acreage, likely contributing to the problem.

The first line of defense in managing rice diseases is planting resistant, or at least less-susceptible, varieties. Strong and durable resistance is not available for all diseases but even partial resistance can be useful, especially where disease pressure indicates a fungicide also needs to be used. Evaluating varieties and breeding lines for disease reactions is a major undertaking for the University of Arkansas Division of Agriculture, and supports the rice breeding programs at the Rice Research and Extension Center. While the principal disease-resistance program headed by Dr. Fleet Lee is located at the Center, a supplemental program is useful in evaluating less-well known disease problems or disease reactions in different areas of the state.

The objectives of this project were to evaluate breeding lines and varieties in the URRN, ARPT, and Rice Disease Monitoring programs in the state and to evaluate reactions to specific diseases in inoculated nurseries, including bacterial panicle blight and black sheath rot.

PROCEDURES

Seed of the URRN was planted in 7 row (7-in. spacing) x 8-ft long plots on a cooperator farm (Site 1) in Lonoke County, Ark., on 12 April, and later in April at a cooperator site in Poinsett County. This second site did not emerge so another URRN was planted 22 May at the UAPB experimental farm (Site 2) in Lonoke Co. using the same plot sizes. Both sites were managed according to current University of Arkansas Cooperative Extension Service recommendations for fertilization, irrigation, and weed control but fungicides were not used.

Site 1 was inoculated with bacterial panicle blight by spraying a fresh cell suspension of the pathogen on emerging panicles in each plot as heading began. Because of differences in maturity, different plots were inoculated on different days, with inoculations made to selected plots on 17 July, 19 July, 21 July, and finally on 24 July. The URRN (Site 1) was evaluated for bacterial panicle blight as each plot reached 100% headed stage, beginning on 9 August for the earliest lines and continuing over the following 2 weeks. Bacterial panicle blight was visually rated for percent panicle sterility. Sheath blight also developed in the URRN at Site 1 and was evaluated at the same time, based on percent of canopy height affected by the disease.

The URRN at Site 2 was inoculated with the black sheath rot pathogen by applying 100 ml of floating calcium alginate pellets containing mycelium evenly by hand over the center rows of each plot on 11 August, when the earliest lines were beginning to boot. The disease was visually rated using a 0 to 9 (0 = no disease and 9 = severe disease and plant death) rating scale on 15 September when early lines were headed. Other foliar diseases that developed in the URRN at Site 2 from natural inoculum including leaf blast (0 to 9 visual rating scale where 0 = no disease and 9 = coalesced leaf lesions and leaf death); neck blast (percent of panicles affected); and narrow brown leaf spot (0 to 9 rating scale where 0 = no disease and 9 = severe foliar and panicle symptoms) were evaluated 13 to 15 September.

The Arkansas Rice Performance Trials located in Jackson and Clay counties on cooperator farms were evaluated during August 2006 but substantial disease was not evident at the Jackson County location. False smut developed in the Clay County ARPT on a few later maturing rice lines and these were evaluated using a 0 to 9 scale (0 = no disease and 9 = severe false smut).

Cultivars or advanced lines in the Arkansas Rice Disease Monitoring Program (RDMP) were inspected during heading at the various locations around the state and those sites with substantial disease problems were evaluated. These sites included the RDMP in Clay County where straighthead was severe; the RDMP in Lonoke County where sheath blight was uniform; the site in Arkansas County in a furrow-irrigated rice field where neck blast was extremely severe; and the RDMP in Jackson County where several foliar diseases including narrow brown leaf spot (0 to 9 scale as before), leaf smut (0 to 9 scale where 0 = no leaf symptoms and 9 = coalesced lesions and leaf blackened), and neck blast (percent affected panicles) developed. Other RDMP sites were evaluated including Independence, White, Craighead, St. Francis, and Faulkner county locations but disease was too minor or erratic to report.

RESULTS AND DISCUSSION

Results for the RDMP and ARPT sites are reported in Table 1. Rice varieties or breeding lines rated with 50% or more straighthead at the Clay County RDMP included

'Cocodrie', RU0501099, 'Bengal', 'Spring', CL 131, 'CL 151', RU0501145, '4484', and 'Trenasse' (Table 1). The most severely affected lines at the Lonoke County RDMP for sheath blight were Trenasse, Cocodrie, 'CL 161', CL 131, and 'Cybonnet', although almost all varieties rated above 30% (Table 1). The new ARS germplasm line 4484 was the most resistant line to sheath blight at this site, rated only 0.5% with little infection noted (Table 1). Neck blast devastated certain rice varieties and lines at the Arkansas RDMP located in a furrow-irrigated field, an irrigation practice that strongly encourages blast development. 'Sierra', 'Francis', CL 151, and 'Dellrose' suffered more than 90% panicle damage from neck blast while CL 161, 'CL 171AR', Cocodrie, 'Wells', and Trenasse rated from 24 to 56% damage (Table 1). All other varieties were rated 9% or less damage (Table 1). While leaf smut is considered a minor disease, several varieties including Bengal, Spring, 'Banks', and 'Jupiter' were noticeably affected at the Jackson County RDMP (Table 1). Narrow brown leaf spot also developed at this site with CL 131, RU0501084, Trenasse, RU0501099, Spring, 'Presidio', 'CL XL 730', 'XL 723', and Wells most affected (Table 1). Neck blast confused the issue at the Jackson County RDMP with Francis, Wells, Bengal, and Cocodrie severely affected and Trenasse, Presidio, CL 171AR, CL 161, and 'Cheniere' showing minor damage (Table 1). Ratings of 1% or less neck blast on certain varieties at this site could not be confirmed microscopically but all higher ratings were (Table 1).

Although two ARPT locations on cooperator farms were inspected several times during 2006, only late-maturing lines at the Clay County ARPT were severely affected by disease, specifically false smut (Table 1). Lines most severely affected (rated 9 on a 0 to 9 scale) included 4484 Mutant, 4484-1665, 'LaGrue', RU0501133, RU0501139, STG03L-10-047, and STG03L-21-113 (Table 1). All other lines affected rated 7 on a 0 to 9 scale while all earlier maturing and other lines had little or no false smut detected and were not listed (Table 1).

Ratings for the URRN sites are reported in Table 2. Sheath blight developed in the URRN at Site 1 in Lonoke County with 81 of the 200 lines rated 70% or higher and 167 of 200 lines rated more than 50% severity (Table 2). Lines rated 70% or more generally had at least some panicle damage from sheath blight. At this site, sheath blight was abnormally severe, even on certain varieties like Francis, which typically react as moderately susceptible. This site was in a slightly potassium-deficient area of the field, and potash was not applied, so low potassium levels in the plants could have been a contributing factor. Bacterial panicle blight was also very severe at Site 1 following inoculation, with 111 of 200 lines suffering 50% or more sterility (Table 2). Even partially resistant varieties like Jupiter had some bacterial panicle blight damage at this site, although Jupiter had only half the damage (35%) of Bengal (70%) (Table 2). Francis was also among the most susceptible with 90% sterility (Table 2) and remains the single long-grain variety that should be watched by growers for this disease problem.

An unusual leaf- and neck-blast epidemic developed in the late-planted URRN at Site 2 (Table 2). This epidemic arose from natural inoculum and was first noticed on a few lines before spreading throughout the URRN by mid-September. Leaf blast was noted on 44 lines (Table 2) with those rated 8 having very large, coalescing lesions with some leaf death. Neck blast was noted on 61 lines (Table 2) and severity did not necessarily correspond to severity of leaf blast, which is not unexpected (Table 2). 'Arborio', an Italian risotto variety, was among the most severely affected commercial varieties at this location (Table 2). On the other hand, Francis and Wells were not affected at this site even though both are considered susceptible to the most common races of the blast pathogen in the state (Table 2). It is likely that the race of the blast pathogen at this location was somewhat different than normally encountered in commercial fields and samples were sent to Dr. Correll at the UA Fayetteville Department of Plant Pathology for analysis. Narrow brown leaf spot also affected the URRN lines at Site 2, with 102 lines showing either leaf, sheath, or panicle symptoms (or a combination) and 45 lines rated 5 or higher on the 0 to 9 scale (Table 2). These results indicate resistant genes are available in the URRN against this pathogen. The URRN at Site 2 was inoculated with the black sheath rot pathogen during early booting and 63 lines rated 5 on the 0 to 9 scale, indicating susceptibility (Table 2). Severity was somewhat lower than previous years, possibly a result of the later than normal inoculation and site conditions. Finally, a number of other conditions developed in this late nursery that were not reported because we could not identify them for certain. These included foliar symptoms that appeared to be stackburn disease but the pathogen could not be isolated, and what appeared to be eyespot disease on the Aromatic SE line was also not confirmed. Brown spot lesions were abundant but variable and since this disease was evaluated elsewhere, we did not collect data.

These results complement those obtained by the principal disease resistance program at the Rice Research and Extension Center and support the southern breeding programs by providing information otherwise not available. Hopefully, the identification of susceptibility in these lines will allow breeders to better direct efforts in crossing and help with future development of resistant varieties suitable to Arkansas and the southern U.S.

SIGNIFICANCE OF RESULTS

These data provide novel and comparative disease reactions for many breeding lines nearing potential release and thus will help prevent the release of extremely susceptible lines to certain diseases and help breeders identify potential sources of resistance to use in the future.

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Table 1. Rating data for disease reactions of varieties at selected locations in the 2006

Clay		Lonoke		Arkansas		Jack-
Variety	Straight head	Variety	Sheath blight	Variety	Neck blast	Variety
Cocodrie	100.0	Trenasse	61.7	Sierra	100.0	Bengal
RU0501099	90.0	Cocodrie	55.8	Francis	99.0	Spring
Bengal	85.5	CL 161	55.6	CL 151	95.0	Banks
Spring	85.5	CL 131	55.0	Dellrose	90.3	Jupiter
CL 131	81.0	Cybonnet	54.7	CL 161	56.0	RU0501084
CL 151	81.0	Cheniere	52.9	CL 171 AR	45.0	CL 131
RU0501145	80.0	Presidio	51.1	Cocodrie	35.0	Pirogue
4484	72.0	CL 171AR	50.0	Wells	28.0	Medark
Trenasse	64.0	Francis	46.5	Trenasse	24.0	RU0501136
CL XL8	32.0	Wells	45.7	Cheniere	9.0	Cheniere
Medark	24.0	Jupiter	44.0	Bengal	4.0	CL 161
CL 171 AR	24.0	RU0501099	42.6	Presidio	4.0	Cocodrie
Banks	20.0	Banks	42.5	Pace	1.0	CL XP 729
RU0501136	20.0	Pirogue	42.3	CL 131	0.5	Cybonnet
CL 161	12.5	XL 723	42.1	Medark	0.1	Francis
Wells	12.0	Pace	40.4	Cybonnet	0.1	Pace
Jupiter	6.3	CL XL 730	40.3	RU0501099	0.1	Presidio
Francis	6.0	Spring	40.3	Spring	0.1	RU0501099
XL 723	2.8	RU0501136	39.0	Banks	0.0	Trenasse
Presidio	2.5	CL XL8	38.3	Pirogue	0.0	Wells
Cheniere	2.0	Medark	37.3	CL XL 730	0.0	CL XL8
Cybonnet	2.0	RU0501084	37.0	CL XL8	0.0	XL 723
Pace	1.0	CL XP 729	35.0	CL XP 729	0.0	RU0501145
Pirogue	1.0	Bengal	32.9	XL 723	0.0	CL XL 730
CL XL 730	1.0	RU0501145	31.5	RU0501084	0.0	CL 171 AR
CL XP 729	1.0	4484	0.5	RU0501136	0.0	4484
RU0501084	1.0			RU0501145	0.0	

Rice Disease Monitoring Program and selected lines in the ARPT.

-son	Jackson		Jackson		Clay ARPT	
Leaf smut	Variety	Narrow brown leaf spot	Variety	Neck blast	Variety	False smut
5.3	CL 131	7.7	Francis	56.7	4484 MUTANT	9
4.0	RU0501084	6.3	Wells	40.0	4484-1665	9
3.7	Trenasse	6.3	Bengal	30.0	LaGrue	9
3.7	RU0501099	5.7	Cocodrie	25.7	RU0501133	9
3.0	Spring	5.7	Trenasse	13.3	RU0501139	9
2.7	Presidio	5.0	Presidio	11.3	STG03L-10-047	9
2.7	CL XL 730	5.0	CL 171 AR	9.7	STG03L-21-113	9
2.7	XL 723	5.0	CL 161	6.7	Banks	7
2.7	Wells	5.0	Cheniere	6.3	Cocodrie	7
2.0	Banks	4.3	RU0501084	1.0	Francis	7
2.0	Cheniere	4.3	RU0501136	1.0	RU0301188	7
2.0	CL 161	4.3	CL 131	0.3	RU0401136	7
2.0	Cocodrie	4.3	Pace	0.3	RU0401164	7
1.0	Pace	4.3	Medark	0.3	RU0501151	7
1.0	CL 171 AR	4.3	Spring	0.3	RU0601127	7
1.0	Francis	3.7	Banks	0.0	RU0601142	7
1.0	CL XP 729	3.7	Cybonnet	0.0	RU0601148	7
1.0	RU0501145	3.7	Jupiter	0.0	RU0601170	7
1.0	Bengal	3.0	Pirogue	0.0	RU0601182	7
1.0	CL XL8	2.3	4484	0.0	RU0601185	7
0.7	RU0501136	2.0	CL XL 730	0.0	RU0601188	7
0.7	Jupiter	1.7	CL XL8	0.0	STG02L-40-131	7
0.7	Medark	1.7	CL XP 729	0.0	STG03AC-07-066	7
0.3	Cybonnet	1.0	XL 723	0.0	STG03L-17-002	7
0.3	Pirogue	0.7	RU0501099	0.0	STG03L-24-052	7
0.0	4484	0.0	RU0501145	0.0	STG03L-31-064	7
					STG03L-36-036	7
					STG03L-43-088	7
					STG03L-50-035	7
					STG03P-70-099	7

Table 2. Rating data for disease reactions of the 2006 URRN varieties under

Variety	Sheath blight	Variety	Bacterial panicle blight	Variety	Leaf blast
RU0602051	83.3	RU0504156	95.0	RU0504191	8
RU0602082	83.3	FRANCIS	95.0	RU0504198	8
RU0503138	83.3	RU0503138	90.0	RU0203032	8
RU0503147	83.3	RU0602174	90.0	RU0604083	8
RU0604016	82.4	RU0602171	90.0	L205	8
RU0604156	82.4	RU0601044	90.0	RU0604122	8
RU0503009	81.3	RU0501136	90.0	RU0604114	8
RU0501093	81.3	RU0602155	90.0	RU0602048	8
RU0503098	80.0	RU0503113	90.0	Arborio	8
RU0601142	80.0	RU0602146	85.0	RU0604194	8
RU0302082	78.9	RU0103123	85.0	RU0103104	8
RU0503049	78.9	RU0602168	85.0	RU0602155	7
RU0504156	78.9	RU0602137	85.0	RU0401136	7
RU0502177	78.9	RU0602149	85.0	RU0604035	7
RU0503150	78.9	RU0603175	85.0	RU0503144	7
RU0601004	77.8	RU0602165	85.0	RU0003009	7
RU0502168	77.8	RU0601176	85.0	RU0503003	7
RU0502103	77.8	RU0501096	85.0	RU0604198	7
RU0502068	77.8	RU0104055	85.0	RU0203172	7
CHENIERE	77.8	RU0401136	80.0	RU0503089	7
RU0602088	77.8	RU0504191	80.0	RU0503006	7
RU0503089	77.8	RU0601127	80.0	RU0203181	7
RU0602091	77.8	CYPRESS	80.0	RU0503169	7
RU0503092	77.8	RU0602180	80.0	RU0503113	6
RU0602094	77.8	RU0604035	80.0	RU0602146	6
RU0602097	77.8	RU0502134	80.0	RU0602143	6
COCODRIE	77.8	RU0602162	80.0	RU9404036	6
RU0303129	77.8	RU0503141	80.0	RU0403078	6
RU0602131	77.8	RU0503144	80.0	RU0403166	6
RU0602146	77.8	RU0503066	80.0	DELLROSE	6
RU0103123	77.8	RU0604100	80.0	RU0003178	6
RU0602168	77.8	RU0502131	80.0	RU0404191	6
RU0602177	77.8	RU0604197	80.0	RU0602137	5
RU0503178	77.8	RU0401182	80.0	RU0503141	5
RU0604186	77.8	RU0602143	80.0	RU0604100	5
RU0602192	77.8	RU0601090	77.0	RU0502091	5
RU0604193	77.8	RU0501093	75.0	RU0401145	5
RU0401145	76.5	RU0502068	75.0	RU0401164	5
RU0604122	76.2	RU0604186	75.0	RU0404194	5
RU0503163	76.2	RU0103184	75.0	RU0404154	5
RU0401136	75.0	RU0502091	75.0	RU0604193	5
RU0602025	75.0	RU0502137	75.0	RU0502131	4
RU0602048	75.0	RU0601161	71.3	RU0502137	4
RU0504191	75.0	RU0503147	70.0	RU0601013	4
RU0601087	75.0	RU0503009	70.0	RU0504156	0
RU0602103	75.0	RU0602097	70.0	FRANCIS	0
RU0601127	75.0	RU0602131	70.0	WELLS	0
RU0402152	75.0	RU0503135	70.0	RU0503138	0
CYPRESS	74.4	RU0504198	70.0	RU0602174	0

Arkansas field conditions, sorted from most to least severe rating for each disease.

Variety	Neck blast	Variety	Narrow brown leaf spot	Variety	Black sheath rot
RU0504198	100.0	RU0403078	7	RU0503049	5
RU0203032	81.0	RU0502091	7	RU0503012	5
L205	80.8	RU0602174	7	RU0602174	5
Arborio	80.0	RU0602192	7	RU0602192	5
RU0003009	72.0	RU0602103	7	RU0401067	5
RU0604194	66.5	RU0601010	7	RU0503092	5
RU0503006	60.0	RU0401067	7	RU0402152	5
RU0503110	56.0	RU0503092	7	RU0203172	5
RU0203172	48.0	RU0402152	7	RU0503169	5
RU0503144	47.5	RU0203172	5	RU0602149	5
RU0604114	45.0	RU0503169	5	CYPRESS	5
RU0103104	42.0	RU0401145	5	RU0503066	5
RU0602189	38.0	RU0602149	5	RU0602051	5
RU0604122	24.0	CYPRESS	5	RU0502094	5
RU0503049	20.0	RU0602180	5	RU0602082	5
RU0503089	20.0	RU0503066	5	RU0602085	5
RU0604198	19.0	RU0501093	5	RU0602025	5
RU0503169	18.0	RU0502068	5	COCODRIE	5
RU0604083	18.0	RU0602097	5	RU0602189	5
RU0602094	18.0	RU0602131	5	RU0602112	5
RU0603175	18.0	RU0501084	5	RU0503166	5
RU0602195	15.0	RU0601148	5	RU0503184	5
RU0601013	15.0	RU0602051	5	Arborio	5
RU0504191	15.0	RU0502094	5	RU0503144	5
RU0401145	12.0	RU0602128	5	RU0602146	5
RU0503069	12.0	RU0602195	5	RU0602137	5
RU0503003	10.0	RU0302082	5	RU0602171	5
RU0503187	10.0	RU0602082	5	RU0602162	5
RU0504073	10.0	RU0602091	5	RU0503046	5
RU0503104	9	RU0602106	5	RU0503104	5
DELLROSE	9.0	RU0602085	5	RU0604156	5
RU0601087	9.0	RU0602183	5	RU0501151	5
RU0501111	9.0	RU0602094	5	RU0601170	5
RU0203181	9.0	RU0602025	5	RU0604016	5
RU0503184	8.5	RU0503095	5	RU0601030	5
RU0604035	8.5	COCODRIE	5	RU0601185	5
RU0501093	8.5	RU0503116	5	RU0604191	5
RU0604196	8.5	RU0602189	5	RU0502022	5
RU0602048	8.5	RU0502168	5	RU0503190	5
TRENASSE	8.0	RU0602112	5	RU0602088	5
RU0604193	8.0	RU0503166	5	RU0503150	5
RU0602088	7.0	RU0503069	5	XP 723	5
RU0504156	7.0	RU0503184	5	RU0503089	5
RU0504193	7.0	SPRING	5	RU0602165	5
RU0403166	6.0	RU0501081	5	RU0504198	5
RU0003178	6.0	Arborio	3	RU0604083	5
RU0404194	6.0	RU0503144	3	RU0604114	5
RU0103123	6.0	RU0602146	3	RU0604194	5
RU0103184	6.0	RU9404036	3	RU0604035	5

continued

Table 2. Continued.

Variety	Sheath blight	Variety	Bacterial panicle blight	Variety	Leaf blast
RU0402097	73.7	RU0003009	70.0	RU0602171	0
COCODRIE	73.7	RU0504196	70.0	RU0601044	0
RU0503116	73.7	RU0604196	70.0	RU0501136	0
RU0503135	73.7	RU0504073	70.0	RU0103123	0
RU0602174	73.7	RU0501124	70.0	RU0602168	0
RU0602180	73.7	RU0503046	70.0	RU0602149	0
RU0301050	72.7	RU9404036	70.0	RU0603175	0
RU0604157	72.7	RU0503110	70.0	RU0602165	0
PI 636726	72.2	RU0503104	70.0	RU0601176	0
RU0604035	72.2	BENGAL	70.0	RU0501096	0
RU0504198	72.2	RU0503003	70.0	RU0104055	0
RU0602112	72.2	RU0501084	70.0	RU0601127	0
RU0602137	72.2	COCODRIE	65.0	CYPRESS	0
RU0602149	72.2	RU0601121	65.0	RU0602180	0
FRANCIS	71.4	RU0601148	65.0	RU0502134	0
RU0502134	70.6	RU0501167	65.0	RU0602162	0
RU0401067	70.6	PI 636725	65.0	RU0503066	0
RU0602071	70.6	RU0601027	65.0	RU0604197	0
RU0601121	70.6	RU0602068	65.0	RU0401182	0
RU0602162	70.6	RU0203032	65.0	RU0601090	0
RU0602171	70.6	RU0403078	65.0	RU0501093	0
RU0503012	70.0	RU0602051	60.0	RU0502068	0
RU0502094	70.0	RU0604156	60.0	RU0604186	0
RU0404194	70.0	RU0503049	60.0	RU0103184	0
FRANCIS	70.0	RU0502177	60.0	RU0601161	0
RU0601090	70.0	RU0401145	60.0	RU0503147	0
RU0003009	70.0	RU0502094	60.0	RU0503009	0
RU0602128	70.0	RU0602128	60.0	RU0602097	0
RU0403132	70.0	RU0602109	60.0	RU0602131	0
RU0503141	70.0	RU0501151	60.0	RU0503135	0
RU0503144	70.0	RU0604198	60.0	RU0504196	0
RU0603175	70.0	RU0401084	60.0	RU0604196	0
RU0503184	70.0	RU0604083	60.0	RU0504073	0
RU0604154	69.6	RU0602195	60.0	RU0501124	0
RU0502022	68.4	RU0401111	60.0	RU0503046	0
RU0602106	68.4	RU0403166	60.0	RU0503110	0
RU0602109	68.4	RU0602134	60.0	RU0503104	0
SPRING	68.2	RU0503107	60.0	BENGAL	0
RU0504196	66.7	RU0501102	60.0	RU0501084	0
RU0602085	66.7	RU0601108	60.0	COCODRIE	0
RU0003178	66.7	RU0601170	60.0	RU0601121	0
PI595900	66.7	RU0503187	60.0	RU0601148	0
RU0503126	66.7	RU0402028	60.0	RU0501167	0
RU0501151	66.7	RU0502125	60.0	PI 636725	0
RU0602165	66.7	RU0503181	60.0	RU0601027	0
RU0604196	66.7	RU0401164	60.0	RU0602068	0
RU0604198	66.7	RU0603187	60.0	RU0602051	0
RU0503123	65.0	RU0302082	57.0	RU0604156	0
RU0203172	65.0	RU0604016	55.0	RU0503049	0

Variety	Neck blast	Variety	Narrow brown leaf spot	Variety	Black sheath rot
RU0502091	6.0	RU0602137	3	RU0503003	5
RU0404191	6.0	RU0601013	3	RU0503006	5
RU0503113	5.0	RU0602171	3	RU0403166	5
RU0402028	5.0	RU0601044	3	DELLROSE	5
RU0602085	4.0	RU0603175	3	RU0003178	5
RU0503046	4.0	RU0601176	3	RU0602168	5
RU0503098	3.0	RU0104055	3	RU0604186	5
RU0503166	2.0	RU0602162	3	RU0504196	5
RU0503066	1.0	RU0503147	3	RU0603187	5
RU0604100	1.0	RU0503135	3	RU0601004	5
RU0602082	0.5	RU0604196	3	INDICA 17	5
RU0403078	0.5	RU0503046	3	INDICA 21	5
RU0503012		RU0503104	3	INDICA 9	5
RU0602174		COCODRIE	3	AROMATIC SE	5
RU0602192		RU0601027	3	RU0403078	3
RU0401067		RU0604156	3	RU0602103	3
RU0503092		RU0501151	3	RU0601010	3
RU0402152		RU0401084	3	RU0401145	3
RU0602149		RU0401111	3	RU0602180	3
CYPRESS		RU0602134	3	RU0501093	3
RU0602051		RU0503107	3	RU0502068	3
RU0502094		RU0601170	3	RU0602097	3
RU0602025		RU0503187	3	RU0602131	3
COCODRIE		RU0604016	3	RU0501084	3
RU0602112		TRENASSE	3	RU0601148	3
RU0602146		RU0601030	3	RU0602128	3
RU0602137		RU0404100	3	RU0602195	3
RU0602171		RU0503163	3	RU0302082	3
RU0602162		RU0503153	3	RU0602091	3
RU0604156		RU0602115	3	RU0602106	3
RU0501151		RU0103101	3	RU0602183	3
RU0601170		RU0501173	3	RU0602094	3
RU0604016		RU0601185	3	RU0503095	3
RU0601030		RU0502103	3	RU0503116	3
RU0601185		RU0604191	3	RU0502168	3
RU0604191		RU0502022	3	RU0503069	3
RU0502022		RU0503190	3	SPRING	3
RU0503190		RU9903092	3	RU0601013	3
RU0503150		RU0602088	3	RU0601044	3
XP 723		RU0503150	3	RU0603175	3
RU0602165		RU0301050	3	RU0601176	3
RU0602168		XP 723	3	RU0503147	3
RU0604186		RU0604154	3	RU0604196	3
RU0504196		RU0503089	1	COCODRIE	3
RU0603187		RU0602165	1	RU0601027	3
RU0601004		RU0401182	1	RU0401111	3
INDICA 17		RU0601090	1	RU0503107	3
INDICA 21		RU0503009	1	RU0503187	3
INDICA 9		RU0502177	1	TRENASSE	3

continued

Table 2. Continued.

Variety	Sheath blight	Variety	Bacterial panicle blight	Variety	Leaf blast
RU0501173	65.0	RU0602192	54.0	RU0502177	0
RU0103104	64.7	DELLROSE	54.0	RU0502094	0
RU0301041	63.6	RU0602082	50.0	RU0602128	0
RU0401084	63.2	RU0601004	50.0	RU0602109	0
RU0601044	63.2	RU0602091	50.0	RU0501151	0
RU0504193	63.2	RU0601087	50.0	RU0401084	0
RU0504073	63.2	RU0604157	50.0	RU0602195	0
RU0604083	63.2	RU0602106	50.0	RU0401111	0
RU0602183	63.2	RU0602085	50.0	RU0602134	0
RU0404100	62.5	RU0504193	50.0	RU0503107	0
RU0203181	62.5	RU0602183	50.0	RU0501102	0
RU0503066	61.9	L205	50.0	RU0601108	0
RU0503069	61.9	TRENASSE	50.0	RU0601170	0
RU0602115	61.1	RU0601030	50.0	RU0503187	0
RU0602195	61.1	RU0404100	48.0	RU0402028	0
RU0601148	60.9	RU0501105	47.5	RU0502125	0
RU0503006	60.0	RU0503098	45.0	RU0503181	0
RU0601013	60.0	RU0602094	45.0	RU0603187	0
RU0103184	60.0	RU0503163	45.0	RU0302082	0
RU0401111	60.0	RU0602103	45.0	RU0604016	0
RU0503153	60.0	RU0401179	45.0	RU0602192	0
DELLROSE	60.0	RU0604122	40.0	RU0602082	0
RU0501167	60.0	RU0602025	40.0	RU0601004	0
RU0503169	60.0	RU0602071	40.0	RU0602091	0
RU0503190	60.0	RU0503126	40.0	RU0601087	0
RU0403166	58.8	RU0203172	40.0	RU0604157	0
RU0604100	58.8	RU0601010	40.0	RU0602106	0
RU0602189	57.9	RU0601130	40.0	RU0602085	0
WELLS	57.1	RU0503153	38.0	RU0504193	0
RU0501133	57.1	RU0503095	38.0	RU0602183	0
RU0602134	57.1	CHENIERE	35.0	TRENASSE	0
RU0601176	57.1	RU0404194	35.0	RU0601030	0
RU0501081	56.5	RU0301041	35.0	RU0404100	0
RU0501105	56.5	JUPITER	35.0	RU0501105	0
Arborio	56.0	RU0503089	30.0	RU0503098	0
RU0601010	55.6	COCODRIE	30.0	RU0602094	0
RU9903092	55.6	RU0503116	30.0	RU0503163	0
JUPITER	55.6	RU0503012	30.0	RU0602103	0
PI 636725	55.6	RU0602115	30.0	RU0401179	0
RU9603178	55.6	RU0602189	30.0	RU0602025	0
RU0604114	55.6	RU0604114	30.0	RU0602071	0
L205	55.6	RU0103101	30.0	FRANCIS	0
RU0502091	55.6	RU0501099	30.0	RU0503126	0
TRENASSE	55.0	RU0404154	28.0	RU0601010	0
RU0503095	55.0	RU0501173	27.0	RU0601130	0
RU0301081	54.5	RU0502168	25.0	RU0503153	0
RU0301188	54.5	RU0602112	25.0	RU0503095	0
RU0501096	54.5	RU0401067	25.0	CHENIERE	0
RU0501124	52.9	PI595900	25.0	RU0301041	0

Variety	Neck blast	Variety	Narrow brown leaf spot	Variety	Black sheath rot
AROMATIC SE		RU0503181	1	RU0503163	3
RU0602103		JUPITER	1	RU0503153	3
RU0601010		PI 636726	1	RU0602115	3
RU0602180		RU0602177	1	RU0103101	3
RU0502068		RU0501111	1	RU0501173	3
RU0602097		RU0504191	0	RU0502103	3
RU0602131		RU0504198	0	RU9903092	3
RU0501084		RU0203032	0	RU0604154	3
RU0601148		RU0604083	0	PI 636726	3
RU0602128		L205	0	RU0504191	3
RU0302082		RU0604122	0	RU0203032	3
RU0602091		RU0604114	0	L205	3
RU0602106		RU0602048	0	RU0602048	3
RU0602183		RU0604194	0	RU0103104	3
RU0503095		RU0103104	0	RU0602155	3
RU0503116		RU0602155	0	RU0401136	3
RU0502168		RU0401136	0	RU0003009	3
SPRING		RU0604035	0	RU0503113	3
RU0601044		RU0003009	0	RU0604100	3
RU0601176		RU0503003	0	RU0401164	3
RU0503147		RU0604198	0	RU0404194	3
COCODRIE		RU0503006	0	RU0604193	3
RU0601027		RU0203181	0	RU0502131	3
RU0401111		RU0503113	0	RU0502137	3
RU0503107		RU0602143	0	RU0504156	3
RU0503163		RU0403166	0	FRANCIS	3
RU0503153		DELLROSE	0	RU0501136	3
RU0602115		RU0003178	0	RU0103123	3
RU0103101		RU0404191	0	RU0103184	3
RU0501173		RU0503141	0	RU0504073	3
RU0502103		RU0604100	0	RU0501124	3
RU9903092		RU0401164	0	RU0503110	3
RU0604154		RU0404194	0	RU0501167	3
PI 636726		RU0404154	0	RU0602068	3
RU0602155		RU0604193	0	RU0602109	3
RU0401136		RU0502131	0	RU0501102	3
RU0401164		RU0502137	0	RU0601108	3
RU0502131		RU0504156	0	RU0502125	3
RU0502137		FRANCIS	0	RU0604157	3
FRANCIS		WELLS	0	RU0504193	3
RU0501136		RU0503138	0	RU0503098	3
RU0501124		RU0501136	0	RU0602071	3
RU0501167		RU0103123	0	FRANCIS	3
RU0602068		RU0602168	0	RU0503126	3
RU0602109		RU0501096	0	CHENIERE	3
RU0501102		RU0601127	0	RU0501099	3
RU0601108		RU0502134	0	PI595900	3
RU0502125		RU0604197	0	RU0501139	3
RU0604157		RU0604186	0	RU0603166	3

continued

Table 2. Continued.

Variety	Sheath blight	Variety	Bacterial panicle blight	Variety	Leaf blast
RU0501136	52.9	RU9603178	25.0	JUPITER	0
RU0401087	52.6	RU0401087	25.0	COCODRIE	0
RU0404154	52.6	RU0501139	25.0	RU0503116	0
RU0601027	52.6	RU0603166	25.0	RU0503012	0
RU0502137	52.6	RU0503166	24.5	RU0602115	0
RU0503046	52.6	RU0601185	23.8	RU0602189	0
RU9404036	52.6	RU0502103	20.0	RU0103101	0
RU0602068	52.6	RU0402097	20.0	RU0501099	0
RU0103101	52.6	RU0503069	20.0	RU0501173	0
RU0503107	52.6	RU0501133	20.0	RU0502168	0
RU0601182	52.6	RU0601188	20.0	RU0602112	0
RU0604194	52.4	RU0604191	20.0	RU0401067	0
RU0601061	52.2	RU0601182	19.6	PI595900	0
RU0503166	50.0	PI 636726	19.0	RU9603178	0
RU0203032	50.0	RU0503178	15.0	RU0401087	0
RU0502131	50.0	RU0503184	15.0	RU0501139	0
RU0501102	50.0	RU0502022	15.0	RU0603166	0
RU0601108	50.0	RU0503123	15.0	RU0503166	0
RU0503110	50.0	RU0503006	15.0	RU0601185	0
RU0501111	50.0	RU0601013	15.0	RU0502103	0
RU0604197	50.0	RU0503190	15.0	RU0402097	0
BANKS	47.8	RU9903092	15.0	RU0503069	0
RU0601185	47.8	RU0303129	12.0	RU0501133	0
RU0601188	47.8	RU0602088	10.0	RU0601188	0
RU0401182	47.6	RU0604193	10.0	RU0604191	0
RU0601170	47.6	RU0601142	9.5	RU0601182	0
RU0503187	47.4	RU0602177	9.5	PI 636726	0
RU0503104	47.4	RU0003178	9.5	RU0503178	0
RU0602155	47.4	RU0503150	9.0	RU0503184	0
RU0401179	45.5	RU0503092	9.0	RU0502022	0
RU0601030	45.0	RU0403132	9.0	RU0503123	0
RU0402028	44.4	SPRING	9.0	RU0503190	0
RU0502125	44.4	RU0203181	9.0	RU9903092	0
BENGAL	44.4	RU0601061	7.5	RU0303129	0
RU0403078	44.4	RU0501111	7.5	RU0602088	0
RU0501145	44.4	RU0501145	7.5	RU0601142	0
RU0601161	43.5	RU0602048	6.0	RU0602177	0
XP 723	42.7	RU0501081	6.0	RU0503150	0
RU0104055	42.1	RU0603075	6.0	RU0503092	0
RU0503113	42.1	Arborio	5.0	RU0403132	0
RU0602143	42.1	RU0404191	5.0	SPRING	0
RU0503003	40.0	RU0301050	4.5	RU0601061	0
RU0501084	40.0	RU0301188	4.5	RU0501111	0
RU0501099	40.0	RU0402152	4.0	RU0501145	0
RU0603075	38.1	RU0604194	3.5	RU0501081	0
RU0503181	38.1	RU0503169	3.0	RU0603075	0
RU0401164	36.4	BANKS	3.0	RU0301050	0
RU0404191	35.0	RU0103104	0.5	RU0301188	0
RU0601130	35.0	XP 723	0.3	RU0402152	0

Variety	Neck blast	Variety	Narrow brown leaf spot	Variety	Black sheath rot
RU0602071		RU0103184	0	RU0402097	3
FRANCIS		RU0601161	0	RU0601188	3
RU0503126		RU0504196	0	RU0303129	3
CHENIERE		RU0504073	0	RU0601142	3
RU0501099		RU0501124	0	RU0403132	3
PI595900		RU0503110	0	RU0603075	3
RU0501139		BENGAL	0	RU0301188	3
RU0603166		RU0601121	0	INDICA 22	3
RU0402097		RU0501167	0	INDICA 12	3
RU0601188		PI 636725	0	RU0601087	1
RU0303129		RU0602068	0	RU0502091	1
RU0601142		RU0602109	0	RU0501081	1
RU0403132		RU0501102	0	RU9404036	1
RU0603075		RU0601108	0	RU0104055	1
RU0301188		RU0402028	0	RU0503135	1
INDICA 22		RU0502125	0	RU0401084	1
INDICA 12		RU0603187	0	RU0602134	1
RU0501081		RU0601004	0	RU0404100	1
RU9404036		RU0604157	0	RU0301050	1
RU0104055		RU0504193	0	RU0401182	1
RU0503135		RU0501105	0	RU0601090	1
RU0401084		RU0503098	0	RU0503009	1
RU0602134		RU0401179	0	RU0502177	1
RU0404100		RU0602071	0	RU0503181	1
RU0301050		FRANCIS	0	JUPITER	1
RU0401182		RU0503126	0	RU0602177	1
RU0601090		RU0601130	0	RU0501111	1
RU0503009		CHENIERE	0	RU0604122	1
RU0502177		RU0301041	0	RU0604198	1
RU0503181		RU0501099	0	RU0203181	1
JUPITER		PI595900	0	RU0602143	1
RU0602177		RU9603178	0	RU0404191	1
RU0602143		RU0401087	0	RU0503141	1
RU0503141		RU0501139	0	RU0404154	1
RU0404154		RU0603166	0	WELLS	1
WELLS		RU0402097	0	RU0503138	1
RU0503138		RU0501133	0	RU0501096	1
RU0501096		RU0601188	0	RU0601127	1
RU0601127		RU0601182	0	RU0502134	1
RU0502134		RU0503178	0	RU0604197	1
RU0604197		RU0503123	0	RU0601161	1
RU0601161		RU0303129	0	BENGAL	1
BENGAL		RU0601142	0	RU0601121	1
RU0601121		RU0403132	0	PI 636725	1
PI 636725		RU0601061	0	RU0402028	1
RU0501105		RU0501145	0	RU0501105	1
RU0401179		RU0603075	0	RU0401179	1
RU0601130		RU0301188	0	RU0601130	1
RU0301041		BANKS	0	RU0301041	1

PEST MANAGEMENT: INSECTS

Volatiles Induction in Rice Stink Bug Host Grasses and Rice Plants

N. Singh, D.T. Johnson, R.J. Bryant, and J.L. Bernhardt

ABSTRACT

Rice stink bug (RSB), *Oebalus pugnax* F., is an important pest of heading rice in the United States. Little is known about plant volatiles production following herbivory by rice stink bug. RSB feeding induced volatiles production in different RSB host grasses and rice varieties, and may help explain RSB movement to heading rice. Limonene and methyl salicylate (MeSA) were found in varying amounts from panicles of host grasses and rice. RSB feeding induced caryophyllene production from panicles of only rice and vaseygrass. Limonene was produced in higher amounts in the RSB-resistant rice cultivar 'Kaybonnet' than in more RSB-susceptible 'Cocodrie' and 'Bengal'. Future studies should be conducted to assess effects of limonene and MeSA on feeding duration and development of RSB and note levels of these volatiles in other rice varieties.

INTRODUCTION

Recently, there has been increased interest in studying the induction of volatile compounds produced in plants and insect-plant interactions and the subsequent effects of these emissions on an herbivore pest and its natural enemies (Turlings et al., 1998). Several biosynthetic pathways involved in volatiles production are activated by herbivory and include the isoprenoid pathways (terpenes), the shikimic pathway (esters), and the lipoxygenase pathway (green leaf volatiles or GLV). The synthesis and release of volatiles induced by herbivore damage are not emitted from uninjured or mechanically injured plants (Rose et al., 1996). Plants emit several volatiles attractive to natural enemies of herbivores when damaged by herbivores and thus use these volatiles as an indirect defense by recruiting natural enemies to prey upon the herbivore (Dicke et al., 1999). Most of the knowledge on herbivore-induced volatiles has come from the study of lepidopterans and phloem-feeders. However, the volatiles response of plants to other insects with piercing-sucking mouthparts has received relatively less attention. Keeping this in mind, we conducted a study using gas chromatography/mass spectroscopy (GC/MS) to determine if plant volatiles were induced in rice and other RSB hosts in response to RSB feeding.

PROCEDURES

Induced Volatiles

Several RSB grass host-plants that were just beginning to head were moved from the field to Fayetteville. Host plants included barnyardgrass, dallisgrass, ryegrass, vaseygrass, a prairiegrass (unknown spp.), and rice variety 'Francis'. Twenty RSB adults were allowed to feed on four panicles for 3 or 5 days in nylon cages. The adults were removed immediately before volatiles collection on Super Q 80/100 mesh (Alltech Associates, Inc., Deerfield, Ill.) traps as described by Singh et al (2007). Two replications were used for each treatment, i.e., healthy panicles, 3-day-fed-on, and 5-day-fed-on panicles. After eluting all volatiles with dichloromethane in 1 ml glass vials, 10 µl ethyl caprate (0.01 ng/ul) were added to each 100 µl volatile sample. Then a 1 µl aliquot of each volatile sample was analyzed on Varian Chrompack CP-3800 GC/MS.

Rice Variety Volatiles

Head space volatiles were collected from plants of 'Kaybonnet', 'Bengal', and 'Cocodrie' rice varieties that were in the milk stage using Solid Phase Microextraction (SPME) 50/30 carboxen/DVB/PDMS fibers (Supelco, Bellefonte, Pa.). Three intact rice panicles were used for volatiles collection. Volatiles from two plants and one control (empty chamber) were collected for each rice variety. SPME fiber samples were desorbed for 0.5 min by inserting the SPME fiber into the Varian Chrompack CP-3800 GC/MS. Peaks were identified using (NIST) mass spectral database.

Quantifying Volatiles

Calibration curves were generated from four serial dilutions of ethyl caprate (99% pure) (Sigma-Aldrich Co., Milwaukee, Wis.). A 1 µl aliquot of each dilution was injected in the GC/MS to generate a standard curve. An estimate of ion abundance for each GC peak for each volatile sample was compared to the peak for the ethyl caprate standard. All the compounds were then calculated as picograms emitted per hr (pg/hr) from different RSB host grasses.

RESULTS AND DISCUSSION

Induced Volatiles

Limonene and MeSA were found in headspace volatiles from panicles of all the RSB host grasses and rice variety Francis whereas caryophyllene was found only in rice and vaseygrass. However, MeSA was produced in higher quantities in unfed-on (0.012 pg/hr) and 3-day (0.014 pg/hr) RSB fed-on panicles of rice variety Francis, but was absent in 5-day fed-on panicles (Table 1). Caryophyllene was induced only in 3-day fed-on panicles of rice (0.007 pg/hr) and vaseygrass (0.14 pg/hr), and was absent in unfed-on and 5-day fed-on panicles. Higher amounts of limonene were emitted in 3-day (0.24 pg/hr) and 5-day (0.29 pg/hr) RSB fed-on barnyardgrass panicles as compared to unfed-on (0.004 pg/hr) panicles. More MeSA was induced in 5-day (0.05 pg/hr) fed-on barnyardgrass panicles as compared to unfed-on (0.001 pg/hr) or 3-day (0.001 pg/hr) RSB fed-on panicles. Significant differences were found in production of limonene in vaseygrass from panicles with 3-day (0.26 pg/hr) RSB feeding versus unfed-on (0.004 pg/hr) and 5-day (0.009 pg/hr) RSB fed-on panicles. MeSA was produced in increased amounts in 5-day (0.32 pg/hr) fed-on prairiegrass panicles as compared to unfed-on (0.045) and 3-day (0.02 pg/hr) RSB fed-on panicles. Ryegrass panicles emitted higher amounts of limonene after being fed on by RSB for 3-day (1.02 pg/hr) than unfed-on (0.12 pg/hr) and 5-day (0.43 pg/hr) fed-on panicles. The MeSA was produced in increased amounts in 3-day (0.25 pg/hr) fed-on ryegrass panicles as compared to 5-day (0.015 pg/hr) RSB fed-on panicles and unfed-on panicles (0.004).

Rice Variety Volatiles

No significant differences in production of MeSA and caryophyllene were found among the three rice varieties Kaybonnet, Bengal, and Cocodrie. However, 20-fold larger ion counts of limonene were produced by Kaybonnet (102) than by either Bengal (6) or Cocodrie (5) rice varieties (Table 2).

Limonene was produced 8.5-fold and 2-fold higher in 3-day RSB fed-on ryegrass panicles than unfed-on panicles and 5-day RSB fed-on panicles, respectively. Whereas MeSA was produced 62-fold more in 3-day RSB fed-on panicles than unfed-on and 3-fold more in 5-day RSB fed-on panicles than unfed-on panicles. Others reported quantitative differences in volatiles production in grasses exposed to other herbivore species for different feeding periods. The levels of volatiles production in different grasses may also depend upon the vigor of plant and duration of heading period of panicles. The drop in volatiles production after 3-day of RSB feeding was attributed to either a short panicle-heading period of certain grass species, like dallisgrass and vaseygrass, or to repellency of RSB-induced volatiles that reduced RSB feeding and further damage to panicles. Limonene released due to 3-day and 5-day feeding was approximately ≥60-fold higher than unfed-on panicles of barnyardgrass, whereas 50-fold more MeSA was produced in 5-day RSB fed-on panicles than 3-day RSB fed-on panicles or unfed panicles. This indicates that the isoprenoid pathway producing limonene and the shikimic pathway producing MeSA may operate differently and independently from each other.

MeSA was identified as an induced volatile from all the RSB host grasses. MeSA was shown to be repellent to hop aphid, *Phorodon humuli* (Schrank), an attractant to natural enemies in traps that were placed in a hop yard (Losel et al., 1996). Caryophyllene was produced only in rice variety Francis and vaseygrass after panicles were fed on for 3 days by RSB. It was absent in unfed-on and 5-day fed-on panicles. Increased amounts of caryophyllene were reported in two legumes, *Vicia fabae* L. and *Phaseolus vulgaris* L., fed on by southern green stink bug, *Nezara viridula* (L.) (Colazza et al., 2004). Findings from volatiles collections from three different rice varieties with different susceptibilities to RSB suggest that limonene may play a role in chemical defense of rice. It is reported that in most years, Kaybonnet plants sustain very little damage by RSB, whereas Bengal and Cocodrie are more susceptible to RSB (Bernhardt et al., 2003). The latter two varieties each produce significantly less limonene than Kaybonnet (Table 2). Singh (2007) noted that combined numbers of RSB in unbaited, yellow pyramid traps (10 RSB) were higher than traps baited with limonene (4 RSB), MeSA (2 RSB), or limonene + MeSA (2.5 RSB) from six locations on different sampling dates during the rice season in 2005. No RSB natural enemies were captured on screen portion of pyramid trap with or without bait attached inside screen.

SIGNIFICANCE OF FINDINGS

These findings may lead to development of RSB-resistant rice varieties with higher levels of limonene (if it turns out to have either antibiotic or antixenosis effects), or RSB repellent spray of limonene or MeSA. Assays should be conducted to compare a series of rice varieties for the quantity of limonene or MeSA and relative susceptibility to RSB. These studies would also assess the amount of damage after RSB feeding on each variety, effect of limonene and MeSA on rice plant attractiveness to RSB, and toxicity to RSB development.

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Table 1. Number of pg/hr (± SE) (N = 2) of limonene, methyl salicylate, and caryophyllene from GC/MS analysis of Super Q trap collections of head space from host-grass panicles either not fed on (unfed-on) or fed on by rice stink bug for 3 or 5 days.

Host grasses (rice variety)	Days of feeding	Limonene	Methyl salicylate	Caryophyllene	Total
(Francis)	(Unfed) 0	0.03 ± 0.005a[z]	0.012 ± 0.002a	0b	0.015
	3	0.05 ± 0.01a	0.014 ± 0.002a	0.007 ± 0.001a	0.07
	5	0.04 ± 0.01a	0b	0b	0.04
Barnyardgrass	(Unfed) 0	0.06 ± 0.002b	0.0012 ± 0.0002b	0	0.06
	3	0.24 ± 0.015a	0.011 ± 0.0015b	0	0.25
	5	0.3 ± 0.02a	0.05 ± 0.004a	0	0.34
Vaseygrass	(Unfed) 0	0.004 ± 0.001b	0.001 ± 0.001a	0b	0.005
	3	0.26 ± 0.01a	0.16 ± 0.1a	0.14 ± 0.05a	0.56
	5	0.009 ± 0.002b	0.0002 ± 0.0003	0b	0.009
Prairiegrass	(Unfed) 0	0.3 ± 0.1a	0.045 ± 0.03b	0	0.32
	3	0.54 ± 0.02a	0.026 ± 0.015b	0	0.56
	5	1.1 ± 0.2a	0.32 ± 0.04a	0	1.5
Dallisgrass	(Unfed) 0	0.3 ± 0.1a	0.0026 ± 0.0002a	0	0.3
	3	0.91 ± 0.3a	0.33 ± 0.1a	0	1.24
	5	0.2 ± 0.06a	0.02 ± 0.001a	0	0.22
Ryegrass	(Unfed) 0	0.12 ± 0.05b	0.004 ± 0.004b	0	0.13
	3	1.0 ± 0.1a	0.25 ± 0.01a	0	1.3
	5	0.43 ± 0.03b	0.015 ± 0.01b	0	0.45

[z] Means in same column with different letters are significantly different ($P < 0.05$, Tukey Kramer HSD-test).

Table 2. GC/MS ion counts (± SE) (N = 2) in pg/hr of limonene, methyl salicylate, and caryophyllene collected on Solid Phase Microextraction fiber from head space from unfed-on panicles of three rice varieties that have different susceptibilities to rice stink bug.

Variety	Susceptibility to RSB	Limonene	Methyl salicylate	Caryophyllene	Total
Kaybonnet	Resistant	102.5 ± 27.0a[z]	3.8 ± 1.2a	29.5 ± 14.0a	135.8
Cocodrie	Susceptible	6.0 ± 4.0b	1.5 ± 0.5a	49.0 ± 11.0a	56.5
Bengal	Susceptible	5.0 ± 3.0b	1.3 ± 0.25a	13.0 ± 1.0a	19.3

[z] Means in same column and the same volatile that have different letters are significantly different ($P < 0.05$, Tukey Kramer HSD-test)

PEST MANAGEMENT: WEEDS

Weed Management Needs in Arkansas Rice

J.K. Norsworthy, N.R. Burgos, R.C. Scott, and K.L. Smith

ABSTRACT

Certified Crop Advisors of Arkansas and members of the Arkansas Crop Consultants Association were surveyed in fall 2006 through direct mail to assess current weed management practices and needs in rice from both a research and educational perspective. Consultants reported scouting 564,000 of the possible 1,400,000 acres (40%) of rice grown in Arkansas. Preemergence herbicides most often recommended were clomazone (93%) and quinclorac (40%). Propanil (55%) and quinclorac (47%) were the two most commonly recommended postemergence herbicides. Thirty-two percent of the consultants often recommend three or more herbicide applications per field. An average of 37% of the fields were believed to have 'serious' or 'very serious' weed infestations, and fields were scouted for weeds on average 11 times per growing season. Ninety-two percent of the consultants had 'moderate' to 'high' concerns with herbicide-resistant weeds. The perceived average additional expense associated with managing a resistant weed in rice was $26.56/acre. Propanil-resistant and quinclorac-resistant barnyardgrass were believed to be infesting 24 and 7% of the scouted rice acres, respectively. Barnyardgrass was the most problematic weed of rice, followed by red rice. Northern jointvetch and smartweeds were the two most problematic broadleaf weeds. The number one research need was improved broadleaf weed control. Respondents indicated that research and educational efforts should continue to focus on herbicide performance and development of economical weed control programs. Information provided by this survey will be instrumental in directing future weed management research and educational efforts in rice.

INTRODUCTION

Weed management surveys are useful for directing future research and educational priorities and identifying the most problematic weeds along with shifts in the weed spectrum (Coble, 1994; Loux and Berry, 1991; Webster and Coble, 1997). Weed management is ever-changing due partially to adoption of new technologies and production practices as well as the evolving complex of available herbicides for managing weeds. For instance, introduction of imidazoline-resistant rice in the early 2000s has benefitted weed management in rice by offering producers an effective means for controlling red rice (Levy et al., 2006).

Herbicide-resistant weeds were not known to occur in rice prior to the early 1990s (Heap, 2006), but since then, barnyardgrass has developed resistance to propanil and quinclorac (Baltazar and Smith, 1993; Lovelace et al., 2002). Although it is believed that barnyardgrass resistance to these herbicides is widespread, the percentage of rice acres infested with these biotypes is not known. What is known is that clomazone, bispyribac-sodium, cyhalofop-butyl, fenoxaprop, and imazethapyr are effective herbicide options for controlling propanil- and quinclorac-resistant barnyardgrass (Malik et al., 2003; Mitchell et al., 1999; Talbert et al., 2003).

Rice producers in Arkansas are making less of the day-to-day management decisions than in years past and instead are relying more on recommendations from consultants, including weed management (Robert Scott, personal observation). Therefore, a survey was constructed to determine the current weed-management practices being recommended or used by rice consultants and their research and educational needs to improve weed management in rice.

PROCEDURES

A direct mail survey was sent to 361 registered Certified Crop Advisors (CCAs) in Arkansas and registered crop consultants with the Arkansas Agricultural Consultants Association. A postage-paid, self-addressed return envelope accompanied each survey. The CCA list for Arkansas was obtained from the national CCA website, and names and addresses of registered consultants were provided by the Arkansas Agricultural Consultants Association. Approximately 50% of CCAs were also members of the Arkansas Agricultural Consultants Association. There was no designation of scouted crops on the two available lists; thus, the survey was sent to all consultants to ensure that as many acres of rice as possible would be surveyed. The survey contained questions regarding a) recommended weed-management practices, b) herbicide-resistant weeds, c) problematic weed rankings, and d) research and educational priorities. From a list of potential research and educational needs and a list of potential weed problems, consultants were asked to rate each item on a scale from 1 to 5 where 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important. Consultants also ranked the three most problematic weeds in order of importance, and the rankings were then weighted such that the most problematic weed was assigned a value of 3, the second most a value of 2, and the third most a value of 1 (Webster and MacDonald, 2001). Importance ratings were subjected to a one-way ANOVA, and means were separated by Fisher's protected LSD test at a = 0.05.

RESULTS AND DISCUSSION

A total of 80 of 361 surveys was returned, resulting in a 22% response rate. This response rate was expected because not all CCAs and registered crop consultants within the state are involved in rice. Consultants reported scouting 564,000 of the possible 1,400,000 acres of rice grown in Arkansas in 2006. Hence, this survey represents 40% of the total rice acres. Of the scouted acres represented in the survey, consultants reported 200,600 acres (36%) were planted to imazethapyr-resistant rice, with 56% of the growers using this technology on a portion of their rice acreage.

General Weed Management

Eighty-four percent of the consultants recommend a preemergence herbicide while the remaining consultants recommend preemergence herbicides only for certain weed complexes or production situations. Clomazone was the most frequently recommended preemergence herbicide (by 93% of consultants) followed by quinclorac, which was recommended by 40% of the consultants. Pendimethalin and imazethapyr applied prior to crop emergence were recommended by 16 and 12% of the consultants, respectively.

Of the herbicides applied after crop emergence, propanil (55%), quinclorac (47%), imazethapyr (21%), and cyhalofop-butyl (20%) were most often recommended. The sum of percentages exceed 100% because most consultants listed two or three of their most frequently recommended herbicides. Other herbicides commonly recommended after crop emergence by 5 to 10% of the consultants included halosulfuron, clomazone, fenoxaprop, and bispyribac-sodium. Thirty-two percent of consultants indicated that herbicide applications were done three or more times to their scouted rice acres and 65% reported making an average of two applications. The decision to apply an herbicide after crop emergence was based on weed size and density by 86% of the consultants. Only 7% of the consultants reported that they had 'no method' for assessing the need for a herbicide after crop emergence.

Consultants reported that weed control decisions were based on economic thresholds (84%), previous weed problems (83%), university recommendations (59%), general appearance of the field (50%), and recommendations from dealers (12%). Other factors on which weed control decisions were based included grower expectations, anticipated weather, budget constraints, nearby crops, crop stage, weed spectrum, and weed density and size. Although economic thresholds were reported to be utilized by most consultants, it is not likely that a large percentage of consultants are using thresholds since yield loss, as a function of weed density, is not currently easily accessible nor available for all the major weeds in rice.

When asked what is the minimum percentage of weed control that you would consider acceptable, the overwhelming response was 91 to 98% control by 61% of the consultants. Thirty-two percent indicated they were satisfied with 81 to 90%, and 5% thought control should be ≥99%. The remaining 3% of the consultants indicated that 80% or less weed control was acceptable. Sixty-five percent of the consultants believe that farmers' weed control expectations are similar to theirs whereas 27% thought farmer expectations were greater.

When asked to characterize the percentage of scouted fields having weed infestation levels of 'none', 'moderate', 'serious', and 'very serious', 37% of the fields were thought to have 'serious' or 'very serious' infestations on average. Fields were scouted for weeds as few as one time per year to as many as 28 times per growing season. Fields were scouted on average 11 times per growing season. Sixty-three percent of the consultants indicated they scout fields at least 10 times per growing season.

Fifty-nine percent of the consultants recommend certain cultivars based on anticipated weed management needs. Characteristics most often recommended were imidazolinone resistance, early or late maturity, vigorous tillering, and crop height specific for the weed problem. Some consultants said that they recommend taller competitive cultivars while others noted that shorter cultivars allow taller weeds such as cattails or red rice to be easily rope-wicked.

Herbicide Resistance

Consultants were asked to rate their concern with herbicide-resistant weeds. Concerns were 'high' for 56% of the consultants and 'moderate' for 36%. The seriousness of their concern for herbicide-resistant weeds is due partially to the widespread occurrence of barnyardgrass resistance to propanil and quinclorac, two of the most commonly used herbicides in Arkansas rice. Furthermore, consultants (8%) were concerned that barnyardgrass will develop resistance to other herbicides. The occurrence of resistance in barnyardgrass throughout the rice-growing region of Arkansas is evidenced partially by 77% of the consultants indicating that they believe more herbicide is being needed to control weeds today than 5 years ago. Furthermore, 53% of the consultants believe that herbicide use in rice will increase further over the next 5 years as a result of increased herbicide resistance. One consultant commented that over the past 13 years grass weeds had become increasingly difficult to control. Only 12% of the consultants believe that herbicide use will decrease, which is based partially on the perception that glyphosate- and glufosinate-resistant rice will soon become available in the U.S.

The occurrence of herbicide-resistant weeds is an additional management cost to the producers (Llewellyn et al., 2002; Mueller et al., 2005). The perceived average additional expense associated with managing a resistant weed in rice averaged $26.56/acre. Twenty-one percent of the consultants believe that managing a resistant weed will add more than $40/acre to current weed management costs.

Seventy-five percent of the consultants suspect or have confirmed herbicide-resistant weeds in the fields they scout. Fifty-one percent of the consultants believe that propanil-resistant barnyardgrass exists in the fields they scout, comprising 129,400 acres of the total 564,000 scouted acres herein reported (23% of acres). Propanil-resistant barnyardgrass was the first herbicide-resistant weed documented in rice in Arkansas in the early 1990's (Baltazar and Smith, 1994) followed by quinclorac-resistant barnyardgrass in the late 1990's (R.E. Talbert, personal communication). Propanil-resistant barnyardgrass rapidly became a widespread problem in Arkansas rice (Carey, 1994), but even so, propanil continues to be routinely applied as noted earlier due to its broad-spectrum control of many weeds common to rice. Continued use of propanil in rice, despite the widespread occurrence of propanil-resistant barnyardgrass, is made possible by the introduction of alternative grass herbicides in rice (Talbert and Burgos, 2007). Examples of herbicides that could control propanil-resistant barnyardgrass include bispyribac-sodium, clomazone, cyhalofop-butyl, fenoxaprop, pendimethalin, and penoxsulam. For the majority of propanil-resistant populations, a quinclorac plus propanil program is the best option (Talbert and Burgos, 2007). The use of this program, however, is limited by the evolution of quinclorac-resistant barnyardgrass.

Quinclorac-resistant barnyardgrass was reported by 43% of the consultants on 39,000 acres (7% of reported acres). Of those reporting propanil- or quinclorac-resistant barnyardgrass, 53% of the consultants indicated that resistance had been confirmed in at least some of these fields. A couple of consultants suspect barnyardgrass has developed resistance to clomazone, fenoxaprop, cyhalofop-butyl, and bispyribac-sodium; however, University trials have not yet been conducted to confirm these suspicions. Other weeds believed by consultants to be resistant were red rice to imazethapyr (perceived by 24% of the consultants on 3,200 acres or 0.6% of the reported, scouted acres), hemp sesbania to acifluorfen, northern jointvetch to triclopyr, and junglerice to fenoxaprop, cyhalofop-butyl, and propanil.

The consultants were asked to describe what is being done to control resistant weeds. Strategies mentioned routinely for controlling propanil-resistant barnyardgrass were 1) rotation with glyphosate-resistant soybean along with increased frequency of glyphosate use to minimize barnyardgrass-seed production, 2) inclusion of a tank-mix partner with propanil specific for controlling the resistant barnyardgrass, 3) applications of quinclorac and clomazone alone or in combination (alternate modes of action) at planting or after barnyardgrass emergence, and 4) control of escapes following propanil with fenoxaprop, cyhalofop-butyl, or bispyribac-sodium (alternate modes of action). One consultant recommends that glyphosate be applied a few days after crop planting but prior to crop emergence to control emerged propanil-resistant and quinclorac-resistant barnyardgrass. Several consultants recommend producers grow imidazolinone-resistant rice on fields having a history of propanil-resistant and/or quinclorac-resistant barnyardgrass.

Similar to barnyardgrass, one of the leading strategies for controlling imazethapyr-resistant red rice was rotation to glyphosate-resistant soybean. One consultant noted that promotion of "the stewardship program" for imidazolinone-resistant rice was one way to manage resistant red rice. The current stewardship program involves sequential imazethapyr applications followed by imazamox late in the season to blank viable seed production by non-controlled red rice and/or roguing non-controlled plants (Anonymous, 2005). Another consultant recommends to growers that fields containing non-controlled red rice be rope-wicked with paraquat, although this practice is not recommended by university specialists nor is it labeled. We are not aware of any research showing that rope-wicking with paraquat removes red rice successfully. Second, rope-wicking would be laborious and difficult to do properly.

Eighty-two percent of the consultants believe that their recommendations are centered around prevention of herbicide-resistant weeds even though most (73%) of these consultants indicated they recommend the same herbicide(s) in a field when rice is grown for consecutive years. The tendency to recommend the same herbicides each year may be due partially to the limited number of registered herbicides in rice that control a broad spectrum of weeds. One consultant noted that the decision by a producer to grow rice continually or with minimal rotation is driven by higher anticipated economic returns from rice than from rotational crops such as soybean. Recommendations given by consultants for preventing resistance included all of those mentioned previously for managing established resistant weeds. Some consultants suggested additional strategies such as applying the highest allowable rate on the manufacturer's label and emphasizing adequate spray coverage and proper spray volume.

Sanitation is one means of minimizing the likelihood of weed introductions and dispersal of existing weeds throughout a farm, especially herbicide-resistant weeds. Sanitation is either routinely or sometimes recommended by 88% of the consultants. Controlling weeds in ditch banks was the most commonly recommended practice (81% of consultants) followed by removing non-controlled weed patches (75%) and purchasing certified seed (74%). Cleaning harvest equipment and cleaning tillage equipment were recommended by 60 and 36% of the consultants, respectively. Several consultants attributed the spread of red rice to certified seed being contaminated with red rice; however, red rice is a noxious weed in Arkansas, and there is zero tolerance for red rice in certified seed (Anonymous, 2006). There is, however, an uncertain number of growers planting non-certified seed for which contamination with red rice is not regulated. Such cases would be among the factors promoting the spread of red rice.

Problem Weeds

Using a weighted scale based on the written ranking of the three most problematic weeds according to each consultant, barnyardgrass is the most problematic weed of rice followed by red rice (Table 1). Fifty-four percent of the consultants listed barnyardgrass as the most problematic weed in rice while 23% ranked red rice as the most problematic. Northern jointvetch and smartweeds were the most problematic broadleaf weeds. Of the top ten problematic weeds, five were grasses, four were broadleaves, and one was a sedge. Of the remaining eleven weeds listed as problematic, eight were broadleaves and three were grasses. Consultants were also asked to rate the importance of individual species from a list of weeds on a scale of 1 to 5, with 1 being not important and 5 being very important. Similar to the previous ranking, barnyardgrass and red rice were the two most important weeds, and smartweeds and northern jointvetch were the most important broadleaves. Overall, results were similar for both methods of ranking. The few exceptions were due to oversight in including some weeds on the list that were perceived to be important to consultants. Weeds that were added by consultants more than once as 'other' weeds of importance included groundcherries, texasweed, and cattails.

Suggested Research and Educational Priorities

When asked to describe two areas of weed management research or educational priorities that would help improve rice production, the overwhelming response was the need for improvements in broadleaf weed control (56% of respondents). These comments stemmed from the following problems: a) lack of late-season control options for northern jointvetch, b) ineffectiveness of residual herbicides in providing season-long broadleaf weed control, c) broadleaf weed control failure on levees, d) inability to manage broadleaf weeds in no-till fields, particularly smartweeds, and e) absence of an effective postemergence, broadleaf product that can be used in areas where cotton is grown. Smartweeds, groundcherries, and northern jointvetch were the three most routinely mentioned broadleaf weeds. Other problematic broadleaf weeds included gooseweed, hemp sesbania, eclipta, morningglories, pigweeds, sicklepod, purple ammannia, common purslane, texasweed, and spreading dayflower. The reason for such emphasis on broadleaf weed control may be due partially to the extensive use of clomazone, which provides less than acceptable control of many of the aforementioned broadleaf species (Mitchell and Gage, 1999; Webster et al., 1999).

Twenty percent of the consultants thought that improved red rice control or introduction of control options that complement imidazolinone-resistant rice should be a research priority. Most of these individuals noted that imidazolinone-resistant rice is only a short-term solution to a long-term problem. It was apparent to 16% of the respondents that more emphasis should be placed on development and release of glyphosate- and glufosinate-resistant rice cultivars along with cultivars having greater tolerance to imazethapyr.

Continued development of new technologies and effective herbicides for controlling the growing problem of propanil- and quinclorac-resistant barnyardgrass was considered to be of utmost importance to 15% of the respondents. One respondent asked "How long will it be before there is clomazone-resistant barnyardgrass?" Some individuals were concerned with the increasing failure of fenoxaprop and cyhalofop-butyl to control barnyardgrass. One blamed the failures on the diversity of barnyardgrass biotypes within the state, thinking that some may be inherently more tolerant to these herbicides than others. Another individual specifically asked for research to determine if barnyardgrass-control failure with these herbicides is linked to establishment of the permanent flood. Four other individuals also voiced concern with the increased difficulty in controlling barnyardgrass post-flood and the need to develop effective post-flood programs for control of this and other troublesome grasses.

Besides barnyardgrass and red rice, the most frequently mentioned problematic grass or grass-like weeds where currently available herbicides were believed to be non-effective were rice cutgrass, crabgrass, and cattails. Crabgrass was most problematic on levees whereas rice cutgrass and cattails were problems in no-till or reduced tillage fields, particularly for producers that insist on growing rice continuously.

A few respondents (9%) indicated that there is an increased need for residual herbicides, especially since there is a trend toward the use of less water to produce rice. This was further emphasized by those that thought furrow-irrigated rice acres would increase and hence a need to develop effective weed-management strategies specific for this production system. Obviously, not all consultants hold the view that furrow-irrigated rice acres are increasing based on its importance rating of only 2.87 out of 5.0 (Table 2).

Some individuals wanted to see research focused on ways to minimize spray drift and coverage problems. This request stems from the fact that glyphosate drift onto rice from neighboring glyphosate-resistant crops was a frequent occurrence throughout Arkansas in 2006. The consultants gave 'herbicide drift' an importance rating of 4.40 (Table 2), indicating it is of utmost significance. Glyphosate and imazethapyr were the two herbicides of greatest concern for spray drift that injures rice. Published research on the effect of glyphosate and imazethapyr drift on rice is available along with ways to minimize drift (Bond et al., 2006; Fietsam et al., 2004; Koger et al., 2005; Ramsdale and Messersmith, 2001). Additionally, printed and electronic educational material on ways to minimize spray drift are available (Dexter, 1993; Pringnitz, 1999). Therefore, further educational efforts may not be the solution, but rather the enforcement of specific herbicide-application guidelines by state regulatory agencies is needed to ensure adoption by applicators. It is well known that as wind speed increases and application volume is reduced, the likelihood of spray drift increases along with inadequate coverage of the intended target.

Four respondents wrote that there should be an increase in ecological research. Specifically, they were concerned with species shifts and knowing which difficult-to-control species would be most commonly associated with specific rotations, tillage practices, and herbicide programs. Additionally, it was thought that research to determine the importance of preventing weed seed production in rotational crops and its impact on the weed seedbank in rice would be beneficial. Along this same thought was the need to continue research on the relationship between weed density and rice yield loss. This information can be used by consultants to make informed decisions about whether an herbicide application is warranted. One respondent requested information on the minimum red rice density needed to recommend an imidazolinone-resistant cultivar. Unfortunately, this decision is speculative currently.

Other areas brought out by two or more respondents were a) the need for weed management research in water-seeded rice; b) development of a one-pass, season-long effective herbicide program; c) consideration of herbicide costs when developing and recommending weed-control programs; and d) research to minimize antagonism from specific herbicide mixtures such as fenoxaprop plus bispyribac-sodium.

It is believed by at least two consultants that some of the weed management difficulty in rice is due to the current herbicide efficacy ratings available in weed-control guides. These individuals thought that a single efficacy rating results in herbicide applications, without regard to weed sizes and rates, to large weeds that cannot be controlled successfully. There is some information on weed sizes in the current Arkansas weed control guide, with details on application rates, adjuvant needs, and other precautions. However, such information may not be specified for all the herbicides. Thus, in future editions, such information will be made more visible. Additionally, there is information on weed size limitations on each herbicide label. Another respondent suggested that a special section be added to the Arkansas weed control guide to reflect anticipated control of weeds commonly found on levees rather than control ratings for those species typically found in flooded fields. It was noted that the efficacy ratings for weeds growing in flooded fields should differ from those growing on levees.

One individual wanted research in no-till and stale-seeded rice where soil-surface residues were believed to commonly reduce the effectiveness of soil-applied herbicides. Another wanted to know if preemergence herbicide use should be a standard practice in hybrid rice since recommended seeding rates are approximately one-third of that for conventional rice cultivars (Chuck Wilson, personal communication). One consultant commented that imazethapyr applied at recommended rates was not providing residual weed control on heavy clay soils. Thus, refining the dose recommendations of imazethapyr based on soil textures needs further experimentation. Lastly, one respondent noted that current research on outcrossing between rice and red rice needs to be continued.

Other educational suggestions were a monthly newsletter for consultants on suggestions for managing certain difficult-to-control weeds in specific situations and that commercial applicators and the general public as well as producers and consultants become educated concerning the causes of drift and the potential for specific herbicides to drift. This idea seems to have a good fit in the Arkansas Rice Newsletter currently being produced by state specialists. In so doing, the content and utility of the newsletter would be even further improved.

Consultants were also given the opportunity to rate various potential concerns or areas of needed research and education related to weed management in rice (Table 2). ‘Performance of current herbicides’ received the highest average rating of 4.70 out of 5.0 followed by ‘economical weed control’ with a rating of 4.61. Nine of the 12 topics were of importance to most consultants as evidenced by ratings of greater than four. Most consultants (58%) indicated that they were concerned with the carryover potential of imazethapyr.

SIGNIFICANCE OF FINDINGS

This survey was instrumental in ranking the most problematic weeds of Arkansas rice and documenting the most prevalent weed-management issues facing decision makers in rice. Barnyardgrass was found to be the most problematic weed in Arkansas rice because of its common occurrence and widespread resistance to propanil and quinclorac, two of the most frequently used herbicides. Hence, research will continue to evaluate strategies to control barnyardgrass and reduce its occurrence in rice. Based on the survey, most of our current weed-management research and educational endeavors are in-line with the problems most frequently encountered by those making weed management decisions; however, there are some research areas and certain weeds that appear to need increased attention. Future research and educational efforts will continue to address weed-management issues and concerns identified through this survey.

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Table 1. Ranking of the most problematic weeds of rice in Arkansas and the importance of these weeds.

Common name	Points[z]	Problematic rank	Importance[y]	Importance rank
Barnyardgrass	149 a[c]	1	4.80 a[c]	1
Red rice	95 b	2	4.75 a	2
Northern jointvetch	34 c	3	3.91 bc	6
Smartweeds	33 c	4	4.09 b	3
Sprangletops	33 c	4	3.66 cd	7
Broadleaf signalgrass	26 cd	6	3.96 b	5
Yellow nutsedge	15 de	7	4.07 b	4
Groundcherries	14 de	8	-----	--
Hemp sesbania	11 de	9	3.58 d	8
Crabgrass	7 e	10	2.86 fgh	14
Morningglory	6 e	11	3.18 e	9
Pigweed	6 e	11	2.83 fgh	15
Spreading dayflower	5 e	13	2.68 h	17
Texasweed	3 e	14	-----	--
Common cocklebur	3 e	14	-----	--
Eclipta	2 e	16	3.11 ef	10
Fall panicum	2 e	16	2.87 fgh	13
Gooseweed	2 e	16	2.01 i	19
Junglerice	2 e	16	-----	--
Rice cutgrass	1 e	20	2.22 i	18
Prickly sida	1 e	20	-----	--
Indian joinvetch	-----	--	3.03 efg	11
Ducksalad	-----	--	3.01 efg	12
Purple ammannia	-----	--	2.80 hg	16
Curly dock	-----	--	2.01 i	19
Common falsepimpernel	-----	--	1.95 i	21
Redvine	-----	--	1.63 j	22

[z] Points were calculated by assigning values of 3, 2, and 1 to the first, second, and third most problematic weeds, respectively, from each survey and then summing values for each weed to determine its ranking.

[y] Importance was based on the average points assigned each weed by consultants. The rating scale was 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important.

[x] Means within a column followed by the same letter are not significantly different at α = 0.05 according to Fisher's protected LSD test.

Table 2. Ratings of the importance of various research and educational topics to rice consultants.

Potential concerns or areas of needed research and education	Importance[z]
Performance of current herbicides	4.70 a[y]
Economical weed control	4.61 ab
Development of new herbicides	4.51 abc
Control strategies for herbicide-resistant weeds	4.47 abc
Herbicide drift	4.40 bcd
Development of herbicide-resistant rice	4.36 bcd
Strategies to prevent occurrence of herbicide-resistant weeds	4.33 cd
Cultural weed management practices	4.28 cd
Rate of spread of herbicide-resistant weeds	4.20 de
Anticipated shifts in the weed spectrum	3.95 e
Herbicide carryover	3.19 f
Weed control in furrow-irrigated rice	2.87 g

[z] Importance was based on the average points assigned each weed by consultants. The rating scale was 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important.

[y] Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Fisher's protected LSD test.

PEST MANAGEMENT: WEEDS

Environmental Implications of Pesticides in Rice Production

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

ABSTRACT

For the past 7 years we have collected and analyzed water from four sites each on the L'Anguille and St. Francis rivers from near Jonesboro in the north to near Marianna in the south. In 2002 we included four sites on Lagrue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt. In 2003 we included four sites on the Cache River from near the level of Jonesboro in the north to just below I-40 in the south. During this period, the most frequently detected compounds were molinate (Ordram), quinclorac (Facet), and clomazone (Command). Each year, most (71 to 87%) of the detections that were over 2 parts per billion (ppb) were less than 5 ppb, but until the past 4 years there had been between one and three detections of a compound in the 30 to 50 ppb range. In 2003 and 2004 the highest detection was 13 ppb; in 2005 it was 20.9 ppb, and in 2006 it was 18.3 ppb. Through 2002, most of the detections each year came from the L'Anguille River with most of those coming at the two most upstream sites. For the past 4 years most of the detections came from the Cache River. There is no trend for the overall frequency of detections over 2 ppb (9.2 % in 2000, 12.0% in 2001, 5.2% in 2002, 6.2% in 2003, 5.4% in 2004, 2.1% in 2005, and 3.3% in 2006).

INTRODUCTION

Some rice pesticides have been found to persist in surfacewaters in California. This project is to determine if there is a persistence problem with rice pesticides or if they are being found more frequently in Arkansas waters. Monitoring for pesticides in water may allow us to detect a potential problem and address it before it becomes a major problem.

Small rivers in watersheds that are predominantly in the Arkansas rice-growing region 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. Therefore, beginning in the year 2000 we sampled the L'Anguille and St. Francis rivers by collecting water from four different sites on each river from near Jonesboro in the north to near Marianna in the south. In 2002 we added four sites on Lagrue Bayou from just below Peckerwood Lake north of Stuttgart to near the bayou's mouth southeast of DeWitt, and in 2003 we added four sites on the Cache River from the level of Jonesboro in the north to below Interstate 40 in the south.

PROCEDURES

Sampling Sites

Surfacewater samples were collected at eight locations during 2000 and 2001, twelve locations in 2002, and sixteen locations in 2003 through 2006. Four samples were taken from 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. Four samples were taken from 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. In 2002 an additional four samples were taken on Lagrue Bayou at a county road approximately a quarter mile below Peckerwood Lake, the second bridge on State Highway 146 west of the State Highway 33 junction, near the town of Lagrue at State Highway 33 before the junction with State Highway 153, and where the Lagrue crosses State Highway 1 outside of DeWitt. In 2003 we added four sites on the Cache River where it crosses State Highway 91 west of Jonesboro, a dirt road off County Road 37 at Algoa, State Highway 260 near Patterson, and US 70 south of Interstate 40. (Fig. 1).

Sampling Procedure

Water samples were collected and extracted onto C18 Speedisks using a mobile field extractor, which allows extraction of the samples immediately after collecting them while we are driving to the next site. A 500 mL aliquot of each sample was extracted onto C18 disks in the field with the 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 May through August in 2000 through 2003. In 2004 we began collection in mid-April and stopped in mid-August.

Pesticides selected for monitoring in 2006 were Bolero (thiobencarb), Facet (quinclorac), Garlon (triclopyr), Command (clomazone), Pursuit (imazethapyr), Stam (propanil), Clincher (cyhalofop-butyl), Quadris (azoxystrobin), and 2,4-D in addition to triclopyridinol (degradation product of triclopyr) and cyhalofop-acid and diacid (both degradation products of cyhalofop-butyl.

RESULTS AND DISCUSSION

In order to make comparisons from year to year, a cut-off point of 2 ppb was used, although for all compounds we can detect lower levels. Our rationale is that it would not be surprising to find low levels of compounds in runoff water adjacent to fields where the compounds are used, especially with the sensitive analytical equipment that is now available. Trying to find meaningful trends in frequency of detection when evaluating changes in small fractions of a part-per-billion 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 river water samples from small rivers surrounded by rice fields, the 2 ppb concentration level would be reasonable for making comparisons.

All the detections from 2006 are listed in Table 1. Table 2 lists the frequency of detections for each year from 2001 to 2006. There are more possible detections now than originally because Lagrue Bayou was added to the list of rivers to sample in 2002 and the Cache River was added in 2003. Table 3 shows the concentration distribution of pesticides in water by year. The concentration distribution was relatively constant from 2001 to 2002. In 2003 the percentage of samples containing only low levels of pesticides increased, and there were no detections in the three highest ranges (i.e., 20 to 20 ppb, 30 to 40 ppb, and 40 to 50 ppb). Part of this may be due to flooding that occurred in the spring, which may have diluted the samples more than usual. This absence of detections in the higher concentration range (i.e., 40 to 50 ppb) was repeated in 2004 through 2006.

Table 4 shows the detection frequency of pesticides by river and site by year. The L'Anguille, especially the upper portion, is completely surrounded by rice fields, so virtually all the water is coming from areas under rice production. This is also true of the upper Cache. The Cache River, while having 25% of the sampling sites, has had a disproportionately large number of detections (46% in 2003, 43% in 2004, 51% in 2005, and 41% in 2006).

Table 5 shows the number of samples each year that contained more than one compound. In 2001 the percent of pesticide-containing samples that contained more than one pesticide was 49%. This has decreased over time to 32% in 2002, 20% in 2003, 18% in 2004, and 14% in 2005 and 2006. There were several samples that contained more than two compounds but the number was variable over years (none in 2004 to 29% in 2001).

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. Table 6 shows when and where there were consecutive detections of a compound in 2006. Not surprisingly, clomazone, which was detected most often, was also the compound that had the most consecutive detection sampling dates. Also, the L'Anguille and Cache rivers that had the highest numbers of detections had the most detections on consecutive sampling dates.

Molinate (Ordram) was the most frequently detected compound in 2000, being found in 39% of the samples. It is no longer used or detected and has been dropped from the sampling list. From 2001 to 2004 quinclorac (Facet) was the most frequently detected compound being found in 36% of the samples containing a pesticide in 2001, 28% in 2002, 37% in 2003, and 48% in 2004. In 2005 clomazone (Command) was the most frequently detected (81%), and in 2006 it was again the most frequently detected with 42%. In 2006 quinclorac made up 29% of the detections.

SIGNIFICANCE OF FINDINGS

It is not surprising to find some pesticides in surfacewater in an agricultural area during the growing season. Most of the detections have been low-level and sporadic. Exceptions for being sporadic would be for clomazone (Command) in the first part of the sampling season and for quinclorac (Facet) in the middle part of the season (Tables 1 and 6). These compounds were detected frequently but usually at low levels. In 2000 the most frequently detected compound was molinate; it was the third most frequently detected compound in 2001 and 2002 and tied for third in 2003. In 2004 there was only one detection above 2 ppb (2.3 ppb). Also, in 2000 the 10 highest concentrations found were for molinate. In 2001 only two of the ten highest concentrations were for molinate, and there were five compounds represented in the ten highest concentrations. In 2002 there were three compounds represented in the ten highest concentrations (molinate with three, clomazone with 3, and quinclorac with 4). From 2001 to 2006 most of the detections (71% to 87%) have been in the lowest concentration range (2 to 5 ppb). The percentage of samples containing more than one compound has steadily decreased from 49% in 2001 to 14% in 2006 (Table 5).

EPA does not have guidelines on acceptable levels for most of these compounds in either the National Recommended Water Quality Criteria - Corrected (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 7.7 ppb in 2004.

The California Department of Pesticide Regulation has a performance goal of 10 ppb for molinate (Anon., 2002). The performance goal is a guide that is not enforceable, but is a level at which there can be toxic effects in some test species. In a personal call to the project leader in California, she likened it to a canary in a mine situation – a reason to be watchful. Our results for molinate in the past were similar to those reported by the California Department of Pesticide Regulation (DPR) in their Rice Pesticides Program Monitoring Data August 20, 2002-Final Update (Anon., 2002).

Since there are no specific guidelines for tolerances for most of these compounds, and since we are not aware of any environmental problems that are occurring in these rivers, we have no reason to say there is a problem.

ACKNOWLEDGMENTS

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Table 1. Results for the year 2006 water samples that contain at least one detection of a pesticide at a limit of quantitation of 2 ppb.

			Compounds and amounts detected^y					
Date	River	Site^z	Clom	Quin	Imaz	Propanil	Azoxy	Thio
			(ppb)					
5/2	L'Anguille	A	14.3	5.2				
5/2	St. Francis	E	4.1					
5/2	St. Francis	F	2.1					
5/2	St. Francis	H	2.1					
5/2	Cache	T	3.0					
5/3	L'Anguille	B	6.1					
5/3	L'Anguille	C	3.3			2.2		
5/3	Cache	Q	6.1					
5/3	Cache	R	16.6					
5/3	Cache	S	18.3					
5/17	Cache	Q	2.4					
5/17	Cache	S	2.4					
5/30	L'Anguille	A	17.3			3.8		
5/30	L'Anguille	C	2.5					
5/30	Lagrue	M		2.1				
5/30	Cache	T	3.4					
5/31	Cache	Q	3.1					
5/31	Cache	R	3.8					
5/31	Cache	S	3.2					
6/13	L'Anguille	A	4.1					
6/13	L'Anguille	B	2.4					
6/13	L'Anguille	C	2.3	2.2		2.3		

continued

Table 1. Continued

			Compounds and amounts detected[y]					
Date	River	Site[z]	Clom	Quin	Imaz	Propanil	Azoxy	Thio
			------------------	--------------	------ (ppb) ------	--------------	--------------	------------------
6/13	Cache	Q	5.7	3.8				
6/13	Cache	R	2.5					
6/13	Cache	S	3.6					
6/27	L'Anguille	A				4.4		2.5
6/27	L'Anguille	B		4.4		2.4		
6/27	L'Anguille	C		2.2				
6/27	Cache	R			2.1			
6/27	Cache	S	2.3					
7/10	L'Anguille	A		4.9				
7/10	L'Anguille	C		5.2				
7/10	Cache	Q		5.5				
7/10	Cache	S		3.6				
7/11	Cache	T		3.0				
7/11	St. Francis	H		2.3				
7/11	Lagrue	N		3.6				
7/26	L'Anguille	A		4.9				
7/26	L'Anguille	C					2.8	
7/26	Cache	Q		5.7				
7/26	Cache	R		2.6				
8/1	Lagrue	N					3.7	
8/2	L'Anguille	A		4.6				
8/2	L'Anguille	C					2.1	
8/2	L'Anguille	D					2.7	
8/2	L'Anguille	E					2.6	
8/2	St. Francis	L					2.0	
8/2	St. Francis	M					2.4	
8/2	Cache	Q					3.8	
8/2	Cache	R					3.2	
8/2	Cache	S					4.1	
TOTAL			25.0	17.0	1.0	5.0	10.0	1.0

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

[y] clom = clomazone; quin = quinclorac; imaz = imazethapyr; azoxy = azoxystrobin; and thio = thiobencarb.

Table 2. Frequency of detections over 2 ppb of pesticides in river water by year.

Year	2001	2002	2003	2004	2005	2006
Number of rivers	2	3	4	4	4	4
Possible detections	565	958	1280	1440	1792	1792
Detections	68	49	79	77	37	59
Percent	12.0	5.1	6.2	5.4	2.1	3.3

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

Concentration range	Amount of detections[z] 2001	2002	2003	2004	2005	2006
	(ppb)					
2-5	48 (71%)	38 (78%)	69 (87%)	63 (82%)	24 (65%)	48 (81%)
5-10	13 (19%)	8 (16%)	9 (11%)	13 (17%)	8 (22%)	7 (12%)
10-20	4 (6%)	1 (2%)	1 (1%)	1 (1%)	5 (14%)	4 (7%)
20-30	2 (3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
30-40	0 (0%)	2 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
40-50	1 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

[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.

Site	Detection frequency 2001	2002	2003	2004
L'Anguille				
A[z]	8	9	4	10
B	6	5	2	4
C	3	9	4	10
D	4	2	2	1
Total	21	25	12	25
St. Francis				
E	0	0	0	2
F	2	3	0	1
G	3	3	2	0
H	4	3	1	2
Total	9	9	3	5
Lagrue				
K	5	2	0	0
L	2	3	1	1
M	4	1	2	2
N	2	4	0	2
Total	13	10	3	5
Cache				
Q	16	11	9	8
R	8	7	4	6
S	6	7	3	7
T	6	8	3	3
Total	36	33	19	24

[z] A-D = L'Anguille upstream to downstream; D-H = St. Francis upstream to downstream; K-M = 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	Amount of detections[z] 2001	2002	2003	2004	2005	2006
	---------- (ppb) ----------					
1	18 (51%)[z]	23 (68%)	49 (80%)	63 (82%)	32 (86%)	44 (86%)
2	7 (20%)	9 (26%)	9 (15%)	14 (18%)	4 (11%)	6 (12%)
3	6 (17%)	1 (3%)	1 (2%)	0	1 (3%)	1 (2%)
4	2 (6%)	0	1 (2%)	0	0	0
5	2 (6%)	1 (3%)	1 (2%)	0	0	0

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

Table 6. Consecutive detections of a given pesticide by river in 2006.

Date	Clomazone					Quinclorac			Azoxystrobin
5/3			Q[z]		S				
5/17			Q		S				
5/31	A	C	Q	R	S				
6/13	A	C	Q	R	S		C		
6/27					S		C		
7/10						A	C	Q	
7/26						A		Q	C
8/02						A			C

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

Fig. 1. Sampling sites for the 2006 water-monitoring program.

Rice Cultivar Response to Low Glyphosate Rates as Influenced by Growth Stage

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

ABSTRACT

Glyphosate drift onto rice has become a major concern for rice producers. Each year extension specialists in Arkansas respond to numerous calls concerning drift injury to non-target crops, especially glyphosate drift onto rice. A study was conducted in 2006 to examine the response of ten rice cultivars to reduced rates of glyphosate at the 3- to 4-leaf (3-4LF), panicle initiation (PI), and boot (BT) growth stages. The cultivars 'Drew', 'Lagrue', 'Cocodrie', 'CL161', 'CLXL8', 'Wells', 'Bengal', 'Katy', 'Banks', and 'Francis' were drill-seeded at 90 lb/acre in a Sharkey clay soil and grown under typical dry-seed, delayed-flood culture. Glyphosate (Roundup WeatherMax®) was applied at 0 (untreated check), 1.1 (1/20X), and 2.2 (1/10X) oz/acre. Plant height, delayed heading, flag leaf length, and yield were evaluated. Applications made at the 3-4LF timing did not affect heading, plant height, flag leaf length, or grain yield at harvest. Heading was delayed longer in all cultivars from 2.2 oz/acre at both the PI and BT applications. It is interesting that plant height and flag leaf length were affected more from applications made at PI although the greatest yield reductions were from applications made at BT. It is evident that a reduction in plant height and flag leaf length is possible from glyphosate drift; however, these reductions are not good indicators of yield loss.

INTRODUCTION

In 2006, more than 90% of the Arkansas cotton and soybean crops and more than 50% of the corn crop was planted in glyphosate-resistant (Roundup Ready®) cultivars (K.L. Smith, personal communication). It is not uncommon for rice, corn, soybean, and cotton to be grown in adjacent fields (Ellis et al., 2003), which has led to problems associated with herbicide drift. Drift rates usually range between 1/100 and 1/10 of the recommended use rates (Al-Khatib et al., 2003; Al-Khatib and Peterson, 1999). Nozzle size and type, operating pressure, wind velocity, boom height, and environmental conditions can contribute to off-target movement of pesticides. Improvements have been made to spray nozzles to enhance drift reduction; however, pesticide drift still occurs. Each year extension specialists in Arkansas respond to numerous calls concerning herbicide drift, especially glyphosate drift onto rice (K.L. Smith and R.C. Scott, personal communication, 2005). With the introduction of Roundup Ready Flex® cotton into the market for 2006, concerns of off-target movement onto other crops, especially rice, are increasing.

Kurtz et al. (2003) reported that a glyphosate rate of 0.25 lb ai/acre (1/4X) applied to rice at the mid-tiller, PI, and BT growth stages reduced rice yield, but reported no differences in response to glyphosate among cultivars. However, the rate of 0.25 lb ai/acre is higher than rates normally associated with drift. Koger et al. (2004) reported that plant height and yield of Cocodrie and 'Priscilla' cultivars was different at comparable rates when applied at PI; however, these differences were attributed to differences in the physiological maturity of the plants at the time of application. The researchers also stated that cultivar sensitivity or environmental conditions at the time of glyphosate application may have affected rice response. Smith et al. (2003) reported a cultivar response in the form of chlorosis from glyphosate applications made at the 3-4LF, 1 week post-flood, and pre-BT growth stages. No yield reductions were observed from the 3-4LF and 1 week post-flood applications; however, yield of all cultivars (Drew, Lagrue, Cocodrie, CL161, XL8, Wells, Bengal, Katy, Ahrent, and Francis) was reduced with 2.2 oz/acre of glyphosate at the pre-BT growth stage (Smith et al., 2003).

This cultivar variability warrants the need for further investigation of tolerance to low glyphosate rates similar to those associated with herbicide drift. The objective of this research was to examine rice cultivar response to low glyphosate rates at different growth stages. Plant height, delayed heading, flag leaf length, and yield were examined at glyphosate rates of 0, 1.1, and 2.2 oz/acre to determine differences among ten selected cultivars similar to those examined by Smith et al. (2003), except for XL8 and Ahrent, which were replaced with CLXL8 and Banks.

PROCEDURES

This experiment was conducted in 2006 at the Southeast Research and Extension Center (SEREC) in Rohwer, Ark., on a Sharkey clay soil in a split-split-block design with application timing as the main-block, glyphosate rate as the sub-block, and cultivar as the sub-sub-block. Drew, Lagrue, Cocodrie, CL161, CLXL8, Wells, Bengal, Katy, Banks, and Francis cultivars were drill-seeded in nine rows spaced six inches apart at 90 lb/acre. Plots were 4.5-ft wide and 25-ft long with 5-ft alleys. All plots were managed for weed, insect, and disease control and fertilized according to University of Arkansas Cooperative Extension Service recommendations. Glyphosate (Roundup WeatherMax®) was applied at 0, 1.1, and 2.2 oz/acre, which represents 0, 1/20, and

1/10 of a normal use rate (22 oz/acre). Applications were made using a CO_2 pressurized backpack sprayer equipped with 110015 green leaf nozzles calibrated to deliver 12 GPA at 32 psi when the respective untreated checks of each cultivar reached the 3-4LF, PI, and BT stages of growth. Plant height (in.) and flag leaf length (in.) were recorded from four plants at random locations in each plot prior to harvest. Heading delay was evaluated as percentage headed by date and was recorded twice weekly when heading began and continued until harvest. The entire plot was harvested for grain yield with a small-plot combine and reported on a 12% moisture basis. Plant height, flag leaf length, and rice yield were subjected to ANOVA, and means were separated using Duncan's New MRT (P=0.05).

RESULTS AND DISCUSSION

Applications made at the 3-4LF timing did not affect heading, plant height, flag leaf length, or grain yield at harvest (data not shown). Heading was delayed longer from 2.2 oz/acre than with 1.1 oz/acre in all cultivars from the PI and BT applications. The longest heading delay was observed in Bengal, which was delayed 21 days and 42 days with 1.1 oz/acre and 2.2 oz/acre, respectively (data not shown). Plant height at harvest was reduced in all cultivars from both rates of glyphosate applied at the PI stage of growth, with the exception of Wells, Banks, and Francis following the 1.1 oz/acre rate (Table 1). Plant height was reduced with 2.2 oz/acre applications made at the BT timing in all cultivars with the exception of Cocodrie, CL161, and Bengal, which are all shorter cultivars, and Wells and Lagrue were the only cultivars that sustained a reduction in plant height from 1.1 oz/acre following the BT applications (Table 2). Flag leaf length was only reduced from applications made at the PI timing (Tables 3 & 4). It is interesting that the flag leaf length of only five of the ten cultivars was reduced, and the flag leaf length of these five (Drew, Cocodrie, CL161, CLXL8, and Bengal) cultivars was reduced by both rates of glyphosate (Table 3). Even though applications made to rice at the PI timing resulted in greater reductions in plant height and flag leaf length, rough rice grain yield was affected most from applications made at the BT timing. Yield reductions from 2.2 oz/acre applied at PI were only significant in Drew, CLXL8, Wells, and Bengal (Table 5), whereas grain yield of all cultivars was reduced by 2.2 oz/acre from the BT application (Table 6). The 1.1 oz/acre rate only reduced the yield of CLXL8 and Bengal when applied at PI (Table 5), and of Drew, Cocodrie, and Banks when applied at BT (Table 6).

SIGNIFICANCE OF FINDINGS

Reductions in plant height and flag leaf length are common symptoms produced by glyphosate drift; however, these reductions are not good indicators of grain yield loss. It is evident from this research that a difference does exist in rice cultivar response to low rates of glyphosate; however, it is not understood why rice cultivars respond differently. More insight into the shikimic pathway of these cultivars may explain how some cultivars can overcome injury better than others. At this time there are no methods to accurately determine yield loss from glyphosate drift; however, there are methods to determine if glyphosate drift has occurred, even at reduced rates and several days after the drift incident has occurred (Singh and Shaner, 1998; Koger et al., 2005). Until RoundupReady® rice is accepted and can be grown commercially, applicators must be more conscious of pesticide drift and the potential effects on non-target crops.

ACKNOWLEDGMENTS

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Table 1. Plant height at harvest from glyphosate applied at panicle initiation growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(in.)									
0 oz/acre	47 a^z	45 a	37 a	39 a	44 a	43 a	40 a	47 a	44 a	40 a
1.1 oz/acre	43 b	41 b	33 b	35 b	41 b	41 a	35 b	43 b	42 a	39 a
2.2 oz/acre	38 c	38 c	31 b	33 b	34 c	38 b	35 b	39 c	39 b	34 b

^{z} Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Table 2. Plant height at harvest from glyphosate applied at boot growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(in.)									
0 oz/acre	47 a^z	42 a	35 a	36 a	42 a	59 a	37 a	44 a	43 a	39 a
1.1 oz/acre	46 b	39 b	32 a	35 a	42 a	40 b	39 a	44 a	41 ab	38 a
2.2 oz/acre	39 b	39 b	31 a	34 a	39 b	38 c	35 a	39 b	39 b	35 b

^{z} Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Table 3. Flag leaf length from glyphosate applied at panicle initiation growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(in.)									
0 oz/acre	14 a^z	10 a	10 a	12 a	15 a	13 a	15 a	13 a	11 a	10 a
1.1 oz/acre	10 b	9 a	7 b	10 b	11 b	12 a	10 b	12 a	10 a	9 a
2.2 oz/acre	9 c	9 a	6 c	9 c	9 b	12 a	11 b	11 a	10 a	8 a

^{z} Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Table 4. Flag leaf length from glyphosate applied at boot growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(in.)									
0 oz/acre	11 a[z]	10 a	9 a	11 a	11 a	10 a	11 a	11 a	10 a	9 a
1.1 oz/acre	11 a	10 a	8 a	11 a	12 a	11 a	11 a	12 a	10 a	9 a
2.2 oz/acre	11 a	10 a	8 a	10 a	12 a	11 a	12 a	11 a	9 a	8 a

[z] Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Table 5. Rough rice yield from glyphosate applied at panicle initiation growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(bu/acre)									
0 oz/acre	118 a[z]	141 a	126 a	102 a	128 a	150 a	109 a	94 a	128 a	132 a
1.1 oz/acre	101 a	133 a	106 a	101 a	103 b	138 a	79 b	86 a	140 a	133 a
2.2 oz/acre	61 b	115 a	101 a	74 a	85 c	111 b	62 b	56 a	118 a	110 a

[z] Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Table 6. Rough rice yield from glyphosate applied at boot growth stage, Rohwer, Ark., 2006.

Glyphosate	Cultivar									
rate	Drew	Lagrue	Cocodrie	CL161	CLXL8	Wells	Bengal	Katy	Banks	Francis
	(bu/acre)									
0 oz/acre	105 a[z]	121 a	111 a	82 a	110 a	118 a	107 a	81 a	128 a	117 a
1.1 oz/acre	60 b	103 a	43 b	58 a	97 a	93 a	84 a	71 a	101 b	106 a
2.2 oz/acre	0 c	13 b	0 c	0 b	20 b	12 b	5 b	7 b	13 c	24 b

[z] Numbers within a column followed by the same letter do not differ significantly (P = 0.05).

Urea Ammonium Nitrate Effects on Bispyribac and Penoxsulam Efficacy

B.A. Pearson, R.C. Scott, K.L. Smith, and T.W. Dillon

ABSTRACT

Greenhouse studies were conducted in 2006 to evaluate the effects of urea ammonium nitrate (UAN) solution on bispyribac and penoxsulam efficacy on barnyardgrass and hemp sesbania. Bispyribac and penoxsulam treatments containing an adjuvant and UAN significantly reduced barnyardgrass biomass over most treatments without UAN. Urea ammonium nitrate did not increase hemp sesbania biomass reduction, as treatments containing bispyribac or penoxsulam and an adjuvant effectively reduced biomass. These results suggest that UAN may be used to increase bispyribac and penoxsulam barnyardgrass control in general and when applications are made to fields under less than optimal conditions.

INTRODUCTION

Bispyribac (Regiment®) and penoxsulam (Grasp®) are selective, contact rice herbicides for postemergence control of grasses, sedges, and broadleaf weeds, including barnyardgrass (*Echinochloa crus-galli*) and hemp sesbania (*Sesbania exaltata*). Both herbicides control weeds by inhibiting the acetolactate synthase (ALS) enzyme, which blocks branched-chain-amino acid biosynthesis (Carey et al., 2000; Vencill, 2002; Dow AgroSciences, 2005).

In research trials, barnyardgrass control with bispyribac has been excellent (98 to 100%) (Williams, 1999). However, inconsistent control has been observed in commercial rice fields. Applications made in less than optimal conditions, such as the use of low application volumes or application to drought-stressed or large plants, may increase the occurrence of inconsistent control (Scott and Carey, personal communication).

Urea ammonium nitrate is a liquid fertilizer that can also be used as an herbicide additive to further increase efficacy (Monaco et al., 2002). The mode of action for UAN is not known, but increased herbicide absorption into plants has been reported, possibly due to breakdown of the cuticle (Thompson et al., 1996). Dodds et al. (2006) found that bispyribac absorption into barnyardgrass increased up to 54% with the addition of UAN. The study was conducted using C^{14} techniques and evaluated herbicide absorption only. No published data are available on the effects of UAN on bispyribac or penoxsulam efficacy. By increasing herbicide absorption into the plant, the addition of UAN may overcome or decrease inconsistent weed control observed with Regiment.

The objective of this study was to evaluate the effects of UAN on bispyribac and penoxsulam efficacy on barnyardgrass and hemp sesbania.

PROCEDURES

Studies were conducted at the Lonoke Extension and Applied Research Center greenhouse in Lonoke, Ark., in 2006. Barnyardgrass and hemp sesbania seeds were planted separately in 1-qt Styrofoam cups. Barnyardgrass was thinned to two plants per cup, and hemp sesbania was thinned to one plant per cup.

The experimental design was completely randomized with five replications and the test was repeated twice. Treatment factors were herbicide rate and adjuvant. Herbicides were bispyribac at 0.32 and 0.63 oz/acre and penoxsulam at 1.4 and 2.8 oz/acre and the rates represent 0.5 and 1 times the labeled field rates, respectively. Adjuvant treatments were no adjuvant, Kinetic at 0.125% v/v, DyneAmic at 5 oz/A, 28% UAN at 2% v/v, Kinetic plus UAN at 0.125% plus 2% v/v, DyneAmic plus UAN at 5 oz/acre plus 2% v/v, or Dyne-A-Pak at 2% v/v (Table 1). Dyne-A-Pak is an adjuvant/UAN premix. In addition to these adjuvants, penoxsulam was also applied with crop oil concentrate (COC) at 1 qt/acre and COC plus UAN at 1 qt/acre plus 2% v/v. An untreated check was included. Herbicide application timings were 3- to 4-lf barnyardgrass, 1- to 3-tiller barnyardgrass, and 5- to 6-in. hemp sesbania. Treatments were applied at 20 GPA with a CO_2-pressurized backpack sprayer.

Barnyardgrass plants were cut at soil level and weighed 28 days after treatment (DAT), and hemp sesbania plants were cut at soil level and weighed 21 DAT. Percentage reduction in fresh weight of each plant was determined by comparing fresh weights to the untreated check. Data were analyzed using Analysis of Variance (ANOVA), with means separated by Fisher's Least Significant Difference (LSD) test (α=0.05).

RESULTS AND DISCUSSION

A significant interaction between herbicide rate and adjuvant, averaged across runs, was obtained for 3- to 4-lf barnyardgrass biomass reduction with bispyribac and penoxsulam. All bispyribac treatments containing both an adjuvant and UAN reduced biomass 95 to 99% (Table 1). The 1X rate plus Kinetic reduced biomass 89%, which was not significantly different from treatments containing an adjuvant and UAN. The 0.5X rate plus Kinetic resulted in 21% biomass reduction and reduced biomass 98% when UAN was added. This 0.5X rate simulates herbicide applications made under less than optimal conditions, resulting in a lower herbicide rate and indicates that UAN may be able to overcome bispyribac inconsistency due to some application errors. Treatments containing bispyribac plus UAN, with no other adjuvant, reduced biomass 3 to 18%, suggesting that UAN cannot be substituted for an adjuvant and must be used in conjunction with an adjuvant.

Penoxsulam treatments containing both an adjuvant and UAN reduced 3- to 4-lf barnyardgrass biomass 88 to 98% (Table 1), with the exception of the 0.5X rate plus DyneAmic and UAN, which reduced biomass 74%. These treatments had significantly higher biomass reduction than all other treatments. Treatments containing penoxsulam plus UAN with no other adjuvant reduced biomass 24 to 58%.

No herbicide rate by adjuvant interaction was found for 1- to 3-tiller barnyardgrass biomass reduction with bispyribac. Adjuvant was the only significant main effect, therefore, biomass reduction data were averaged across runs and bispyribac rates. Adjuvant combinations containing both an adjuvant and UAN had significantly higher biomass reduction than all other treatments, indicating that regardless of bispyribac rate, the addition of UAN increased biomass reduction of 1- to 3-tiller barnyardgrass (Table 2). DyneAmic plus UAN reduced biomass 92% and Kinetic plus UAN reduced biomass 91%. Dyne-A-Pak, a UAN premix, reduced biomass 88%. Biomass reduction was 19% when bispyribac was applied with UAN only.

An interaction between herbicide rate and adjuvant, averaged across runs, was found for 1- to 3-tiller barnyardgrass biomass reduction using penoxsulam. Penoxsulam applied at the 1X rate plus an adjuvant and UAN reduced biomass 75 to 89%, yet when applied with an adjuvant only, reduced biomass 25 to 46%. Treatments containing penoxsulam plus UAN, with no other adjuvant, had 16 to 47% biomass reduction.

An interaction between herbicide rate and adjuvant, averaged across runs, was found for hemp sesbania biomass reduction with bispyribac and penoxsulam. Biomass reduction of hemp sesbania using bispyribac was 92 to 97% and was not significantly different for any treatments containing an adjuvant (Table 4). The 0.5X bispyribac rate plus UAN with no other adjuvant, resulted in 27% biomass reduction and the 1X rate plus UAN reduced biomass 52%.

Biomass reduction of hemp sesbania using penoxsulam was not significantly different for any treatments containing an adjuvant, regardless of the addition of UAN (Table 4). Biomass reduction with these treatments ranged from 91 to 97%. The 0.5X penoxsulam rate plus UAN with no other adjuvant reduced biomass 49%, and the 1X rate plus UAN reduced biomass 59%. These data indicate that bispyribac and penoxsulam are effective in controlling hemp sesbania as long as an adjuvant is used. UAN does not significantly increase bispyribac or penoxsulam efficacy on hemp sesbania.

SIGNIFICANCE OF FINDINGS

The addition of UAN to herbicide-adjuvant tankmixes increases bispyribac and penoxsulam control of smaller (3- to 4-lf) and larger (1- to 3-tiller) barnyardgrass. Although 3- to 4-lf biomass reduction with the 1X bispyribac rate plus Kinetic was not significantly different from treatments containing an adjuvant and UAN, the 0.5X rate simulating low herbicide-application rates showed increased biomass reduction with the addition of UAN. The effectiveness of bispyribac and penoxsulam treatments applied with an adjuvant and UAN on 1- to 3-tiller barnyardgrass suggests that the addition of UAN may overcome some inconsistency of applications made to larger weeds. Urea ammonium nitrate solution cannot be substituted for an adjuvant and must be used in conjunction with an adjuvant for increased control of barnyardgrass using penoxsulam or bispyribac.

Hemp sesbania biomass reduction with either herbicide was not increased with the addition of UAN. Treatments containing either herbicide plus an adjuvant effectively controlled hemp sesbania, regardless of the addition of UAN.

These data indicate that UAN may be used to increase the consistency of bispyribac and penoxsulam on barnyardgrass in general and when applications are made in fields under less than optimal conditions. This includes application errors resulting in use of a lower herbicide rate and applications made to larger weeds.

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Table 1. Biomass reduction of 3- to 4-lf barnyardgrass with bispyribac and penoxsulam.

Adjuvant combination	Bispyribac		Penoxsulam	
	Rate	Biomass reduction[z]	Rate	Biomass reduction[z]
	(oz/acre)	(%)	(oz/acre)	(%)
None	0.32	3	1.4	39
Kinetic 0.125% v/v +	0.32	21	1.4	58
COC[y] 1 qt/acre		-		30
DyneAmic 5 oz/acre	0.32	85	1.4	31
UAN[x] 2% v/v		5		24
Kinetic 0.125% +	0.32	98	1.4	30
UAN 2% v/v				
COC 1 qt/acre +	0.32	--	1.4	
UAN 2% v/v				88
DyneAmic 5 oz/acre +	0.32	99	1.4	
UAN 2% v/v				74
Dyne-A-Pak 2% v/v	0.32	95	1.4	94
None	0.64	17	2.8	49
Kinetic 0.125% v/v +	0.64	89	2.8	65
COC 1 qt/acre		-		75
DyneAmic 5 oz/acre	0.64	84	2.8	67
UAN 2% v/v		18	2.8	58
Kinetic 0.125% +	0.64	98	2.8	64
UAN 2% v/v				
COC 1 qt/acre +	0.64	--	2.8	
UAN 2% v/v				95
DyneAmic 5 oz/acre +	0.64	98	2.8	98
UAN 2% v/v				
Dyne-A-Pak 2% v/v	0.64	99	2.8	96
LSD (0.05)		11		15

[z] Biomass data are averaged across greenhouse runs.

[y] COC = crop oil concentrate.

[x] UAN = urea ammonium nitrate solution.

Table 2. Biomass reduction of 1- to 3-tiller barnyardgrass with bispyribac.

Adjuvant combination	Biomass reduction[z]
	(%)
None	45
Kinetic 0.125% v/v	33
COC[y] 1 qt/acre	46
DyneAmic 5 oz/acre	53
UAN[x] 2% v/v	16
Kinetic 0.125% + UAN 2% v/v	54
COC 1 qt/acre + UAN 2% v/v	65
DyneAmic 5 oz/acre + UAN 2% v/v	56
Dyne-A-Pak 2% v/v	65
LSD (0.05)	16

[z] Biomass data are averaged across greenhouse runs and bispyribac rates.

[y] COC = crop oil concentrate.

[x] UAN = urea ammonium nitrate solution.

Table 3. Biomass reduction of 1- to 3-tiller barnyardgrass with penoxsulam.

	Penoxsulam	
Adjuvant combination	Rate	Biomass reduction[z]
	(oz/acre)	(%)
None	1.4	45
Kinetic 0.125% v/v	1.4	33
COC[y] 1 qt/acre		46
DyneAmic 5 oz/acre	1.4	53
UAN[x] 2% v/v		16
Kinetic 0.125% + UAN 2% v/v	1.4	54
COC 1 qt/acre + UAN 2% v/v	1.4	65
DyneAmic 5 oz/acre + UAN 2% v/v	1.4	56
Dyne-A-Pak 2% v/v	1.4	65
None	2.8	45
Kinetic 0.125% v/v	2.8	46
COC 1 qt/acre		25
DyneAmic 5 oz/acre	2.8	41
UAN 2% v/v		16
Kinetic 0.125% + UAN 2% v/v	2.8	54
COC 1 qt/acre + UAN 2% v/v	2.8	65
DyneAmic 5 oz/acre + UAN 2% v/v	2.8	56
Dyne-A-Pak 2% v/v	2.8	65
LSD (0.05)		16

[z] Biomass data are averaged across greenhouse runs.

[y] COC = crop oil concentrate.

[x] UAN = urea ammonium nitrate solution.

Table 4. Biomass reduction of 12.5- to 15-cm hemp sesbania with bispyribac and penoxsulam.

	Bispyribac		Penoxsulam	
Adjuvant combination	Rate	Biomass reduction[z]	Rate	Biomass reduction[z]
	(oz/acre)	(%)	(oz/acre)	(%)
None	0.32	29	1.4	41
Kinetic 0.125% v/v	0.32	92	1.4	96
COC[y] 1 qt/acre	0.32	--	1.4	96
DyneAmic 5 oz/acre	0.32	94	1.4	91
UAN[x] 2% v/v	0.32	27	1.4	49
Kinetic 0.125% + UAN 2% v/v	0.32	95	1.4	97
COC 1 qt/acre + UAN 2% v/v	0.32	--	1.4	96
DyneAmic 5 oz/acre + UAN 2% v/v	0.32	96	1.4	95
Dyne-A-Pak 2% v/v	0.32	97	1.4	97
None	0.64	46	2.8	58
Kinetic 0.125% v/v	0.64	96	2.8	97
COC 1 qt/acre	0.64	--	2.8	97
DyneAmic 5 oz/acre	0.64	96	2.8	96
UAN 2% v/v	0.64	52	2.8	59
Kinetic 0.125% + UAN 2% v/v	0.64	96	2.8	97
COC 1 qt/acre + UAN 2% v/v	0.64	--	2.8	96
DyneAmic 5 oz/acre + UAN 2% v/v	0.64	96	2.8	96
Dyne-A-Pak 2% v/v	0.64	97	2.8	95
LSD (0.05)		14		8

[z] Biomass data are averaged across greenhouse runs.

[y] COC = crop oil concentrate.

[x] UAN = urea ammonium nitrate solution.

PEST MANAGEMENT: WEEDS

Nitrogen Stress Response in Red Rice and Wells Rice Grown in Hydroponics

M.A. Sales, N.R. Burgos, and V.K. Shivrain

ABSTRACT

Red rice *(Oryza sativa* L.*)* is a prevalent weed in rice production, competing with cultivated rice for nutrients and other resources. We hypothesize that red rice has a more efficient nitrogen (N) assimilation due to adaptive molecular mechanisms that are absent in rice. Our greenhouse experiments comparing the growth and physiological responses between red rice and 'Wells' rice, one of the commonly grown rice cultivars, at N stress demonstrated these differences in N assimilation. The experimental design was a split plot: main plot was a randomized complete block with rice type (Wells cultivar and Stuttgart strawhull red rice) as factor; split plot factor was the N treatment [T_1 (Full N); T_2 (N starvation); T_3 (early N supplementation after N starvation); and T_4 (late N supplementation)]. Plants were hydroponically grown in Yoshida solution until panicle initiation (PI) when the N stress treatments were implemented. Nitrogen stress was defined as an N-sufficiency index (NSI) <95% calculated from chlorophyll meter readings. Starvation and supplementation were the removal and addition, respectively, of NH_4NO_3 in the nutrient solution. Growth responses including plant height, tiller number, biomass, root length, and number of root tips were determined from days of emergence to PI. Shoot tissue concentrations of N, other essential elements, and total sugars were analyzed to determine physiological response. Data were subjected to ANOVA in SAS and means were separated by Fisher's protected LSD (α=0.05). Red rice had significantly higher growth measurements: 90 cm tall, 10-m roots, 59 x 10^3 root tips, 7 tillers, and 5-g biomass. Red rice sucrose was highest (23.0 mg/g; LSD=4.09) when N was at its lowest (2.78%; LSD=0.27). Wells rice did not show significant differences in sucrose at all treatments (9.61 to 11.63 mg/g). Plant tissues were collected for genomic analysis to explain the physiological differences between these two rice types.

INTRODUCTION

Nitrogen is the most growth-limiting nutrient in rice production systems. Its availability for use by the cultivated rice is further limited by competition from red rice, a weedy rice relative, which has been reported to be more efficient in accumulating fertilizer N and translating it into biomass production (Burgos et al., 2006). It is hypothesized that red rice will have more efficient N assimilation owing to adaptive molecular mechanisms that are absent in rice. Comparing the growth and physiological responses of the weedy and cultivated rice types under N stress conditions is the first step toward elucidating the processes underlying N acquisition and assimilation at the molecular level. Thus, the objectives of this study were to: 1) compare the growth responses of red rice and Wells rice under optimal N conditions; and 2) determine the physiological responses of these two rice types under N stress.

PROCEDURES

Growth Responses Under Greenhouse Conditions

Uniformly germinated seeds of Stuttgart strawhull red rice (Acc. Stf-3) (Shivrain, 2004) and Wells rice (Moldenhaeur et al., 1999), were planted in black plastic trays fitted into 35-L plastic tubs (36 cm x 62 cm x 31 cm) containing aerated, half-strength Yoshida nutrient solution made up with deionized water (Yoshida et al., 1976), pH 5.0; pH was adjusted every other day for the first week, then daily. Each rice type was grown in four trays, and each tray contained four rows with three plants per row. The plants were grown until panicle initiation (PI) under greenhouse conditions (temperature range of 24 to 27°C and a day/night length of 14/10 h) in August to September 2006. Nutrient solution strength was doubled after 2 weeks. Water evaporating from the tubs was replaced with deionized water daily and the nutrient solution was replaced weekly. The growth-staging system developed by Counce et al. (2000) was used in recording the days to PI. Other data collected to determine growth responses were height and tiller number, which were recorded weekly. Biomass, root length, and number of root tips were determined at harvest.

Physiological Responses at N Stress

To simulate N stress, defined as an N-sufficiency index (NSI) < 95%, the plants were exposed to four treatments: T_1 (Full N, Control); T_2 (N starvation until N stress); T_3 (N supplementation for 24 h after N stress); and T_4 (N supplementation for 48 h after N stress). The NSI was calculated from chlorophyll meter readings using the following formula (Peterson et al., 1996):

$$\text{NSI} = \frac{\text{Average reading of plants in N-stress tub}}{\text{Average reading of control plants } (T_1)} \times 100 \qquad (1)$$

At PI, the control plants (T_1) were transferred into tubs with fresh nutrient solution. The other plants ($T_{2\text{-}4}$) were grown until NSI <95% in fresh nutrient solution prepared without ammonium nitrate (NH_4NO_3). At NSI <95%, T_2 plants were harvested. The T_3 and T_4 plants were placed in fresh nutrient solution containing NH_4NO_3 for 24 h and 48 h, respectively, and harvested. The youngest fully expanded leaves were collected for subsequent analysis of nutrient uptake and total sugars.

Data Collection

To determine biomass production, whole plants were collected, washed with deionized water, and separated into shoots and roots. Shoots were immediately oven-dried to a constant weight at 60°C. Roots were blotted dry with a paper towel, stained with methylene blue in 10% ethanol, and stored at 4°C until scanned for length, surface, area, average diameter, and number of root tips using the WinRHIZO 5.0 image analysis software. After root analysis, roots were oven-dried to constant weight at 60°C.

To determine nutrient concentration, the youngest, fully expanded leaves were cut from the whole plant, oven-dried to constant weight at 60°C, ground in a rice mill, and analyzed for total N by the combustion method and for the 22 other essential elements by inductively coupled plasma-emission spectrophotometry.

To determine sugar concentration, the youngest, fully expanded leaves were cut from the whole plant, wrapped in aluminum foil, and frozen in liquid N until freeze-dried to constant weight in a lyophilizer at -70°C. Freeze-dried samples were ground in a rice mill and extracted for total sugars using ion-exchange columns. The sugar extracts were analyzed for fructose, glucose, and sucrose by high-performance liquid chromatography.

Statistical Analysis

The experimental design was a split plot. The main plot was a randomized complete block with rice type as the factor; the split plot factor was the N treatment. Data were subjected to analysis of variance in SAS Proc GLM. Significant means were separated by Fisher's protected LSD at a significance level of 0.05.

RESULTS AND DISCUSSION

There was strong evidence of rice-type effect on all growth responses, with red rice having higher values in all growth measurements. Although the two rice types reached PI within 2 days of each other, red rice was 90 cm tall, had 10-cm long roots, 59 x 10^3 root tips, 7 tillers, and 5-g biomass (Table 1). Sucrose and N concentrations in the shoots were significantly affected by rice type and N treatment interaction, with red rice showing an increased level of sucrose (23.0 mg/g; LSD=4.09) at N stress condition when N was at its lowest concentration (2.78%; LSD = 0.27) (Fig. 1). Sucrose in red rice was lowest at T_1 (11.13 mg/g), when N concentration was highest (4.17%). On the other hand, Wells rice did not respond to the N treatments as much as the red rice, showing no differences in sucrose concentrations at all treatments (9.61 to 11.63 mg/g).

Like red rice, the lowest sucrose concentration in Wells was at T_1, when N concentration was highest (3.16%).

SIGNIFICANCE OF FINDINGS

Our findings corroborate the only report on red rice having higher nitrogen use efficiency (NUE) than cultivated rice (Burgos et al., 2006), and support our hypothesis that a higher NUE is due to more efficient N assimilation, as deduced from increased sucrose concentrations in red rice even when N supply is low. Earlier studies have attributed the accumulation of leaf carbohydrates in response to low-N stress as a result of C partitioning between carbohydrates and amino acids (Rufty et al., 1988). Since regulation of multiple enzyme activities involving changes in gene expression is apparently involved in C-partitioning (Foyer et al., 1988), we further hypothesize that gene expression of these enzymes differ in red rice and rice. Thus, a genomic analysis of the genes responding to N stress conditions will be conducted to identify the genes that are repressed or upregulated at varying levels of N.

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Table 1. Growth characteristics of red rice and Wells rice under optimal nitrogen conditions in hydroponics culture (n = 48).

Rice type	Days from emergence to panicle initiation	Height	No. of tillers	Biomass	Root length	No. of root tips
		(cm)		(g)	(cm)	(x 10^3)
Red rice	29	90.1 a^z	7 a	4.97 a	10.59 a	59.40 a
Wells rice	31	68.0 b	3 b	2.11 b	4.02 b	21.06 b

^{z} Means within a column followed by different letters are significantly different at the P=0.05 level of significance.

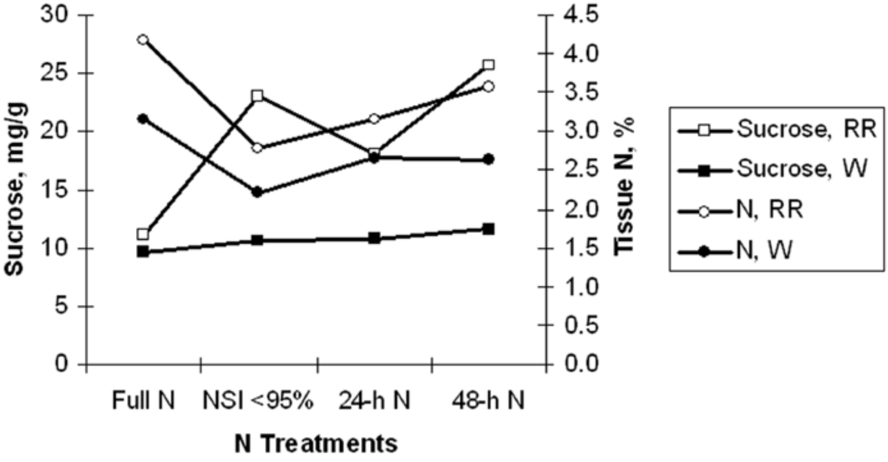

Fig. 1. Effect of nitrogen (N) concentration in nutrient solution on sucrose content of red rice (RR) and Wells rice (W). Nitrogen LSDs (P=0.05): 0.28 (within rice type); 0.37 (between rice types). Sucrose LSDs (P=0.05): 4.09 (within rice type); 5.05 (between rice types).

PEST MANAGEMENT: WEEDS

Greenhouse Evaluation of Herbicide Options for Cattail Control in Rice

R.C. Scott, J.W. Dickson, and J.K. Norsworthy

ABSTRACT

Little data exist on cattail control in rice, yet cattail has become a significant pest in rice with reduced tillage and water-seeded cultivation practices. Two studies were conducted in the greenhouse to evaluate cattail control with herbicides commonly available to rice producers. SuperWham (propanil), Duet (propanil + bensulfuron), Facet (quinclorac), Grasp (penoxsulam), Storm (acifluorfen + bentazon), Arrosolo (propanil + ordram), and Aim (carfentrazone) controlled cattails less than 70% when applied alone. Also, regrowth occurred 2 to 3 weeks after harvest with these treatments. Both Clearfield herbicides [Beyond (imazamox) and Newpath (imazethapyr)] reduced biomass 81% and 71%, respectively, with little regrowth observed. When evaluated over two runs in the greenhouse, glyphosate at 4 qt/acre reduced biomass of cattail by 81% with little regrowth. The most effective in-season option was a tank mix of Aim (3.2 oz/acre) + Permit (halosulfuron) (2.6 oz/acre); however, it simply "burned down" the cattails which later re-grew. The results of these studies indicate that the best herbicide options for cattail control are a high rate (4 qt/acre) of glyphosate applied preplant or post harvest, either Clearfield herbicide (imazamox or imazethapyr), or a tank-mix of carfentrazone (3.2 oz/acre) + halosulfuron (2.6 oz/acre).

INTRODUCTION

Common cattail (*Typha latifolia*) can be considered a significant weed pest in rice production. In 1999, cattail was considered the most troublesome weed in Arkansas' aquatic environments (Dowler,1999). Its presence in rice is almost always associated with reduced tillage production systems, which is similar to other aquatic environments. Moreover, it is primarily a problem in reduced tillage, zero-grade water-seeded production systems in Arkansas, which account for only approximately 6% of the rice produced in Arkansas (Wilson and Branson, 2005).

Cattails can be controlled in non-cropland areas using high rates of glyphosate, imazapyr, diquat, and 2,4-D, but Arkansas producers report that commonly used rice herbicides do not control cattails (Brunson, 2004; Scott et al., 2006). This can result in significant yield reductions and problems with combine harvest efficiency.

Because of the type of production system involved and difficulties in finding consistent populations in field and fallow locations, research on cattails can be problematic and little data exist on most rice herbicides. Also, rates used on highway right-of-ways and other non-cropland areas are often higher than those in production agriculture. Therefore, data from those trials are not always applicable for making preplant, in-season, or fall (post-harvest) cattail control recommendations in rice production. With this in mind, a greenhouse study was conducted to provide some baseline information on cattail control with herbicides commonly available to rice producers.

PROCEDURES

Cattail plants were obtained from a local source, divided, and transplanted into 0.5-gal pots in the greenhouse. The plants were allowed to grow and become well established for 3 months prior to herbicide application. Top growth was removed and regrowth occurred at least 3 times per pot during establishment.

At application, pots contained 1 to 3 shoots and were 30 in. tall. At 27 days after treatment (DAT), pots were harvested and fresh weights were obtained. Yield was converted to percent of check for analysis (P=0.05). Pots were maintained and watered for an additional 30 days to determine if the cattails were going to regrow or not. Treatments are listed in Table 1.

RESULTS AND DISCUSSION

Treatments in Table 2 represent a preliminary screening of numerous burndown, in-season, and post-harvest treatment options for rice. Select treatments from run 1 were repeated. Based on the results of the first run, some rates were increased. These included: Ignite (glufosinate), halosulfuron, carfentrazone, Regiment (bispyribac), and IR5878 (orthosulframuron)(Table 3).

As reported from the field, most in-season options for rice failed to control cattails. Propanil, propanil + bensulfuron, quinclorac, penoxsulam, acifluorfen + bentazon, propanil + ordram, and carfentrazone controlled cattails less than 70% when applied alone (Table 2). Also, re-growth occurred 2 to 3 weeks after harvest with all these treatments.

Due to high variation between replications and treatments, an LSD of 30 was generated at P=0.05 level of confidence, so treatment separations were difficult. However, both Clearfield herbicides (imazamox and imazethapyr) reduced biomass 81% and

71%, respectively, with little regrowth observed (Table 2). When averaged over two runs, Imazamox controlled cattail 59% with no regrowth (Table 3). From these data, we feel that Clearfield rice is one possible system for control of cattails in a growing rice crop. These results need to be verified in the field.

Non-selective herbicides can be used preplant and post-harvest for cattail control in rice. Due to the perennial nature of cattails and their massive root reserves, multiple applications and/or high rates are recommended in non-cropland areas (Brunson, 2004; Scott et al., 2006). When evaluated over two greenhouse runs (Table 3), glyphosate at 4 qt/acre reduced biomass of cattail by 81%, with little regrowth reported.

When the glyphosate rate was reduced to 3 qt/acre, control dropped to 57% with glyphosate alone. The addition of 2,4-D at 2 qt/acre to glyphosate controlled cattail 66%. Gramoxone Inteon (paraquat) at 3 pt/acre controlled cattail 77% with little regrowth. Glufosinate was the least effective non-selective herbicide evaluated.

The most effective in-season options were a tank mix of carfentrazone (3.2 oz/acre) + halosulfuron (2.6 oz/acre); however, it simply “burned down” the cattails which later regrew (Table 3). Similar results were observed for several treatments in the first run (Table 2).

SIGNIFICANCE OF FINDINGS

When farm-management practices switch to reduced tillage and water-seeded rice-cultivation practices, weed population shifts are expected. These weed population shifts may cause producers to change production practices. This will likely be required for successful cattail control in rice. Cattails do not usually present a problem in conventional tillage systems, and suggestions to producers may be to alternate cultivation practices if feasible. Another suggestion may be to grow Clearfield varieties to take advantage of the cattail control obtained by imazethapyr and imazamox herbicides. Glyphosate at a high rate (4 qt/acre) at preplant or post-harvest is also an effective cattail control option. As new herbicides become available, more cattail control options may be discovered.

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Table 1. Herbicide treatment list for run 1 and 2 of the study.

Run 1		Run 2	
Herbicide	Rate	Herbicide	Rate
Paraquat +	3 pt/acre	Paraquat +	3 pt/acre
COC[z]	1% v/v	COC	1% v/v
Glyphosate 4 +	2 qt/acre	Glyphosate 4 +	3 qt/acre
COC	1% v/v	COC	1% v/v
Glyphosate 4 +	4 qt/acre	Glyphosate 4 +	4 qt/acre
COC	1% v/v	COC	1% v/v
Glyphosate 4v	2 qt/acre	Glyphosate 4	2 qt/acre
2,4-D amine +	2 qt/acre	2,4-D amine +	2 qt/acre
COC	1% v/v	COC	1% v/v
Glufosinate +	0.5 lb/acre	Glufosinate +	1 lb/acre
COC	1% v/v	COC	1% v/v
Propani +	4 qt/acre	Imazamox +	5 oz/acre
Propanil + bensulfuron	4 qt/acre	COC	1% v/v
Quinclorac +	0.66 lb/acre	Halosulfuron	2.6 oz/acre
COC	1% v/v	Carfentrazone +	3.2 oz/acre
Penoxsulam +	2 oz/acre	COC	1% v/v
COC	1% v/v	Carfentrazone +	2.6 oz/acre
Imazamox +	5 oz/acre	COC	1% v/v
COC	1% v/v	Penoxsulam	2 oz/acre
Imazethapyr +	8 oz/acre	Bispyribac	0.63 oz/acre
COC	1% v/v	Orthosulfamuron +	0.025 lb/acre
Bispyribac +	0.4 oz/acre	Class Act	32 oz/acre
Class Act	32 oz/acre		
Orthosulfamuron +	0.01 lb/acre		
COC	1% v/v		
Halosulfuron +	1.3 oz/acre		
COC	1% v/v		
Trifloxysulfuron +	0.4 lb/acre		
COC	1% v/v		
Halosulfuron	1.3 oz/acre		
Carfentrazone +	1.6 oz/acre		
COC	1% v/v		
Carfentrazone +	1.5 pt/acre		
COC	1% v/v		
Acifluorfen + bentazon +	1.5 pt/acre		
COC	1% v/v		
Fenoxaprop +	16 oz/acre		
COC	1% v/v		
Prosulfuron +	1 oz/acre		
COC	1% v/v		
Penoxsulam	2 oz/acre		
Bispyribac	0.4 oz/acre		
Orthosulfamuron +	0.01 lb/acre		
Class Act	32 oz/acre		
Propanil + ordram	4 qt/acre		
Propanil	4 qt/acre		
Quinclorac +	0.66 lb/acre		
COC	1% v/v		
Triclopyr	1.3 pt/acre		
Propanil +	4 qt/acre		
COC	1% v/v		

[z] COC = crop oil concentrate.

Table 2. Reduction in biomass (control) and potential regrowth of cattail for all herbicides in first run of study.

Herbicide	% Control	Regrowth^z
Check	0	1
Paraquat 3 pt/acre	83	2
Glyphosate 2 qt/acre	82	2
Glyphosate 4 qt/acre	97	2
Glyphosate 2qt + 2,4-D amine 2 qt/acre	92	2
Glufosinate 0.5 lb/acre	50	1
Propanil 4 qt/acre	53	1
Propanil + bensulfuron 4 qt/acre	56	1
Quinclorac 0.66 lb/acre	33	1
Penoxsulam 2 oz/acre	65	1
Imazamox oz/acre	81	2
Imazethapyr 8 oz/acre	71	2
Bixpyribac 0.4 oz/acre + Class Act 32 oz/acre	58	1
Orthosulfamuron 0.01 oz/acre	56	1
Halosulfuron 1.3 oz/acre	59	1
Trifloxysulfuron 0.4 lb/acre	41	1
Halosulfuron 1.3 oz/acre + carfentrazone 1.6 oz/acre	72	1
Carfentrazone 1.3 oz/acre	69	1
Acifluorfen + bentazone 1.5 pt/acre	27	1
Fenoxaprop 16 oz/acre	67	1
Prosulfuron 1 oz/acre	60	1
Penoxsulam 2 oz/acre + bispyribac 0.4 oz/acre + orthosulfamuron 0.01 lb/acre + Class Act 32 oz/acre	78	1
Propanil + ordram 4 qt	62	1.2
Propanil 4 qt/acre + quinclorac 0.66 lb/acre	75	1
Triclopyr 1.3 pt/acre + propanil 4 qt/acre	48	1.3
LSD (0.05)	30.5	0.3

[z] 1 = regrowth, 2 = no regrowth observed 30 days after harvest.

Table 3. Reduction in biomass (control) and potential regrowth of cattail for selected treatments (Run 2).

Herbicide	% Control	Regrowth after 30 days[z]
Check	0	1.0
Paraquat (3 pt/acrere) + COC[y] 1% V/V	77	1.9
Glyphosate (4 qt/acre) + COC 1% V/V	81	1.9
Glyphosate (3 qt/acre) + COC 1% V/V	57	1.8
Glyphosate (2 qt/acre) + 2,4-D Amine (2 qt/acre) + COC 1% V/V	66	1.5
Glufosinate (1 lb/acre) + COC 1% V/V	37	1.2
Imazamox (5 oz/acre) + COC 1% V/V	59	2.0
Halosulfuron 2.6 (oz/acre) + carfentrazone (3.2 oz/acre) + COC 1% V/V	47	1.0

[z] 1=Yes, 2=No for regrowth observed 30 days after harvest.

[y] COC = crop oil concentrate.

PEST MANAGEMENT: WEEDS

Broadleaf Weed Control with Strada

R.C. Scott, B.A. Pearson, K.L. Smith, and N.D. Pearrow

ABSTRACT

Studies were conducted in 2006 to evaluate Strada efficacy on broadleaf weeds in rice. Applied early postemergence following Command (clomazone), no difference was found between hemp sesbania and northern jointvetch control with Strada (orthsulfamuron) or Permit (halosulfuron). When applied at 1-lf rice following clomazone, halosulfuron was more effective for rice flatsedge control, but no difference in halosulfuron and orthosulfamuron was found when applied at 3-lf rice. When tankmixed with Newpath (imazethapyr) at 1-lf rice, halosulfuron controlled hemp sesbania and northern jointvetch more effectively than orthosulfamuron. Orthosulfamuron provided good control of hemp sesbania and northern jointvetch when tankmixed with imazethapyr at 3-lf rice. In general, orthosulfamuron performed better at the 3-lf rice stage than the 1-lf rice timing. Applications made mid-postemergence with orthosulfamuron applied alone, or tankmixed with SuperWham (propanil), Facet (quinclorad), Grandstand (triclopyr), or Aim (carfentrazone), provided excellent control of hemp sesbania and northern jointvetch.

INTRODUCTION

Orthosulfamuron is a new sulfonylurea herbicide being developed by Isagro USA. Orthosulfamuron is a postemergence herbicide for broadleaf, sedge, and aquatic weed control in rice. Evaluation of weed control with orthosulfamuron began in 2003, and orthosulfamuron was originally developed as a barnyardgrass (*Echinochloa crus-galli*)-control product. However, the weed-control focus with orthosulfamuron has shifted away from barnyardgrass to broadleaf and sedge control. Full registration of orthosulfamuron is expected in 2007 (AgriMarketing, 2007; Dickson et al., 2007, MidSouth Farmer, 2007).

The objective of these studies was to evaluate broadleaf weed-control using orthosulfamuron in conventional and Clearfield weed control programs.

PROCEDURES

Studies were conducted in 2006 to evaluate orthosulfamuron efficacy on broadleaf weeds in rice. These studies were conducted on the University of Arkansas at Pine Bluff farm near Lonoke, Ark. Two studies were conducted, one evaluating orthosulfamuron applied early postemergence (EPOST) at 1- or 3-lf rice, and one evaluating orthosulfamuron applied mid-postemergence (MPOST) at 3- to 4-tiller rice.

Experimental design was a randomized complete block with four replications. In the EPOST study, 'CL 131' was drill-seeded at 90 lb/acre. In the MPOST study, 'CL XL8' was drill-seeded at 37 lb/acre. Standard irrigation practices for drill-seeded, delayed-flood rice in Arkansas were followed. Treatments were applied with a MudMaster (Bowman Manufacturing Company, Newport, Ark.) at 10 gpa.

The EPOST treatments consisted of orthosulfamuron (0.0656 lb ai/acre) and halosulfuron (0.047 lb ai/acre) applied at either 1- or 3-lf rice. All treatments were either made following a preemergence (PRE) application of clomazone (0.03 lb ai/acre) or tankmixed with imazethapyr (0.094 lb ai/acre). Mid-postemergence treatments consisted of orthosulfamuron (0.0656 lb ai/acre) applied alone, and tankmixed with propanil (3 or 4 lb ai/acre), quinclorac (0.5 lb ai/acre), triclopyr (0.25 lb ai/acre), and carfentrazone (0.0156 lb ai/acre). All MPOST treatments were made following clomazone (0.03 lb ai/acre) PRE.

Visual ratings for weed control in the EPOST study were taken 41 and 85 days after flood (DAF). Visual weed ratings in the MPOST study were taken 2, 41, and 85 DAF. Only ratings taken 2 and 41 days after flood will be reported. Visual ratings were based on a scale of 0 to 100%, with 0% equal to no weed control and 100% equal to complete weed death. All treated plots were rated as compared to untreated check plots.

RESULTS AND DISCUSSION

Hemp sesbania (*Sesbania exaltata*), northern jointvetch (*Aeschynomene virginica*), and rice flatsedge (*Cyperus iria*) control was evaluated in the EPOST study (Table 1). Orthosulfamuron applied at 1-lf rice following clomazone controlled hemp sesbania 69% and northern jointvetch 64%, while halosulfuron controlled hemp sesbania 73% and northern jointvetch 61%. Orthosulfamuron and halosulfuron provided 46% and 100% rice flatsedge control, respectively, with halosulfuron having significantly higher control.

When applied at 3-lf rice, orthosulfamuron provided 95% and 90% control of hemp sesbania and northern jointvetch, respectively (Table 1). Halosulfuron provided 100% and 88% control of hemp sesbania and northern jointvetch, which was not significantly different from orthosulfamuron . When applied at 3-lf rice, rice flatsedge control with orthosulfamuron (78%) and halosulfuron (100%) was not significantly different.

When applied at 1-lf rice in a tankmix with imazethapyr, orthosulfamuron controlled hemp sesbania 58% and northern jointvetch 8% (Table 2). Halosulfuron had significantly higher control of both weeds, with 84% control of hemp sesbania and 63% control of northern jointvetch. Both herbicides provided 100% rice flatsedge control. Halosulfuraon was not applied with imazethapyr at 3-lf rice. Orthosulfamuron applied with imazethapyr at 3-lf rice controlled hemp sesbania 99%, northern jointvetch 94%, and rice flatsedge 100%.

Hemp sesbania, northern jointvetch, and annual sedge (*Cyperus compressus*) control was evaluated in the MPOST study (Tables 3 and 4). Annual sedge data were taken at 2 DAF, and northern jointvetch data was taken at 41 DAF. At 2 DAF, hemp sesbania control was most effective when orthosulfamuron was tankmixed with propanil at 3 or 4 lb ai/acre (95% and 91%, respectively) or carfentrazone (93%) (Table 3). When orthosulfamuron was tankmixed with quinclorac, hemp sesbania control was 84% and 79% control was provided when orthosulfamuron was tankmixed with triclopyr. When applied alone, orthosulfamuron controlled hemp sesbania 61%. Annual sedge control was most effective when orthosulfamuron was tankmixed with propanil at 3 or 4 lb ai/acre, with 90% and 94% control, respectively. Annual sedge control was 66% when orthosulfamuron was tankmixed with carfentrazone or quinclorac. Orthosulfamuron applied alone provided 48% control of annual sedge and tankmixed with triclopyr provided 35% control.

At 41 DAF, hemp sesbania control was 100% with all treatments, except when orthosulfamuron was tankmixed with propanil at 4 lb ai/acre, which provided 95% control (Table 4). Northern jointvetch control was not significantly different for any treatments. All treatments provided 100% control of northern jointvetch, with the exception of orthosulfamuron tankmixed with propanil at 4 lb ai/acre, which provided 94% control.

SIGNIFICANCE OF FINDINGS

Data from these research trials suggest that orthosulfamuron could be used in place of halosulfuron in conventional rice production systems. If rice flatsedge is present, orthosulfamuron must be applied at 3-lf rice, although control of rice flatsedge may be slightly less effective than with halosulfuron. Orthosulfamuron could also be used effectively in Clearfield rice production systems if applied no earlier than on 3-lf rice. If imazethapyr applications must be made to smaller rice, tankmixing with halosulfuron would be more effective for control of hemp sesbania and northern jointvetch. For MPOST applications, orthosulfamuron could be tankmixed with commonly used rice herbicides in a conventional weed-control program for effective control of hemp sesbania, annual sedge, and northern jointvetch. In general, orthosulfamuron performed better at the 3-lf rice stage than at the 1-lf rice timing.

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Table 1. Hemp sesbania, northern jointvetch, and rice flatsedge control with orthosulfamuron (0.0656 lb ai/acre) and halosulfuron (0.047 lb ai/acre) applied at 1- and 3-lf rice following clomazone PRE (0.3 lb ai/acre).

		Control[y]		
Herbicide[z]	Application timing	Hemp sesbania	Northern jointvetch	Rice flatsedge
		----------	(%)	----------
Orthosulfamuron				
	1-lf rice	69	64	46
	3-lf rice	95	90	78
Halosulfuron	1-lf rice	73	61	100
	3-lf rice	100	88	100
LSD (0.05)		15	28	30

[z] All treatments were applied with 0.25% v/v NIS.

[y] Weed control ratings taken 41 days after flood.

Table 2. Hemp sesbania, northern jointvetch, and rice flatsedge control with orthosulfamuron (0.0656 lb ai/acre) and halosulfuron (.047 lb ai/acre) applied at 1- and 3-lf rice and tankmixed with imazethapyr (0.094 lb ai/acre).

		Control[y]		
Herbicide[z]	Application timing	Hemp sesbania	Northern jointvetch	Rice flatsedge
		------------------------------ (%) ------------------------------		
Orthosulfamuron				
	1-lf rice	58	8	100
	3-lf rice	99	94	100
Halosulfuraon	1-lf rice	84	63	100
LSD (0.05)		15	28	30

[z] All treatments were applied with 0.25% v/v NIS.

[y] Weed control ratings taken 41 days after flood.

Table 3. Hemp sesbania and annual sedge control with orthosulfamuron applied at 3- to 4-tiller rice following clomazone PRE (0.03 lb ai/acre).

		Control[z]	
Herbicide	Rate	Hemp sesbania	Annual sedge
	(lb ai/acre)	---------------------(%)-------------------	
Clomazone	0.03	0	0
Orthosulfamuron[y]	0.0656	61	48
Orthosulfamuron + propanil[x]	0.0656 3	95	90
Orthosulfamuron + propanil[x]	0.0656 4	91	94
Orthosulfamuron + quinclorac[x]	0.0656 0.5	84	66
Orthosulfamuron + triclopyr[x]	0.0656 0.25	79	35
Orthosulfamuron + Carfentrazone[y]	0.0656 0.0156	93	66
LSD (0.05)		9	16

[z] Weed control ratings taken 2 days after flood.

[y] Applied with 0.25% v/v NIS.

[x] Applied with 1% v/v COC.

Table 4. Hemp sesbania and annual sedge control with orthosulfamuron applied at 3- to 4-tiller rice following clomazone PRE (0.03 lb ai/acre).

Herbicide	Rate	Control[z] Hemp sesbania	Control[z] Annual sedge
	(lb ai/acre)	---------------------(%)	-------------------
Clomazone	0.03	0	0
Clomazone	0.03	0	0
Orthosulfamuron[y]	0.0656	100	100
Orthosulfamuron + propanil[x]	0.0656 3	100	100
Orthosulfamuron + propanil[x]	0.0656 4	95	94
Orthosulfamuron + quincloral[x]	0.0656 0.5	100	100
Orthosulfamuron + triclopyr[x]	0.0656 0.25	100	100
Orthosulfamuron + carfentrazone[y]	0.0656 0.0156	100	100
LSD (0.05)		4	6

[z] Weed control ratings taken 41 days after flood.

[y] Applied with 0.25% v/v NIS.

[x] Applied with 1% v/v COC.

PEST MANAGEMENT: WEEDS

Outcrossing Frequency and Phenotypes of Outcrosses Based on Flowering of Red Rice Accessions and Clearfield™ Cultivars in the Grand Prairie

V.K. Shivrain, N.R. Burgos, J.A. Bullington, D.R. Gealy, and H.L. Black

ABSTRACT

Outcrossing between Clearfield (CL) cultivars and red rice (RR) has been documented in experimental plots as well as in fields. The authors hypothesize that CL cultivars, red rice type, planting time, and flowering time of CL and RR influence the transfer of imazethapyr-resistance genes from CL rice to RR. Our objectives were to 1) evaluate the flowering behavior of RR accessions and CL rice cultivars with respect to planting dates, 2) determine outcrossing rates between CL cultivars and RR accessions, and 3) determine the phenotypes of outcrosses.

The experiments were conducted at the Rice Research and Extension Center (RREC), Stuttgart, and Southeast Research and Extension Center (SEREC), Rohwer, Ark., in the summers of 2005 and 2006. The experimental design was a split-split plot with three replications. Planting time (4), CL cultivar (2), and RR accessions (12) were main-, sub-, and sub-sub-plot, respectively. Each RR accession was planted in the middle of 9-row, 10-ft long plots with four rows of CL rice on both sides. Red rice seeds were collected in 2005 from individual plots for outcrossing rate determination. Seeds collected in 2005 were planted in the summer of 2006. Red rice seedlings at the 2-lf stage were sprayed with imazethapyr. Survivors of imazethapyr applications were characterized morphologically at maturity. Leaf tissues were also collected from survivors for confirmatory test of outcrossing by DNA analysis.

Earlier-planted RR accessions and CL rice took longer to flower than later-planted ones. Flowering period of RR accessions ranged from 83 to 114, 83 to 110, 70 to 100, and 70 to 94 days after planting (DAP), in the first, second, third, and fourth plant-

ings, respectively. On average, ‘CL XL-8’ flowered 3 to 5 days earlier than ‘CL 161’, although flowering was completed within a week in all plantings in both cultivars. CL XL-8 had a higher outcrossing rate in all planting dates compared with CL 161. Outcrosses between CL 161 and red rice accessions were phenotypically uniform. In contrast, outcrosses between CL XL-8 and red rice accessions segregated in terms of flowering time, height, and various other plant characteristics.

INTRODUCTION

Red rice control in the drill-seeded delayed-flood cultural system using traditional rice herbicides is challenging due to the genetic similarity between cultivated rice and RR. Selective control of RR can be achieved in a CL rice production system. However, the transfer of the acetolactate synthase (ALS)-resistant gene from CL rice to RR is a valid concern. Imazethapyr-resistant RR plants were found in farmers’ fields in Arkansas and Louisiana within 2 years of the introduction of CL rice (Scott and Burgos, 2004; Zhang et al., 2004).

Synchronization in the flowering time of red rice and rice is an important factor in gene transfer (Gealy et al., 2003). Red rice accessions in Arkansas have been documented as highly diverse in terms of morphology, especially in their flowering time (Shivrain, 2004). Outcrossing rate varies within CL cultivars, planting date, and synchrony in flowering time (Shivrain et al., 2007). Disparity in CL cultivars, planting time, and flowering time of RR accessions have significant impacts on gene transfer. As more CL cultivars and hybrids are released, gene transfer will become more complex due to the diversity in RR populations. Understanding the flowering pattern of different types of RR and CL cultivars will help us develop better strategies in mitigating outcrossing and managing RR.

PROCEDURES

Experiments were conducted at the Rice Research and Extension Center (RREC) at Stuttgart, and the Southeast Research and Extension Center (SEREC), Rohwer, Ark., in the summers of 2005 and 2006, respectively. The soil at the RREC experimental site is a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) with 1.2% organic matter and a pH of 5.8; the soil at the SEREC experimental site was a Sharkey clay with <1% organic matter and a pH of 7.2. In 2005, the experimental design was split-split plot with three replications. Planting time, CL cultivar, and RR accessions were main-, sub-, and sub-sub-plot, respectively. Planting dates were selected to cover early to late rice-planting time in Arkansas. There were four plantings: 16 April (PD 1), 27 April (PD 2), 13 May (PD 3), and 26 May (PD 4). Two CL cultivars, CL 161 and hybrid CL XL-8, were planted at 90 and 30 lb/acre, respectively, with 12 RR accessions representing RR from four rice-growing zones in Arkansas: White River, Grand Prairie, Delta 1, and Delta 2 (the Delta region is divided into two due to differences in flowering time of RR accessions from these regions) in Arkansas. The accessions represent an assortment of characteristics: strawhull, blackhull, and brownhull color; short and tall; awned and awnless; and early and late to flower. Each RR accession was planted in the middle of 9-row, 10-ft long plots with four rows of rice on both sides. Both CL cultivars were planted at a distance of 30-ft to prevent pollen movement from one cultivar to the other. Propanil and Facet were applied at 3 qt. and 0.35 lb/acre, respectively, at 5 weeks after planting to control other weeds. Volunteer RR plants were rouged by hand. Standard agronomic and pest-management practices were implemented during the growing season. Data on flowering were collected three times a week. When flowering of red rice was over, panicles were enclosed in Delnet bags to collect seeds. At maturity, RR seeds collected in the Delnet bags and those remaining on the panicles were harvested, cleaned, and stored until screened for imazethapyr-resistant outcrosses.

In 2006, a sub-sample of approximately 3,000 seeds from each plot was planted at SEREC. Red rice seedlings were treated with three applications of Newpath® at 8 oz/acre starting at 2-lf stage. Leaf tissues were collected from survivors for DNA analysis; SSR primers RM 253 and 234 were used to confirm the outcrosses. Outcrossing rate was calculated based on the number of confirmed hybrids. Outcrosses were grown until the end of the season and characterized morphologically.

RESULTS AND DISCUSSION

Results on four RR accessions (2 strawhull, 1 blackhull, 1 brownhull) that originated from the White River Zone are presented in this report. CL rice and RR accessions planted earlier took relatively more days to flower than those planted later. Flowering period of RR accessions ranged from 83 to 114, 83 to 110, 70 to 100, and 70 to 94 DAP, in the first, second, third, and fourth plantings, respectively (Fig. 1). Early flowering at later planting date is common among strawhull RR and CL cultivars (Burgos et al., 2004). On average, CL XL-8 flowered at 95 to 98 DAP and CL 161 flowered 3 to 5 days later.

The outcrossing rate with RR accessions ranged from 0 to 1.55% (Fig. 2). Interactions between planting date by CL cultivars (Table 1) and planting date by RR accessions (Fig. 2) were significant ($p<0.05$) for outcrossing rate. However, no interaction was detected between CL cultivars and RR accessions for outcrossing rate. In general, higher outcrossing was observed with brownhull type compared with blackhull and strawhull types. The outcrossing rate differed among accessions in the same planting date due to various degrees of overlap in flowering. CL XL-8 had higher outcrossing rate in all planting dates compared with CL 161 (Table 1). Most of the red rice in the southern U.S. is an indica type, whereas cultivated rice, including CL 161, is a japonica type (Vaughan et al., 2001). The reason for higher outcrossing rate between the CL XL-8 hybrid and RR accessions is not clear.

The outcrosses between CL 161 and RR accessions were phenotypically uniform (Fig. 3), and were significantly taller than both parents, which is consistent with observations in other studies (Shivrain et al., 2007). All the outcrosses had pale-colored, rough-textured leaves, which are traits similar to those of the RR parent. Sixty-five percent of outcrosses were late in flowering and did not mature in the field. Increased height, flag-leaf length, and general plant size indicate that the outcrosses would be more competitive in terms of occupying space, intercepting light, and acquiring nutrients in the field compared with RR and CL rice cultivars.

The outcrosses between CL XL-8 and RR accessions segregated in terms of flowering time, height (Fig. 4), and leaf color and texture. Nearly 50% of the outcrosses flowered during the season. The outcrosses started flowering 5 weeks earlier than any of the RR accessions or CL XL-8 hybrid and continued flowering until the onset of cold weather. A wide range in height of outcrosses was observed (70 to 165 cm). Therefore, some outcrosses were shorter than the shortest parent and others were taller than the tallest parent (data not shown). The outcrosses that are smaller than the cultivated rice will be difficult to detect in the fields. The outcrosses that produce seeds and shatter before rice harvest will increase the ALS-resistant RR seed bank.

SIGNIFICANCE OF FINDINGS

Results of this study suggest that the flowering pattern of RR accessions varies and affects outcrossing rate. CL XL-8 has higher outcrossing rate with RR accessions than CL 161. Brownhull RR has higher outcrossing rate than strawhull and blackhull RR with both CL cultivars. Outcrosses between CL 161 and RR accessions were phenotypically uniform, whereas outcrosses between CL XL-8 and RR accessions segregated. This experiment demonstrates that outcrossing rate is influenced by CL cultivars, RR type, and planting time. Hence, outcrossing mitigation and RR management strategies need to consider these factors.

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This study was supported by the rice growers' checkoff funds through the Arkansas Rice Research and Promotion Board. We would like to thank Mellisa Jia at USDA-ARS, Stuttgart, Ark., for her help in DNA analysis. The authors would also like to extend their gratitude to Larry Earnest and his crew for their help in this research.

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Table 1. Estimated outcrossing rates as affected by cultivar and planting date. Red rice seedlings screened with imazethapyr at the Southeast Research and Extension Center, Rohwer, Ark., in 2006.

	Outcrossing rate	
Planting date (2005)	CL 161	CL XL-8
	(%)	
16 April (PD 1)	0.06	0.40
27 April (PD 2)	0.05	0.13
13 May (PD 3)	0.07	0.19
26 May (PD 4)	0.05	0.48
LSD[z] (0.05)	(0.11)	

[z] LSD values for comparing cultivar within planting dates or comparing planting dates within cultivar are the same.

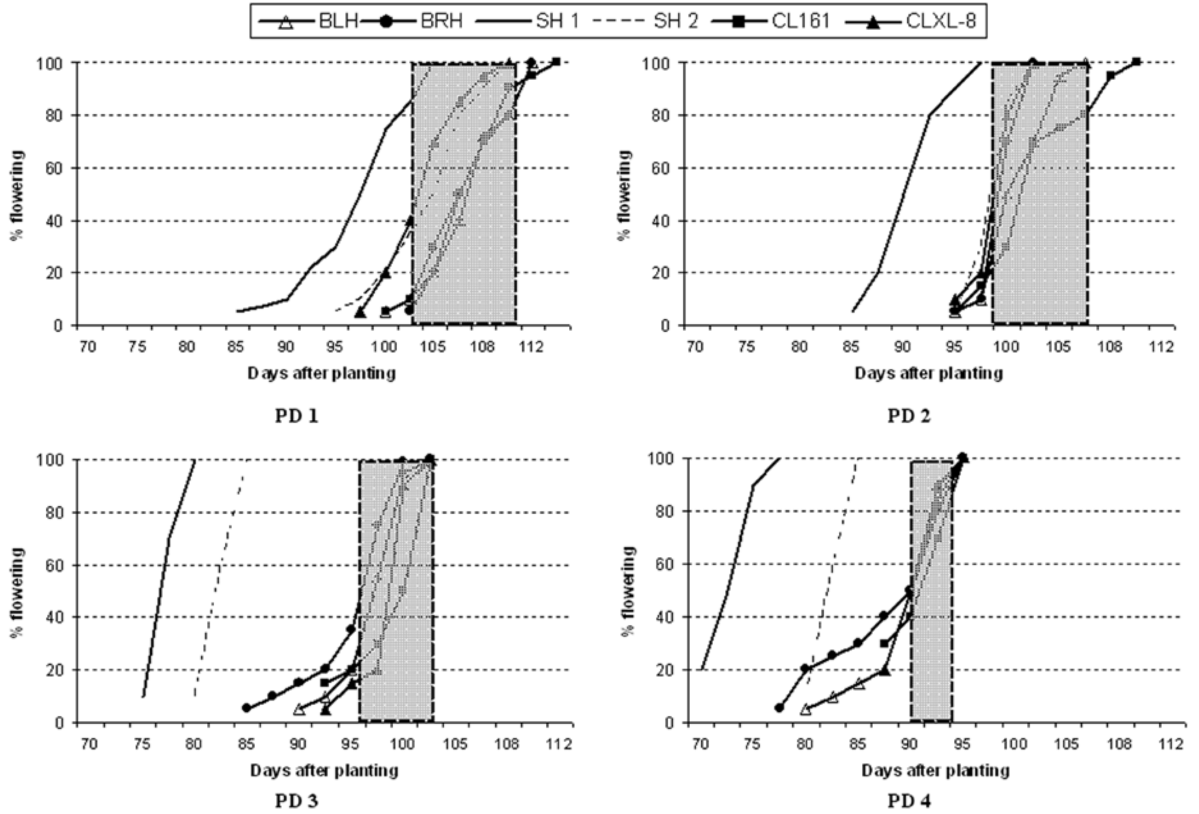

Fig. 1. Flowering of blackhull (BH), brownhull(BRH), strawhull1 (SH 1), and strawhull 2 (SH 2) accessions; CL 161; and CL XL-8 at four planting dates (PD) at the Rice Research and Extension Center, Stuttgart, Ark., 2005. Shaded areas represent the period of time when at least one CL cultivar overlapped ≥50% in flowering with any red rice accession.

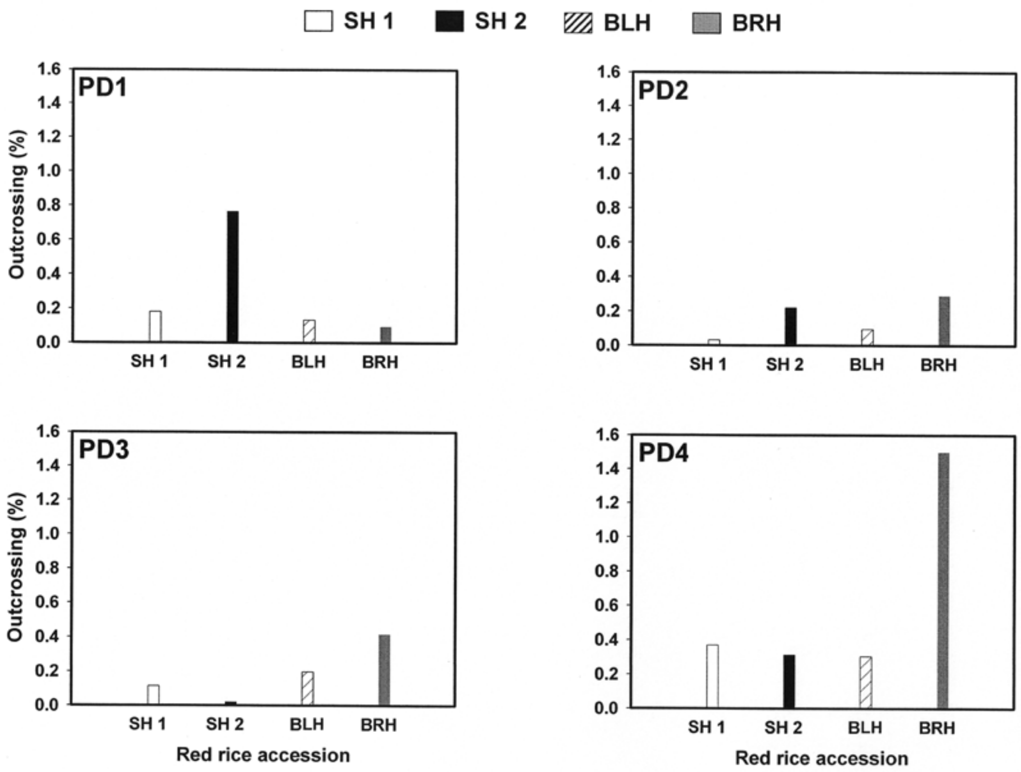

Fig. 2. Outcrossing rate (%) between strawhull (SH1 and SH 2), blackhull (BLH), brownhull(BRH) and CL 161 and/or CL XL-8 at four planting dates (PD) at the Southeast Research and Extension Center, Rohwer, Ark., 2006. LSD (0.05) values for comparing outcrossing rates of red rice accessions within and between planting dates are 0.3 and 1.02, respectively.

Fig. 3. Two outcrosses between CL161 x Red Rice. Note uniformity in height and flowering of both plants.

Fig. 4. Three outcrosses between CLXL-8 x Red Rice. Note segregation of height and flowering time.

Outcrossing Frequency Based on Flowering of Red Rice Accessions and Clearfield Cultivars in the Delta Region

V.K. Shivrain, N.R. Burgos, J.A. Bullington, K.L. Smith, J.R. Meier, and R.C. Doherty

ABSTRACT

Higher outcrossing was documented between Clearfield™ (CL) rice cultivar 'CL161' and Stuttgart strawhull red rice (RR) compared with 'CL 121' in Arkansas. The authors hypothesize that besides the CL rice cultivar, the type of RR, flowering time of CL and RR, and seeding time influence the herbicide-resistant gene-transfer frequency. In this study our objectives were to: 1) evaluate the flowering pattern of RR accessions from different rice-producing zones in Arkansas and CL rice cultivars with respect to seeding dates, and 2) determine the outcrossing frequency between these RR accessions and CL cultivars.

Experiments were conducted at the Southeast Research and Extension Center (SEREC), Rowher, Ark., in the summers of 2005 and 2006. Clearfield and RR were sown at three seeding dates (SD) initiated in the last week of April through end of May. Twelve RR accessions from four rice-growing zones in Arkansas and two CL rice cultivars were used. Each RR accession was planted in the middle of 9-row, 15-ft long plots with four rows of CL rice on both sides. Data on flowering of CL rice and RR were recorded. At maturity, RR seeds were collected to determine outcrossing rate. Seeds collected in 2005 were seeded in the summer of 2006 at the SEREC. The RR seedlings at 2-lf stage were sprayed with three applications of Newpath® at 8 oz/acre. Survivors of Newpath were confirmed as outcrosses by DNA analysis.

Red rice accessions and CL cultivars took longer to flower from planting date 1 than planting dates 2 and 3. A variable rate of synchronization was observed between RR accessions and CL cultivars in different seeding dates. Highest synchronization in flowering of RR accessions and CL cultivars was observed in SD1. Flowering synchronization of RR and CL cultivars decreased with later plantings. Overall, higher outcrossing was observed in SD1 than SD2 and SD3. Outcrossing rate ranged from 0.01 to 0.74% in different RR accessions. In general, higher outcrossing was observed in RR accessions that originated from the southern part of the state. Brownhull accessions and strawhull accessions had higher outcrossing compared with blackhull types. 'CL XL-8' had a higher outcrossing rate compared to CL 161. Outcrossing frequency varies with RR type and CL cultivar, and, to an extent, is influenced by synchronization in flowering.

INTRODUCTION

Studies conducted in experimental plots provided evidence of herbicide-resistant gene transfer from CL to RR and this was endorsed by the presence of imazethapyr-resistant RR at farmers' fields where CL rice was grown in Arkansas and Louisiana (Scott and Burgos, 2004; Zhang et al., 2004). In previous studies, we documented that RR populations in Arkansas are highly diverse in terms of morphology, especially in their flowering time (Shivrain, 2004). Studies conducted at Stuttgart, Ark., showed that overlap/synchronization in flowering of RR and cultivated rice affect the gene-transfer rate (Gealy et al., 2003).

Due to increasing acreage of CL rice and the release of new CL cultivars and hybrids, it is important to determine the effects of seeding time, CL cultivars, and RR type on outcrossing frequency. This information not only will improve our understanding about gene transfer from CL rice to RR, but also will be applicable to future herbicide-resistant rice cultivars or hybrids regardless of herbicide.

PROCEDURES

Experiments were conducted at the SEREC, Rowher, Ark., in 2005 and 2006. The soil at the experimental site is a Sharkey clay with <1% organic matter and a pH of 7.2. The experimental design was a split-split plot with four replications. Seeding time, CL cultivar, and RR accession were main-, sub-, and sub-sub-plot, respectively. In 2005, planting dates were: 28 April (SD 1), 12 May (SD 2), and 26 May (SD 3). CL 161 and CL XL-8, were seeded at 90 and 30 lb/acre, respectively. Twelve RR accessions from four rice-growing zones in Arkansas were used (Fig. 1). These RR accessions represent an assortment of characteristics: straw- (SH), black- (BLH), and brown- (BRH) hull color; short and tall; awned and awnless; and early and late to flower (Table 1). Each RR accessions was planted in the middle row of 9-row, 15-ft long plots with four rows of CL rice on both sides. Both CL cultivars were separated by a 50-ft alley to prevent pollen movement from one cultivar to the other. The experimental area was treated with Propanil, Facet, and Command at 3 qt, 0.35 lb, and 1 pt/acre, respectively, to control other weeds. Standard agronomic and pest-management practices were implemented during the growing season.

Data were collected on flowering time of RR accessions and CL rice every other day. Flowering data were not collected in SD 3 due to heavy predation of black birds on CL rice and RR; however, RR seeds were collected to calculate outcrossing rate. At maturity, RR seeds were harvested, cleaned, and stored for screening of outcrosses. In 2006, a sub-sample of approximately 3,000 seeds from each plot was sown at the SEREC. Red rice seedlings were treated with three applications of Newpath at 8 oz/acre starting at the 2-lf stage. Leaf tissues were collected from survivors for DNA analysis; SSR primers RM 253 and 234 were used to confirm the outcrosses. Outcrossing rate was calculated based on the number of confirmed hybrids. Data were analyzed using the GLM procedure in SAS.

RESULTS AND DISCUSSION

The flowering period of RR accessions ranged from 88 to 122 and 89 to 106, in SD 1 and SD 2, respectively. On average, CL XL-8 flowered 2 to 4 days earlier than CL 161, although flowering was over within a week in all seedings in both CL cultivars. CL rice and RR accessions seeded earlier took longer to flower than those planted later.

Both SH accessions from the White River zone flowered earlier than CL cultivars in SD 1, whereas in SD 2, both CL cultivars flowered earlier than RR accessions (data not shown). The accessions from the Grand Prairie zone had very little overlap in flowering with CL cultivars in SD 1. In SD 2, synchronization further decreased due to early flowering in CL cultivars compared with RR accessions (data not shown). The SH accession from the Delta 1 zone did not overlap in flowering with any CL cultivar at any planting date. The RR accessions from the Delta 2 zone started flowering earlier than both CL cultivars in both planting dates. Some overlap in flowering of RR accessions from Delta 2 occurred at 98 to 102, and 95 to 100 days after seeding in SD1 and SD2, respectively.

The outcrossing rate with various red rice accessions ranged from 0.01 to 0.74 % (Table 1). Higher outcrossing was observed between RR accessions that originated from Delta 2 zone and CL cultivars than the RR accessions from other zones. The BRH accessions had higher outcrossing followed by SH and BLH types. The BLH accession (Poi-104) from Delta 1 zone had the least outcrossing rate. Similarly, higher outcrossing frequency between BRH and CL rice compared with SH and BLH types has been observed in other studies conducted at farmers' fields in Arkansas (Burgos et al., 2007). Interactions between seeding date by RR accessions were significant ($p<0.05$) for outcrossing rate (Table 2). In general, BLH and BRH accessions from the White River and Delta 2 zone had higher outcrossing rates in SD1 than the rest of the RR accessions. In general, SD 2 had minimal outcrossing rates in all RR accessions compared with SD1 and SD3. No interaction was detected between CL cultivars and RR accessions on outcrossing rate. On average, CLXL-8 had higher (0.32%) outcrossing rates compared with CL161 (0.05%) in all seedings.

The authors observed that RR type, CL cultivar, and seeding date affect flowering time and therefore the outcrossing rate. The degree of flowering synchronization, which is dependent on the factors previously mentioned, acts in conjunction with other plant factors to influence the outcrossing rate. Experiments are being conducted in the greenhouse to further elucidate the differences in outcrossing rates of RR accessions and CL cultivars.

SIGNIFICANCE OF FINDINGS

This study shows that accessions of red rice from diverse rice-growing zones flower at different times. Red rice accessions have a wide-window flowering period compared with CL cultivars, which make them prone to acquire the imazethapyr-resistant gene from CL rice. CL XL-8 has higher outcrossing rates with RR accessions than CL 161. Brownhull RR has higher outcrossing rates than strawhull and blackhull RR with either CL cultivar. Seeding time and cultivar should be carefully considered to mitigate outcrossing between CL rice and red rice.

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This study was supported by the rice growers' checkoff funds through the Arkansas Rice Research and Promotion Board. The authors would like to thank Mellisa Jia at USDA-ARS, Stuttgart, Ark., for her help in DNA analysis. The authors would also like to extend their gratitude to Larry Earnest and his crew for their help in this research.

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Table. 1. Outcrossing rate for red rice (RR) accessions from different rice-production zones in Arkansas. Experiments were conducted at the Southeast Research and Extension Center, Rohwer, Ark., in 2005 and 2006.

Zone	RR accession no.	Red rice characteristics Hull color[z]	Height	Days to flower	Outcrossing rate
			(in.)		(%)
Grand Prairie	Lon- 83	SH	55	112	0.04 bc[y]
	Phi- 98	SH	49	106	0.01 c
	Pop-215	SH	43	86	0.05 bc
White River	Cla- 27	SH	57	99	0.34 a
	Gre- 57	SH	50	80	0.11 bc
	Poi- 101	BLH	63	96	0.17 bc
	Ran- 119	BRH	63	98	0.22 b
Delta 1	Poi- 104	BLH	57	97	0.01 c
Delta 2	Chi- 21	SH	57	109	0.39 a
	Chi- 22	SH	52	100	0.40 a
	Dre- 52	BRH	54	87	0.74 a

[z] Abbreviations used: SH= strawhull, BLH= blackhull, BRH= brownhull.

[y] Means followed by the same letter/s are not significantly different.

Table 2. Outcrossing rate for red rice (RR) accessions in three seeding dates (SD). Experiments were conducted at the Southeast Research and Extension Center, Rohwer, Ark., in 2005 and 2006.

Zone	RR accession no.	Hull color[z]	Outcrossing SD 1	SD 2	SD 3
			---------------------	(%)	--------------------
Grand Prairie	Lon- 83	SH	0.01 d[y]	0.01 d	0.11 cd
	Phi- 98	SH	0.01 d	0.03 d	0.00 d
	Pop-215	SH	0.02 d	0.04 d	0.08 d
White River	Cla- 27	SH	0.22 cd	0.76 cb	0.05 d
	Gre- 57	SH	0.03 d	0.11 cd	0.20 cd
	Poi- 101	BLH	0.33 bcd	0.15 cd	0.04 d
	Ran- 119	BRH	0.36 bcd	0.18 cd	0.12 cd
Delta 1	Poi- 104	BLH	0.00 d	0.02 d	0.00 d
Delta 2	Chi- 21	SH	0.05 d	0.20 cd	0.91 ab
	Chi- 22	SH	0.00 d	0.05 d	0.07 d
	Dre- 52	BRH	1.56 a	0.04 d	0.62 bcd
	Ash- 13	BLH	0.12 cd	0.15 cd	0.13 cd

[z] Abbreviations used: SH= strawhull, BLH= blackhull, BRH= brownhull.

[y] Means followed by the same letter/s are not significantly different.

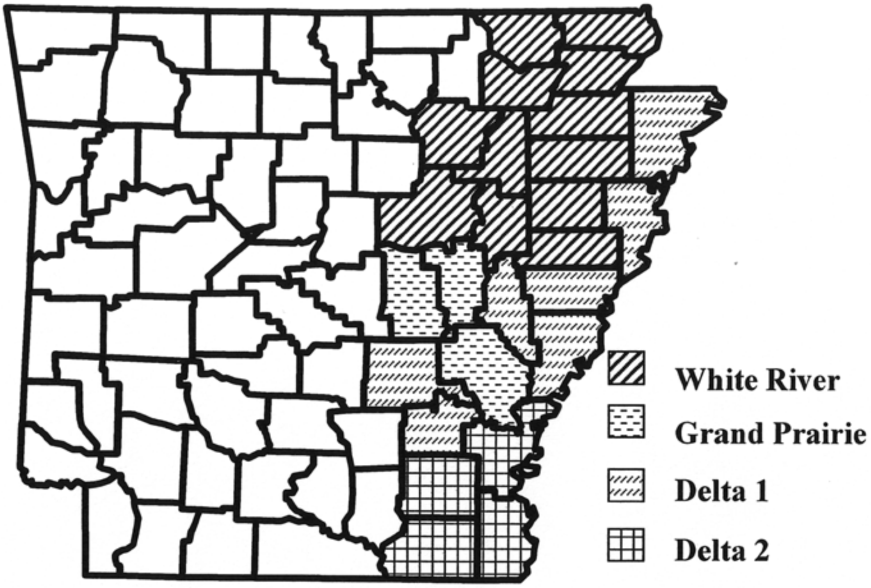

Fig. 1. Rice-growing zones in Arkansas. The Delta zone is divided into two due to differences in flowering of red rice accessions from those regions.

RICE CULTURE

The Effect of Rotation, Tillage, Fertility, and Variety on Rice Grain Yield

M.M. Anders, K.B. Watkins, K.A.K. Moldenhauer, J.W. Gibbons, and R.W. McNew

ABSTRACT

Average grain yield for the full-season varieties, over all treatment combinations, was 165 bu/acre. This average was impacted primarily by variety differences with 'Wells' averaging 180 bu/acre and 'Cybonnet' averaging 152 bu/acre. There were no significant differences between rotation, tillage, or fertility main-effect treatments. Summaries of grain yields for the main effect of tillage indicated that no-till treatments were equal to or higher than conventional-till treatments in 6 of 7 years. In all 7 years, lowest grain yields were from the continuous rice rotation while highest yields were from the two rotations that included rice every third year. There was no difference in rice-grain yields in the two-phase rotations that had either soybeans or corn as alternate crops. Fertility had no significant effect on grain yield in any of the 7 years summarized in this study. Variety differences occurred only after Cybonnet was introduced to the study as a replacement for 'LaGrue'. Summarized results illustrate a potential to reduce production costs by reducing or eliminating tillage and reducing fertilizer rates. Low grain yields in the continuous rice rotation are a concern only if they are sufficiently low to reduce net returns below those of alternate crops used in the rotation.

INTRODUCTION

Passage of the 1996 and 2002 Farm Bills has provided rice farmers with incentives to increase the frequency of rice in their rotations. However, escalating production costs in the past two seasons combined with low commodity prices for rice have resulted in reduced rice acres. Farmers are now faced with a production environment that demands they reduce production costs without significantly impacting grain yield. In the process of doing this they must evaluate a number of production options that will assist them in achieving this goal while maintaining production stability. The study described here provides insights into how grain yield will be impacted by changes in rotation, tillage, fertility, and variety decisions. The results summarized here provide a look at how these factors impacted grain yields from 2000 to 2006. They provide insight into how farmers might alter their management in order to remain profitable in the future.

PROCEDURES

Field #8 at the University of Arkansas Rice Research and Extension Center was selected for this study and precision graded to a 0.15% slope in February of 1999. Soil at the site is referred to as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludolf. Initial soil samples showed a pH range of 5.6 to 6.2 with carbon content averaging 0.84% and nitrogen 0.08%. Plots measuring 250 ft x 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. Because the field was precision graded in 1999, tillage comparisons were not possible until the 2000 crop. Each tillage treatment was then split into a standard and high-fertility treatment. For rice, 'standard fertility' consisted of a single preflood nitrogen (N) application of 100 lb N/acre and preplant applications of phosphorus (P) at 40 lb P_2O_5/acre and potassium (K) at 60 lb K_2O/acre. Rates increased to 150 lb N/acre, 60 lb/acre P_2O_5, and 90 lb/acre K_2O for the 'enhanced' 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 rice varieties used in 2006 were Wells and Cybonnet for the full-season rotations and 'XP 723' and 'Spring' for the rice planted after wheat. 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. Those rotations containing standard full-season rice varieties are 1, 3, and 5. Short-season rice varieties are used in rotations 6, 7, and 8.

All full-season rice plots were sown on 15 May 2006. Command herbicide was applied at sowing with Permit and Clincher used following emergence for weed control. Command rates were 1.33 pt/acre and 0.80 pt/acre in the no-till and conventional-till plots, respectively. An Almaco no-till plot drill was used with a 7.5-in. row spacing. The seeding rate was 90 lb/acre. Phosphorus and K were applied prior to sowing and a single preflood-N application was made prior to flooding. Phosphorus and K were incorporated in the conventional-till treatment and not in the no-till treatment. Short-season plots were sown on 30 June 2006. The same management and sampling procedures were used.

RESULTS AND DISCUSSION

Rice-Grain Yields (2006)

Rice-grain yields for the full-season treatments averaged 165 bu/acre (Table 1). This was well below the previous year when average yields were 192 bu/acre. Unlike 2005, no-till did not result in a higher grain yield than conventional-till. There were no significant differences between rotation main effects. This result was unlike all previous years when rotation main effects were significantly different. As in all previous years, there was not a significant difference between fertility treatments. For the third consecutive year, grain yields for the variety Cybonnet were significantly lower than those for Wells. This difference was very highly significant and suggests possible problems with this variety; particularly in years when yields are low. Milling yields (not reported here) were consistently higher for Cybonnet but this difference was not sufficient to make up for lost yields when economic returns were calculated.

The variety XP 723 was substituted for 'XP 721' in the late-planted rice. This change did not prove to be successful as XP 723 is too long-duration and was damaged by cold weather prior to reaching maturity. Spring grew well but overall yields were low (110 to 140 bu/acre). Milling yields for Spring were acceptable and we hope to replace XP 723 with a true short-duration variety in next year's study.

Tillage Effects Over Time

No-till rice production is practiced on only a small percentage of farms in Arkansas (Wilson and Branson, 2004). This is not the case with many other row crops where no-till and minimum-till are the norm (Peterson, 2005). Production costs for no-till rice production are estimated to be less than for conventional-till (Watkins et al., 2005) while it is generally accepted that sowing can commence earlier in the season . One commonly cited reason for not using no-till is an expected drop in grain yields. Of the 7 years' data collected in this study, no-till managed plots had grain yields equal to or higher than conventional-till plots in 6 of the 7 years (Fig. 1). Over all years, there was less yearly variation in the no-till treatments when compared to the conventional-till treatments. With lower production costs in the no-till treatments, it is expected that net income for the no-till treatments will be higher and more stable than for the conventional-till treatments. This comparison was made using the same management, other than tillage, for all plots. These results suggest that it is possible to switch from conventional-till to no-till and keep other management aspects the same.

Rotation Effects Over Time

Rotation effects were significant in all but the last 2 years (Table 1). Of the five rotations studied, continuous rice tended to have the lowest yield every year (Fig. 2) and was significantly lower in 2000, 2001, 2002, and 2004 (Table 1). Consistently lower yields in the continuous rice rotation suggest that management changes such as increased fertilizer rate might be necessary to achieve grain yields comparable to other rotations. Nitrogen studies carried out in these plots and reported by Anders et al. (2005) show a decline in plant N uptake in the continuous rice rotation compared to the rice-soybean rotation after green ring. Lower grain yields in continuous rice may not result in overall losses in net income compared to other rotations if the profitability of other crops used in the rotation are less than rice at a lower yield level. We have found this to be the case with rotations containing corn. Of the rotations compared in this study, rice-soybean, appears to be the highest-yielding and most stable.

Fertility Effects Over Time

In no year was there a statistical advantage to increasing fertility rates (Table 1). Soil samples collected in 2002 and 2003 indicated that increasing P and K fertilizer rates resulted in increased soil P and K levels but not increased yields. Nitrogen was applied as a single preflood application at rates lower than and comparable to those recommended. All plots were flooded within a day of fertilizer applications thus we expect little N was lost. Grain yields for individual treatments were occasionally over 200 bu/acre and our average grain yields were comparable to or greater than state averages. These results strongly suggest that given the soil we used and other management practices, there would be no financial gain to increasing fertilizer rates higher than our 'standard' rate treatment. Nitrogen rates used by most farmers are considerably higher and this might be necessary for clay soils and fields where flooding is delayed but, in general, our results suggest most farmers are applying more fertilizer than is necessary.

Variety Effects Over Time

The study began with a comparison between LaGrue, an older but popular variety, and Wells, a new variety at the beginning of the study. There were no significant differences between these varieties in any of the first 4 years of the study (Table 1). This is not surprising as both varieties were developed in the same breeding program and share some parentage. LaGrue was replaced by Cybonnet in 2004 because it was not grown extensively and Cybonnet provided a semidwarf comparison. Of the 3 years Cybonnet was compared to Wells, Cybonnet's grain yields were significantly lower in 2 years (Fig. 4). In all years of this comparison Cybonnet milling yields were better than Wells (data not presented) but this improved milling yield was not sufficient to offset grain-yield differences in terms of net income. These results suggest that for the soil and management we are using in this study it would be advisable to grow Wells.

SIGNIFICANCE OF FINDINGS

Seven years of comparing rotations, tillage approaches, fertility, and varieties illustrate management approaches that will help farmers maintain profitability in an environment of rising production costs and a renewed concern about resource management. A combination of appropriate rotation selection, reduced tillage, reduced fertilizer inputs, and appropriate variety selection will result in increased profits.

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Table 1. Summary of full-season rice mean grain yield (bu/acre) for treatment main effects in 2000, 2001, 2002, 2003, 2004, 2005, and 2006 in the long-term cropping systems study at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

	Year						
Treatment	2000	2001	2002	2003[z]	2004	2005	2006
All	178	158	166	153	173	192	165
Tillage							
Conventional	188 a[y]	156 a	176 a	153	184 a	184 b	165 a
No-till	169 a	160 a	155 b	153	162 a	201 a	166 a
Rotation							
Continuous rice	155 b	144 b	132 b	132	156 b	177 a	161 a
Rice-soybeans	190 a	164 a	174 a	173	187 a	195 a	168 a
Rice-corn	190 a	165 a	165 a	176	177 a	190 a	168 a
Rice-corn-soybeans	NA	NA	180 a	NA	NA	199 a	NA
Rice-soybeans-corn	NA	NA	177 a	NA	NA	203 a	NA
Fertility							
Standard	181 a	155 a	161 a	159	173 a	192 a	165 a
Enhanced	175 a	161 a	170 a	147	174 a	193 a	166 a
Variety							
Wells	184 a	158 a	168 a	153	182 a	196 a	180 a
LaGrue	173 b	158 a	164 a	157	NA	NA	NA
Cybonnet	NA	NA	NA	NA	164 b	189 a	152 b

[z] Roundup drift destroyed a number of plots, thus a full statistical analysis was not available; mean values are used.

[y] Means within a column followed by different letters are significantly different at the P=0.05 level of confidence.

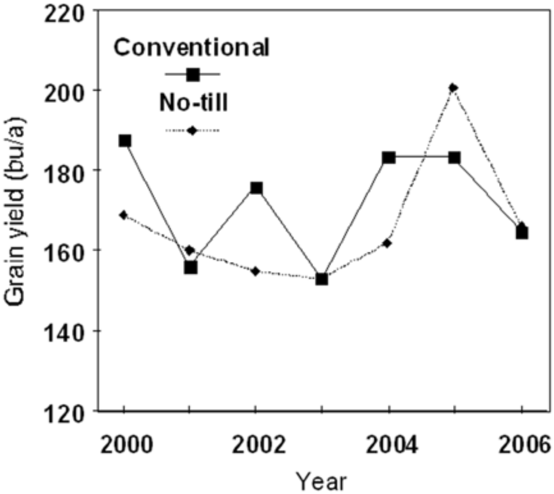

Fig. 1. Rice-grain yields (bu/acre) for conventional and no-till plots averaged over all treatment combinations from 2000 to 2006.

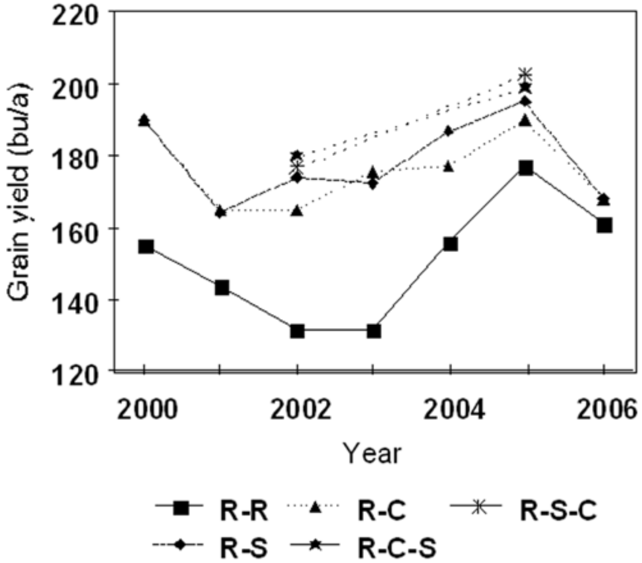

Fig. 2. Rice-grain yields (bu/acre) for five rotations, averaged over all treatment combinations from 2000 to 2006. R = rice, S = soybeans, and C = cotton.

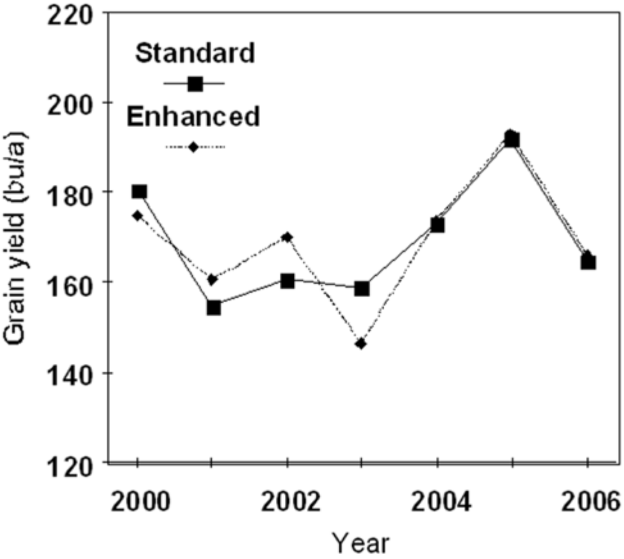

Fig. 3. Rice-grain yields (bu/acre) for plots receiving 'standard' or 'enhanced' fertilizer levels averaged over all treatment combinations from 2000 to 2006.

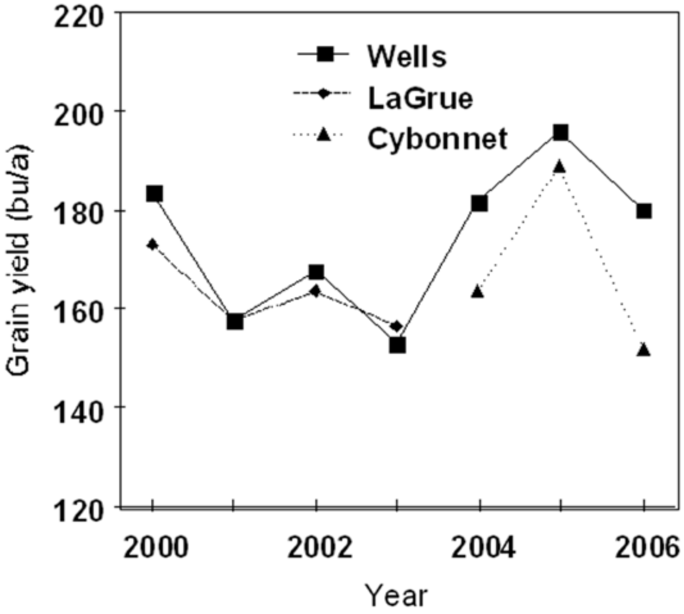

Fig. 4. Rice-grain yields (bu/acre) for plots planted into LaGrue, Wells, or Cybonnet averaged over all treatment combinations from 2000 to 2006.

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

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ABSTRACT

The Degree-Day 50 (DD50) computer program must be continually updated as new rice cultivars and hybrids are named and 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 cultivar were evaluated over four seeding dates in the dry-seeded, delayed-flood management system. Rice cultivars and experimental rice varieties evaluated in 2006 were: ‘Banks’, ‘Cheniere’, ‘CL 131’, ‘CL 161’, ‘CL 171 AR’, ‘Cybonnet’, ‘Francis’, ‘Jupiter’, ‘4484’, ‘Medark’, ‘Pace’, ‘Pirogue’, ‘Presidio’, ‘RU0401182’, ‘Spring’, ‘Trenasse’, and ‘Wells’; Rice Tec experimental hybrids ‘XL 723’, ‘XP 729’, and ‘CL XL 730’.

INTRODUCTION

The DD50 computer program has been one of the most successful programs developed by the University of Arkansas Division of Agriculture. Approximately 50% of the rice farmers in Arkansas utilize this program as a production-management tool and other rice-producing states have developed similar programs based on this model. The program requires 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 varieties and all newly released rice cultivars and hybrids for at least 3 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, the influence of seeding date on a cultivar's grain- and milling-yield performance was measured to determine the optimal time to seed each of the new cultivars.

PROCEDURES

The 2006 study was conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark., on a DeWitt silt loam soil. Seventeen rice cultivars (Banks, Cheniere, CL 131, CL 161, CL 171 AR, Cybonnet, Francis, Jupiter, 4484, Medark, Pace, Pirouge, Presidio, RU0401182, Spring, Trenasse, and Wells) and three Rice Tec experimental hybrids (XL 723, XP 729, and CL XP 730) were drill-seeded at a rate of 40 seeds/ft^2 in nine-row (7-in. spacing) wide plots, 15 ft in length, except the Rice Tec hybrids, which were sown at 16 seeds/ft^2 according to recommendations provided by RiceTec. The seeding dates were 16 March, 14 April, 9 May, and 5 June 2006. General seeding, seedling emergence, and flood dates are shown in Table 1. The normal cultural practices for dry-seeded, delayed-flood rice were followed. All plots received 120 lb N/acre as urea at the 4- to 5-lf growth stage immediately prior to flooding. The flood was established and maintained at a 2- to 4-in. depth until the rice was mature. The design of the experiment for each seeding date was a randomized complete block with three replications. Data collected included: maximum and minimum daily temperatures, seedling emergence, and the number of days and DD50 thermal units required to reach ½-in. internode elongation (IE), 50% heading, and maturity. At maturity, 12 ft of the center four 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. The dried rice was milled to obtain percent total white rice and percent head rice. 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 5 to 24 days (Table 1). As the seeding date was delayed, the time between seeding and emergence was generally shorter. The earlier the rice was seeded the time required from seeding to flooding was generally longer, ranging from 22 days to 60 days. The range from emergence to flooding was from 17 to 36 days.

The time required from emergence to ½-in. IE averaged 57 days across all varieties and seeding dates (Table 2). Average time for all cultivars ranged from 69 days when seeded in March to 49 days when seeded in June. Although the days varied by as much as 14 days, DD50 accumulation across all seeding dates for a cultivar was relatively similar. This variation was due to cool temperatures during April, which slowed development of rice in the earliest seeding dates. Cultivar Spring had the shortest vegetative growth period in the study with an average of 52 days, which is approximately 6 days earlier than Wells. The DD50 accumulations during vegetative growth ranged from a low of 1344 for Spring to a high of 1749 for Pirogue when averaged across seeding dates. This difference was realized in approximately 14 days in 2006.

The time required for development between emergence and 50% heading averaged 85 days across all cultivars and seeding dates (Table 3). While many of the commonly produced cultivars were within 2- to 3-days of the average, Spring and Trenasse were much earlier. The time required to reach 50% heading for these varieties averaged 77 days and ranged from 75 to 79 days. These cultivars are approximately 9 days earlier than Wells. The DD50 unit accumulations ranged from a low of 2014 for Spring to a high of 2584 for 4484. The average DD50 unit accumulation required to reach 50% heading was 2230 heat units.

Due to severe injury from lespedeza worms, the DD50 accumulations required to reach ½-in. IE and 50% heading were greater than normal (Tables 2 and 3). The difference, as determined by "check" varieties such as Wells, indicated that crop development was delayed approximately 230 DD50 units. This substantiated the importance of including known varieties in the study. By including Wells, for which a large amount of historical data are available, corrections can be made to account for the year-to-year variability that occurs when the crop is delayed beyond normal. Also, it demonstrated the need to understand that when the crop is delayed, the DD50 predictions will be affected. Crop delays, such as that caused by herbicide injury, fertilizer deficiency, insect injury, or other factors, should be considered when utilizing the DD50 program.

When averaged across seeding dates, the cultivars with the highest yields were the Rice Tec hybrids XL 723, CL XP 729, and XL 730 (Table 4). The highest-yielding conventional varieties were Wells, Francis, and Banks. Most varieties performed best when seeded in March or April. As previously observed, Wells was among the most stable conventional varieties when seeded late. However, some of the hybrids performed very well when seeded in June, particularly Rice Tec CL XL 730 and CLXP 729.

Long-grain varieties with the greatest milling-yield potential include Cheniere and CL 171 AR (Table 5). Seeding date did not significantly influence head-rice yields. Some cultivars have demonstrated little tolerance to wet and dry conditions associated with the inability to harvest at 17 to 18% moisture. Spring appears to be particularly sensitive to harvest moisture in maintaining good head-rice yields.

SIGNIFICANCE OF FINDINGS

The data from 2006 will be used to refine the DD50 thermal-unit thresholds for the new cultivars and hybrids in this study. The grain- and milling-yield data will be used to help producers make decisions regarding variety selection, particularly for early- and late-seeding situations.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board; this support is greatly appreciated.

Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 (DD50) seeding date study in 2006 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date			
Parameter	16 March	14 April	9 May	5 June
Emergence date	9 April	30 April	19 May	10 June
Flood date	15 May	5 June	12 June	27 June
Days from seeding to emergence	24	16	10	5
Days from seeding to flooding	60	51	34	22
Days from emergence to flooding	36	37	24	17

Table 2. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to ½-in. internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2006.

	½-in. Internode elongation									
	16 Mar 06		14 Apr 06		9 May 06		5 Jun 06		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
4484	71	1657	64	1631	49	1398	49	1457	58	1536
Banks	---	---	---	---	---	---	---	---	---	---
Cheniere	---	---	---	---	---	---	---	---	---	---
CL 131	66	1491	62	1556	49	1387	46	1355	56	1447
CL 161	70	1601	61	1535	48	1370	46	1364	56	1468
CL 171 AR	66	1492	61	1535	52	1482	48	1404	57	1478
Cybonnet	---	---	---	---	---	---	---	---	---	---
Francis	67	1512	61	1546	48	1378	49	1436	56	1468
Jupiter	75	1750	66	1669	53	1525	52	1543	61	1622
Medark	72	1653	66	1675	51	1450	50	1489	60	1567
Pace	73	1694	66	1669	54	1557	52	1553	61	1618
Pirogue	79	1858	69	1752	57	1653	58	1734	66	1749
Presidio	70	1601	66	1685	50	1429	50	1479	59	1548
RT CL XL 730	66	1472	58	1435	48	1362	45	1317	54	1397
RT CL XP 729	65	1462	60	1492	49	1388	47	1373	55	1429
RT XL 723	66	1481	58	1452	48	1378	45	1326	54	1409
RU 0401182	70	1603	64	1635	50	1440	51	1500	59	1544
Spring	65	1446	56	1389	44	1266	43	1276	52	1344
Trenasse	67	1502	58	1454	45	1307	46	1366	54	1407
Wells	69	1582	64	1616	50	1419	49	1436	58	1513
Mean	69	1580	62	1572	50	1423	49	1436	57	1503
LSD	3	87	3	80	2	54	2	48		
C.V.	2.6	3.3	2.7	3.0	2.2	2.3	1.9	2.0		

Table 3. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2006.

	50% Heading									
	16 Mar 06		14 Apr 06		9 May 06		5 Jun 06		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
4484	106	2683	98	2660	85	2509	83	2483	92	2584
Banks	98	2421	92	2468	80	2373	79	2381	87	2411
Cheniere	95	2325	88	2352	78	2298	75	2261	84	2309
CL 131	95	2336	88	2351	78	2309	73	2208	84	2301
CL 161	102	2553	93	2500	79	2330	78	2357	88	2435
CL 171 AR	96	2378	92	2479	79	2330	77	2325	86	2378
Cybonnet	96	2357	91	2425	79	2341	77	2314	86	2359
Francis	97	2389	89	2384	79	2319	76	2304	85	2349
Jupiter	99	2463	88	2343	79	2319	75	2272	85	2349
Medark	97	2399	88	2332	78	2298	73	2198	84	2307
Pace	98	2421	91	2425	80	2351	76	2296	86	2373
Pirogue	95	2346	86	2284	77	2256	78	2346	84	2308
Presidio	94	2293	87	2313	75	2213	73	2190	82	2252
RT CL XL 730	97	2389	90	2415	79	2319	77	2333	86	2364
RT CL XP 729	96	2357	89	2374	79	2319	76	2282	85	2333
RT XL 723	96	2378	88	2342	77	2266	75	2272	84	2314
RU 0401182	101	2527	93	2489	82	2435	79	2381	89	2458
Spring	85	2049	80	2104	68	1983	67	2014	75	2038
Trenasse	91	2218	83	2195	71	2064	69	2089	79	2142
Wells	97	2389	91	2436	79	2330	77	2336	86	2373
Mean	96	2383	89	2383	78	2298	76	2282	85	2337
LSD	3	104	3	83	2	77	2	60		
C.V.	2.1	2.6	1.8	2.1	1.9	2.0	1.6	1.6		

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2006.

	Grain yield				
Cultivar	16 Mar 06	14 Apr 06	9 May 06	5 Jun 06	Average
	(bu/acre)				
4484	119	168	104	107	124
Banks	171	181	131	116	150
Cheniere	155	171	105	115	137
CL 131	154	166	119	119	139
CL 161	123	154	109	110	124
CL 171 AR	154	177	104	114	137
Cybonnet	169	179	108	123	145
Francis	172	178	125	124	150
Jupiter	162	167	116	107	138
Medark	115	131	86	93	106
Pace	136	140	96	110	120
Pirogue	64	109	99	70	85
Presidio	119	140	107	106	118
RT CL XL 730	196	248	203	156	200
RT CL XP 729	217	276	219	180	223
RT XL 723	218	265	208	177	217
RU 0401182	152	167	119	136	143
Spring	102	139	131	111	121
Trenasse	159	158	133	98	137
Wells	158	178	133	142	153
Mean	151	175	128	121	143
LSD	20	17	18	15	
C.V.	8.2	6.0	8.4	7.6	

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2006.

Cultivar	Milling yield				
	16 Mar 06	14 Apr 06	9 May 06	5 Jun 06	Average
	---------------------------- (% head rice / % total rice)---------------------------				
4484	46-68	45-68	58-67	59-70	52-68
Banks	61-70	50-68	58-68	63-72	58-69
Cheniere	63-72	59-69	61-69	65-72	62-71
CL 131	64-71	58-68	57-69	63-71	61-70
CL 161	62-69	58-67	63-69	61-71	61-69
CL 171 AR	66-73	61-69	61-69	61-71	62-71
Cybonnet	65-71	55-67	63-70	60-71	61-70
Francis	63-71	53-68	58-69	63-72	59-70
Jupiter	65-70	56-69	60-69	63-71	61-70
Medark	63-71	58-68	60-69	64-72	61-70
Pace	61-70	50-68	58-68	62-71	58-69
Pirogue	63-73	60-69	60-70	60-70	61-71
Presidio	63-70	61-70	57-69	62-71	61-70
RT CL XL 730	60-72	57-69	60-70	62-71	60-71
RT CL XP 729	58-71	56-69	57-69	63-72	58-70
RT XL 723	58-70	57-70	58-70	65-71	60-70
RU 0401182	61-72	58-68	59-69	62-72	60-70
Spring	52-69	56-69	51-69	66-72	56-69
Trenasse	56-68	50-66	53-67	64-71	56-68
Wells	61-72	51-70	55-70	61-72	58-71
Mean	60-71	58-69	58-69	63-71	59-70
LSD	4-1	4-1	3-1	5-2	
C.V.	3.6-08	4.8-1.2	2.9-1.0	4.2-1.5	

Predictability of Crop Production in a Clay Soil Based on a Comprehensive, Post-Land-Leveling Soil-Property Evaluation

K.R. Brye

ABSTRACT

Land leveling is a common, yet severe, soil disturbance in the rice (*Oryza sativa* L.)-producing regions of the mid-southern United States. Land leveling is a soil- and crop-management practice that can disrupt the theoretically predictable soil-plant relationship that exists in undisturbed conditions. The objective of this study was to determine whether crop growth and production were predictable with some degree of confidence based on a comprehensive soil-property characterization following land leveling of a clay soil at the Northeast Research and Extension Center in Mississippi County, Ark. Significant correlations between soil properties and crop responses were generally weak ($r < 0.4$) and inconsistent across crops and growing seasons. Results indicate that soybean [*Glycine max* (L.) Merr.] and rice growth and response in the first three growing seasons following land leveling cannot be reliably predicted based on a suite of 25 immediate post-leveling soil physical, chemical, and biological properties. Based on the results of this and a previous study, it appears that the negative effects of land leveling on soil properties may be less in clay than in silt-loam soils. Though land leveling may facilitate the uniform distribution of irrigation waters, the resulting increased spatial variability and distributions of soil properties and crop response will likely make long-term, post-leveling management challenging.

INTRODUCTION

Under natural conditions, plant productivity is intimately related to the condition of the soil in which that plant is growing. For example, plant productivity would be expected to be high where sufficient nitrogen (N) exists and low where insufficient N exists in the soil. Similarly, plant productivity would be expected to be high where sufficient moisture was present and low where insufficient moisture was present in the soil. This plant-soil relationship can certainly be extended to include the response of agricultural field crops to the soil in which they are grown. However, certain agricultural-management practices, such as land leveling, can severely disrupt the near-surface natural condition of the soil (Brye et al., 2005).

Land leveling is relatively commonplace as a water-conservation practice in the mid-southern United States, particularly in regions of rice (*Oryza sativa* L.) and soybean [*Glycine max* (L.) Merr.] production (Brye et al., 2003). Land leveling creates a slight surface gradient to facilitate the uniform distribution of irrigation water. However, to achieve the slight, uniform soil surface gradient, large, heavy machinery is necessary to remove soil from local high spots (i.e., a cut) and add soil to local low spots in a field (i.e., a fill). This removal, addition, and relocation of soil within a field during land leveling activities substantially alters the magnitude and spatial variability and distribution of soil properties throughout the field (Brye et al., 2003, 2004a, 2005, 2006; Brye, 2006a).

With increased spatial variability and distributions of soil properties following land leveling, one might reasonably expect that the plant-soil relationship be even more pronounced than under natural, undisturbed conditions. However, Brye et al. (2004b) demonstrated that a relatively comprehensive, immediate post-leveling soil-property evaluation, which included more than 20 physical, chemical, and biological properties, was unsuccessful at predicting crop response with any degree of confidence in the first (soybean) or second (rice) growing season after shallow-cut land leveling of a silt-loam Alfisol in south-central Arkansas.

The nature of the predominately silty alluvial parent material likely contributed greatly to the outcome of the Brye et al. (2004b) study. Compared to the deep, highly clayey, alluvial Vertisols located nearer to the Mississippi River channel and its floodplain, the soil profile of the silt-loam Alfisol would tend to be more vertically differentiated meaning that there is more vertical soil-property change, particularly with particle-size distribution and texture, from horizon-to-horizon in the silt-loam Alfisol than in a highly clayey Vertisol. Thus, one could contend that land leveling would have a greater negative impact on resulting soil properties and crop response in a silt-loam Alfisol than in a highly clayey Vertisol (Norman et al., 2003). This contention was supported by the results of Brye et al. (2006) and Brye (2006a).

Under the assumption that a clayey Vertisol is less prone to severe disturbance by land-leveling activities than a silt-loam Alfisol, the objective of this study was to determine whether crop growth and production were predictable with some degree of confidence based on a comprehensive soil-property characterization following land leveling of a clay soil in northeast Arkansas. Contrary to the results of Brye et al. (2004b), it was hypothesized that crop growth and production are correlated to near-surface soil properties immediately following relatively deep-cut land leveling of a clay soil and that crop response following land leveling would be somewhat predictable based on a reasonably comprehensive, post-leveling soil evaluation.

PROCEDURES

Site Description and Experimental Design

A 12-acre (4.9-ha) field, previously cropped to soybean, on a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquert) at the Northeast Research and Extension Center (NEREC), Keiser, Ark., was land leveled in April 2004 (Brye, 2006a). Prior to land leveling, two 197-ft (50-m)-wide by 395-ft (100-m)-long study areas were established parallel to one another and separated by 98 ft (25 m) within the field. Each study area was divided into 10, 39.5-ft-wide (10 m) by 197-ft-long (50 m) plots. One study area was used to evaluate the use of poultry litter while the other study area was used to evaluate deep tillage as potential management practices that could be used to improve soil quality following land leveling in clay soils. Poultry-litter and deep-tillage treatments were randomized within each study area such that a completely random experimental design resulted with five treatment replications and five control replications in each study area (Brye, 2006b).

In addition to the poultry litter and deep tillage treatments, a 50-point grid system was superimposed onto each study area such that grid points were evenly spaced at 39.5 ft (10 m) apart from one another. The grid system was established to facilitate soil and plant sampling from the same point in each study area from year to year to allow for the effects of land leveling over time to be evaluated (Brye, 2006a; Brye et al., 2006). Except for a minimal, though statistically significant ($P < 0.05$), 6.5% larger soybean yield without deep tillage than with deep tillage in the first growing season (i.e., 2004) following land leveling (Brye, 2006b), neither poultry litter nor deep-tillage affected crop yields in the three subsequent growing seasons following land leveling (Brye, 2006b; K.R. Brye, unpublished data). Therefore, since neither the application of poultry litter nor the implementation of deep tillage resulted in any substantive crop response in the three years following land leveling, the presence of these treatments was assumed to be negligible and was ignored for the purposes of this present study.

Details of the imposition of the poultry-litter and deep-tillage treatments will not be described here, but can be found in Brye (2006b). Similarly, additional details regarding the study site and experimental design can be found in Brye (2006a,b) and Brye et al. (2006).

Field Management

Land-leveling activities were described in detail by Brye et al. (2006), thus only an abbreviated description follows. Land-leveling activities began on 18 April and were completed on 20 April 2004. Following initial land-leveling activities, the entire field was disked three times and land-planned (i.e., floated) twice on 27 May to reduce soil-clod size to an approximate diameter of < 1 in. (2 cm) for a proper seed bed.

A RoundupReady (i.e., glyphosate-resistant) soybean cultivar was drill-seeded at a 7.5-in. row spacing throughout both study areas on 17 June 2004 (Brye, 2006b). After emergence, approximately 1 week after planting, a 100 lb/acre rate of triple-super phosphate was manually applied with a hand spreader to both study areas. No potassium (K) or N was applied to the soybean crop. Soybeans were furrow-irrigated on an as-needed basis throughout the growing season and harvested on 22 October 2004. The entire study area was left fallow over winter.

In 2005, two passes across both study areas were made with a soil conditioner (i.e., Do-All) and then land-planned twice to prepare a proper seed bed (Brye, 2006b). 'Wells' rice was drill-seeded on 27 April at a 7.5-in. row spacing and at a seeding density of 100 lb/acre. On 9 June, at about the 5-lf rice stage, a blanket application of 167 lb/acre of N as urea was spread manually across both study areas. Previous soil-test results indicated no additional P or K was needed for optimal rice production. The flood was established on 10 June and released on 26 August in preparation for harvest on 16 September 2005.

In 2006, the study area was prepared in a similar manner to that in 2005. Wells rice was drill-seeded on 28 April at a 7.5-in. row spacing and at a seeding density of 100 lb/acre. On 13 June, again at about the 5-lf rice stage, a blanket application of 150 lb/acre of N as urea was spread manually across both study areas. Soil-test results again indicated no additional P or K was necessary. The flood was established on 14 June and released on 8 September in preparation for harvest on 27 September 2006.

Soil Sampling and Analyses

Immediately prior to (17 April) and shortly after land-leveling activities were completed (29 and 30 April), elevation was measured using a laser level and stadia rod at each of the 50 grid points in each study area to characterize the relative elevational changes that occurred throughout the entire study area as a result of land leveling (Brye et al., 2006). In addition, within 2 weeks following land leveling, soil samples were collected from the top 4 in. (10 cm) from each of the grid points throughout the entire study area to characterize soil physical, chemical, and biological properties (Brye, 2006a; Brye et al., 2006).

A single 1.9-in. (4.8 cm) diameter soil core was collected from the 0- to 4-in. depth within an 8-in. (20-cm) radius surrounding each grid point, oven-dried at 70°C for 48 hr, and weighed for soil bulk-density determination (Brye et al., 2006). The soil-core sampling chamber was beveled to the outside to minimize compaction upon sampling. Oven-dry soil was subsequently crushed and sieved to pass a 0.08-in. (2-mm) mesh screen for particle-size analysis using the 2-hr hydrometer method (Arshad et al., 1996). Oven-dry soil was also used for soil-chemical property characterization [i.e., pH, electrical conductivity (EC), extractable nutrients, soil organic matter (OM), and total soil N and C] (Brye, 2006a). Soil pH and EC were determined with an electrode on a 1:2 soil-to-water solution. Soil sub-samples were extracted with Mehlich-3 extractant solution (Tucker, 1992) in a 1:10 soil-to-extractant-solution ratio and analyzed for extractable nutrients [i.e., P, K, calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu)] by inductively coupled argon-plasma spectrophotometry (CIROS CCD model, Spectro Analytical Instruments, Fitchburg, Mass.). Organic matter was determined by weight-loss-on-ignition after 2 hr at 360°C. Total soil C and N were determined by high-temperature combustion using a LECO CN-2000 analyzer (LECO Corp., St. Joseph, Mich.) and used to calculate soil C:N ratios.

A second set of samples consisting of 10, 0.8-in. (2-cm)-diameter soil cores were collected and composited from the 0- to 4-in. depth from within an 8-in. radius surrounding each grid point for total fungal and bacterial biomass determinations (Brye et al., 2006).

Extractable soil-nutrient and microbial biomass concentrations, expressed on a mass-per-mass basis, and the soil bulk density measured at each grid point were used to calculate extractable-nutrient and microbial biomass contents, expressed on a mass-per-area basis for the top 4 in. (10 cm) of soil.

Plant Response Measurements

At maturity each year, a 3-ft (1 m) section of the row straddling each grid point was cut at the soil surface and collected for total aboveground dry matter, yield, and partial harvest index determinations. Actual samples were collected on 22 October 2005 (soybean), 16 September 2005 (rice), and 26 September 2006 (rice). Plant samples were dried at approximately 30°C for two weeks in a forced-draft oven and weighed. In 2004, soybean samples were mechanically threshed to separate the seed from the remaining plant material. The seed was collected and weighed for soybean-seed yield determination. Similar to Brye et al. (2004b), for rice grown in 2005 and 2006, all panicles in a sample were cut and removed at the first node and weighed for rice-panicle yield determination. Soybean-seed and rice-panicle yields were divided by total aboveground dry matter to calculate a partial harvest index (PHI) at each grid point (Brye et al., 2004b).

Statistical Analyses

Whole-field summary statistics were calculated for post-leveling soil properties and annual crop-response variables. Linear correlations between post-leveling soil properties and annual crop-response variables (i.e., total aboveground dry matter, yield, and PHI) were initially performed. Multiple linear regression analyses were then performed to demonstrate the predictability of annual crop response based on all 25 post-leveling soil properties measured. All statistical analyses were conducted with Minitab (Minitab 13.31, Minitab Inc., State College, Pa.).

RESULTS AND DISCUSSION

Land-Leveling Effects on Soil Properties

Land leveling resulted in an average surface elevational change of -0.34 ft (-0.11 m; i.e., an overall cut), ranging from +0.19 (0.06 m; i.e., a fill) to -0.95 ft (-0.29 m), across the entire study area (Brye et al., 2006; Brye, 2006b). This degree of soil-surface manipulation represented a significant amount of soil deposition, removal, and relocation throughout the study area.

Land leveling also resulted in significant changes to near-surface soil properties. Numerous soil-property magnitudes increased or decreased significantly as a result of land leveling (Brye et al., 2006; Brye, 2006a). Few near-surface soil properties remained unaffected by land leveling (Brye et al., 2006; Brye, 2006a). Similar to soil-property magnitudes, the variability associated with many soil properties increased significantly due to land leveling (Brye et al., 2006; Brye, 2006a) resulting in a soil surface across the entire field that was less uniform after land leveling than before land leveling occurred.

As hypothesized, it was expected that the degree of subsequent crop uniformity across the entire field would be correlated to the degree of post-leveling soil property uniformity. Whole-field, post-leveling soil property statistics are summarized in Table 1.

Post-Leveling Crop Response

In 2004, the first growing season following land leveling, soybean aboveground dry matter averaged 6654 lb/acre, yield averaged 2633 lb/acre (43.9 bu/acre based on 60 lb/bu), and PHI averaged 0.36 across the entire study area (Table 2). Soybean yield immediately following land leveling was substantially greater than the estimated whole-field average of 33 bu/acre prior to land leveling (Sam Atchley, personal communication, 2005; Brye, 2006b). Therefore, it is clear that land leveling caused a positive crop response. However, the exact explanation for the positive crop response is still unclear since near-surface soil bacterial and fungal biomass (Brye et al., 2006), organic matter, total C and N, and extractable P (Brye, 2006a) all decreased significantly, while bulk density (Brye et al., 2006), pH, and extractable K, Ca, and Mg (Brye, 2006a) all increased significantly as a result of land leveling.

In 2005, the second growing season following land leveling, rice aboveground dry matter averaged 15,973 lb/acre, panicle yield averaged 8740 lb/acre (194 bu/acre based on 45 lb/bu), and PHI averaged 0.49 across the entire study area (Table 2). Rice had not been grown in this particular field recently, thus there is no field-specific, historic rice yield for comparison.

In 2006, the third growing season following land leveling, rice aboveground dry matter averaged 13,170 lb/acre, panicle yield averaged 6830 lb/acre (152 bu/acre based on 45 lb/bu), and PHI averaged 0.47 across the entire study area (Table 2). Rice aboveground dry matter, panicle yield, and PHI all decreased significantly ($P < 0.05$) from 2005 to 2006, but each crop response parameter had similar variabilities both years (Table 2).

Post-Leveling Soil Property and Crop Response Correlations

Immediate, post-leveling soil-property correlations to subsequent crop response were inconsistent, at best, from parameter to parameter and year to year (Table 3). In 2004, the first growing season following land leveling, aboveground soybean dry matter, yield, and PHI were generally weakly ($0.20 < | r | < 0.65$), though significantly ($P < 0.05$), correlated both positively and negatively with 7, 7, and 15, respectively, of the 25 post-leveling soil properties evaluated. Each crop-response variable in 2004 was significantly correlated with at least one post-leveling physical, chemical, and biological soil property evaluated.

In 2005, the first rice growing season after land leveling, aboveground dry matter, yield, and PHI were only weakly ($0.21 < r < 0.35$), though significantly ($P < 0.05$), positively correlated with 6, 6, and 0, respectively, of the 25 post-leveling soil properties evaluated (Table 3). Crop response was unrelated to any post-leveling soil biological property evaluated in 2005.

In 2006, the second consecutive rice growing season after land leveling, aboveground dry matter, yield, and PHI were again only weakly ($0.22 < | r | < 0.37$), though significantly ($P < 0.05$), correlated both positively and negatively with 2, 6, and 10, respectively, of the 25 post-leveling soil properties evaluated (Table 3). At least one of the three crop-response variables evaluated in 2006 was significantly correlated with at least one post-leveling physical, chemical, and biological soil property.

The lack of correlation consistency among soil properties and crop responses from year to year was somewhat surprising. For example, as one might expect, the more compacted the soil is (i.e., increasing bulk density), the poorer the crop response. This relationship was shown to exist for soybean in 2004, where aboveground dry matter was weakly ($r = -0.20$), though significantly ($P < 0.05$), negatively correlated with soil bulk density, indicating that as bulk density increased, aboveground dry matter tended to decrease (Table 3). However, the relationship was still significant, though opposite for soybean yield and PHI, where both were positively correlated ($0.22 < r < 0.53$) with soil bulk density. In 2005, rice response was unrelated to soil bulk density. However, in direct contrast to 2004, rice yield and PHI in 2006 were weakly, though significantly ($P < 0.05$), negatively correlated ($r = -0.26$ and -0.21, respectively) with soil bulk density.

One would also tend to expect crop response to be consistently correlated with other soil properties such as pH or organic matter. However, crop response was unrelated to soil pH in any of the first three growing seasons following land leveling (Table 3).

Similarly, crop response was unrelated to soil organic matter in the first two growing seasons, but soil organic matter was weakly, though significantly ($P < 0.05$), positively correlated ($r \approx 0.23$) with rice aboveground dry matter and yield in 2006, the third growing season following land leveling (Table 3).

Walker et al. (2003) demonstrated a significant correlation between rice yield and the amount of soil manipulated in an area (i.e., whether the area was a cut or a fill) in a recently leveled clay soil in Mississippi. However, in this study, the estimated amount of soil moved on a grid-point-by-grid-point basis was only weakly, though significantly ($P < 0.001$), positively correlated with rice yield ($r = 0.34$) and aboveground dry matter ($r = 0.32$) in 2005, the second growing season after leveling (Table 3). There was no correlation between estimated soil moved and yield for soybean in 2004 or rice in 2006. In contrast, rice PHI in 2006, the third growing season after leveling, was weakly, though significantly ($P < 0.01$), negatively correlated with estimated soil moved, indicating that rice PHI tended to be greater (i.e., greater grain mass per unit of total aboveground dry matter) in areas where soil was removed and tended to be smaller (i.e., less grain mass per unit of total aboveground dry matter) in areas where soil was added.

Based on a multiple linear regression approach using 25 post-leveling soil properties, including physical, chemical, and biological properties, the greatest degree of crop response predictability, as one might expect, was observed in the first growing season after land leveling (Table 4). The 25-variable regression model was significant for soybean aboveground dry matter ($P = 0.007$), yield ($P < 0.001$), and PHI ($P < 0.001$), but the models only explained between 42 and 58 % of the variability in crop response. Except for rice aboveground dry matter in 2005 ($P = 0.013$; $R^2 = 0.401$), the second growing season after leveling, the 25-variable regression models were non-significant for all other crop responses ($P > 0.09$) with only between 22 and 34 % of the crop response variability being explained with the comprehensive soil-property evaluation.

SIGNIFICANCE OF FINDINGS

In theory, land leveling is conducted to facilitate the delivery of irrigation waters to fields that under natural conditions have surfaces that undulate too much to uniformly apply water across the whole field. However, though improved uniformity of applied irrigation waters may be achieved, land leveling severely disrupts the biogeochemical equilibrium of the subsequent plow layer and root zone. Recent evidence exists that demonstrates how relatively shallow-cut land leveling in a silt-loam soil and relatively deep-cut land leveling in a clay soil in the rice-growing region of eastern Arkansas result in more spatially variable soil properties and crop response than existed prior to land leveling. The lack of apparent crop-response predictability based on a comprehensive post-leveling soil property evaluation indicates that the post-leveling management of recently leveled fields, regardless of soil texture (i.e., silt loam or clay), may be quite challenging to sustain high productivity beyond the initial few growing seasons. The observations made in this study regarding the lack of consistent soil-property correlations to crop response in a land-leveled clay soil suggest that possible solutions–such as variable-rate herbicide and fertilizer applications, deep-tillage to alleviate compaction during land leveling, and the addition of organic soil amendments like poultry litter–may not be as effective as once thought at improving the uniformity of crop growth and production in the long term.

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Table 1. Whole-field summary (n = 100) of post-leveling soil physical, chemical, and biological properties in the top 4 in. (10 cm) of a clayey Aquert in the Mississippi River Delta region of northeast Arkansas.

Soil property	Minimum	Maximum	Mean	SE[z]	CV[y]
					(%)
Physical					
Sand (%)	14	49	23	1.0	34.6
Silt (%)	14	28	22	<1.0	8.6
Clay (%^{1})	37	67	55	1.0	14.5
Bulk density (g cm^{-3})	1.09	1.76	1.34	0.01	10.5
Chemical					
pH	5.6	6.9	6.3	0.02	3.3
Electrical Conductivity (dS m^{-1})	0.14	0.39	0.25	0.01	20.6
Extractable P (kg ha^{-1})	21.6	123	51.5	1.9	37.0
Extractable K (kg ha^{-1})	274	504	367	4.5	12.2
Extractable Ca (kg ha^{-1})	3803	5833	4929	43	8.8
Extractable Mg (kg ha^{-1})	843	1292	1066	8.7	8.1
Extractable S (kg ha^{-1})	9.6	27.6	17.1	0.4	21.2
Extractable Na (kg ha^{-1})	28.0	139	73.3	2.7	36.5
Extractable Fe (kg ha^{-1})	196	389	272	5.0	18.3
Extractable Mn (kg ha^{-1})	28.6	137	28.7	3.1	45.0
Extractable Zn (kg ha^{-1})	3.0	56.5	5.4	0.5	102
Extractable Cu (kg ha^{-1})	0.04	6.9	4.9	0.1	17.9
Organic matter (%)	2.35	4.51	3.64	0.04	10.8
Total C (%)	1.06	2.07	1.39	0.02	17.0
Total N (%)	0.09	0.20	0.14	<0.01	15.8
C:N ratio	6.6	12.8	9.9	0.08	8.5
Biological					
Bacterial biomass (g m^{-2})	35.4	653	186	14.5	77.8
Fungal biomass (g m^{-2})	0.3	16.5	3.7	0.3	84.4
Fungal:bacteria biomass ratio	< 0.01	0.12	0.03	< 0.01	94

[z] Standard error (SE).

[y] Coefficient of variation (CV) based on absolute value of the mean.

Table 2. Whole-field summary (n = 100) of total aboveground dry matter ($AbvDM_{tot}$), seed yield, and partial harvest index (PHI) for three consecutive years following land leveling of a clayey Aquert in the Mississippi River Delta region of northeast Arkansas.

Year/plant property	Minimum	Maximum	Mean	SE[z]	CV[y]
					(%)
2004 - First growing season after leveling (soybean)					
$AbvDM_{tot}$ (lb/acre)	3518	8866	6654	98	14.5
Yield (lb/acre)[x]	1231	3743	2633	50	18.2
PHI	0.22	0.46	0.36	< 0.01	12.5
2005 - Second growing season after leveling (rice)					
$AbvDM_{tot}$ (lb/acre)	7411	22973	15973	339	21.0
Yield (lb/acre)[w]	3720	12430	8740	190	22.3
PHI[v]	0.39	0.71	0.49	< 0.01	8.2
2006 - Third growing season after leveling (rice)					
$AbvDM_{tot}$ (lb/acre)	6250	22580	13170*[u]	339	25.9
Yield (lb/acre)[w]	3220	11080	6830*	170	25.4
PHI[v]	0.31	0.55	0.47*	< 0.01	9.3

[z] Standard error (SE).

[y] Coefficient of variation (CV).

[x] Soybean yield is expressed at 13 % moisture.

[w] Rice yield is based on mass of panicles cut above first node and expressed at 12% moisture.

[v] Partial harvest index (PHI) for rice calculated based on total aboveground dry matter and dry mass of panicles cut above first node.

[u] An asterisk denotes significant difference based on paired *t*-tests between 2005 and 2006 rice crop.

Table 3. Summary of significant linear correlations (*r*; n = 100) between immediate post-leveling, top 4-in. (10 cm) soil properties and total aboveground dry matter ($AbvDM_{tot}$), yield, and partial harvest index (PHI) for three consecutive years following land leveling of a clayey Aquert in the Mississippi River Delta region of northeast Arkansas. Asterisks denote significant correlations at $P \le 0.05$ (*), $P \le 0.01$ (**), or $P \le 0.001$ (***). Non-significant correlations are denoted with NS.

	2004 - Soybean			2005 - Rice			2006 - Rice		
Soil property	$AbvDM_{tot}$	Yield	PHI	$AbvDM_{tot}$	Yield	PHI	$AbvDM_{tot}$	Yield	PHI
Elevation change	NS	NS	NS	0.34***	0.32***	NS	NS	NS	0.30**
Estimated soil moved	NS	NS	NS	0.35***	0.33***	NS	NS	NS	0.30**
Sand	-0.28**	NS	0.51***	NS	NS	NS	-0.20*	-0.24*	NS
Silt	NS	NS	NS	NS	NS	NS	NS	NS	NS
Clay	0.29**	NS	-0.55***	NS	NS	NS	NS	0.25*	NS
Bulk density	-0.20*	0.22*	0.53***	NS	NS	NS	NS	-0.26**	-0.21*
pH	NS	NS	NS	NS	NS	NS	NS	NS	NS
Electrical conductivity	NS	NS	-0.35***	NS	NS	NS	NS	NS	NS
Extractable P	NS	0.22*	0.50***	NS	NS	NS	NS	NS	-0.22*
Extractable K	NS	NS	NS	0.35***	0.30**	NS	NS	NS	-0.33***
Extractable Ca	0.23*	NS	-0.21*	NS	NS	NS	NS	NS	NS
Extractable Mg	0.22*	NS	NS	NS	NS	NS	NS	NS	NS
Extractable S	NS	NS	NS	NS	NS	NS	NS	NS	-0.21*
Extractable Na	NS	-0.21*	-0.50***	NS	NS	NS	NS	NS	NS
Extractable Fe	NS	0.33***	0.65***	NS	NS	NS	NS	-0.23*	-0.21*
Extractable Mn	NS	NS	0.30**	0.23*	0.24*	NS	NS	NS	-0.37***
Extractable Zn	-0.25*	NS	0.25*	NS	NS	NS	NS	NS	NS
Extractable Cu	NS	NS	-0.22*	NS	NS	NS	NS	NS	NS
Organic matter	NS	NS	NS	NS	NS	NS	0.24*	0.23*	NS
Total C	NS	NS	0.31**	0.25*	0.24*	NS	NS	NS	-0.26**
Total N	NS	NS	NS	0.21*	0.21*	NS	NS	NS	NS
C:N ratio	NS	0.28**	0.52***	NS	NS	NS	NS	-0.22*	NS
Bacterial biomass	NS	0.27**	0.44***	NS	NS	NS	NS	NS	NS
Fungal biomass	-0.23*	NS	0.28**	NS	NS	NS	NS	NS	-0.22*
Fungal:bacterial biomass ratio	NS	-0.20*	NS	NS	NS	NS	NS	NS	NS

Table 4. Linear regression summary of whole-model *P* and R^2 values when 25 immediately post-leveling soil properties were used as a comprehensive set of soil evaluation data to predict subsequent crop growth and production parameters [i.e., total aboveground dry matter ($AbvDM_{tot}$), yield, and partial harvest index (PHI)].

Year/plant property	Whole-model *P*	R^2
		(%)
2004 - Soybean		
$AbvDM_{tot}$	0.007	41.9
Yield	< 0.001	47.8
PHI	< 0.001	58.2
2005 - Rice		
$AbvDM_{tot}$	0.013	40.1
Yield	0.106	33.1
PHI	0.437	25.9
2006 - Rice		
$AbvDM_{tot}$	0.694	22.0
Yield	0.356	27.2
PHI	0.091	33.7

A Model to Predict Safe Stages of Development for Draining Rice Fields

P.A. Counce, K.B. Watkins, and T.J. Siebenmorgen

ABSTRACT

A computer program has been developed to predict the stage of development for draining rice at which the risk of reduced grain yield or milling quality from insufficient water is considered zero. Experiments to test the predictions were conducted in 2006: one experiment each at Dewitt, Gillett, and Stuttgart, Ark. The model predicted the safe stage for draining was R7 (one grain on the main stem panicle is yellow) for all three locations. Yields were not reduced by draining at the R7 stage of development compared to later stages of development. Draining at R7 allows a minimum water savings of one irrigation. Budget analysis led us to predict water savings from one-less 3-in. irrigation could range between \$3.97 to \$18.82/acre depending on flood depth. Consequently, our tests in 2006 showed that the program predictions allowed earlier draining, water savings, and no losses of grain yield or of milling quality.

INTRODUCTION

A rice-growth staging system has been developed to allow clear communication among farmers, researchers, extension personnel, and others working with rice (Counce et al, 2000). Research on the growth-staging project has allowed us to time the intervals between the different reproductive growth stages after heading (Watson et al., 2005; Clements et al., 2003). This is partially because of the objective features of the staging system, which allow clear determination of each growth stage. Generally, rice yield is sensitive to water stress through the R9 (all grains that reached R6 have a brown hull) growth stage. This is the case for corn and grain sorghum as well–the crops are sensitive to drought stress until the kernels are filled.

We assume that any water deficit prior to crop maturity is likely to lead to reductions in both rough-rice yield and milling quality. With this caveat in mind, it is worthwhile draining as early as possible without reducing rough-rice yield or milling quality. Consequently, we are faced with the prospect that rice can in some cases be drained 2 weeks after 50% heading without reducing yield or quality and the other fact that the plant is sensitive to drought stress until the kernels have filled. It is apparent that the soil profile contains significant water after draining and this water can prevent drought stress. Within the root zone of a DeWitt silt loam soil with 4 to 8 in. to the impervious layer, there are 2.6 to 4.0 in. of water available to the rice crop after draining [0.44 in. of water per inch of soil (Davis, 2002)]. The crop uses between 0.33 in./day at the R3 growth stage (heading or emergence of the main stem panicle) and 0.2 in. at the R8 growth stage (one or more brown kernels on the head) (Lage et al., 2003). Therefore, water use by the rice crop is great as heads emerge, progressively less as the grain develops, and very low towards harvest.

With these three elements–intervals between growth stages in DD50 units, water use at different growth stages, and soil water content at draining–an Excel computer program has been developed to predict the safe growth stage for draining rice. Data needed for input are soil type, rooting-zone depth, and the projected (or actual) date of 50% heading. There are reproductive data sets with DD50 determinations for different cultivars (Watson et al., 2005; Clements et al., 2003). The outputs from the program are a predicted growth stage and date of that stage for safely draining the rice field without reducing grain yield or milling quality. Results of three experiments to test the model are reported.

PROCEDURES

At Stuttgart, the control treatment was drained 28 days after heading (DAH). At Gillett, the control treatment was drained 21 DAH and an additional treatment that was bounded by metal frames was drained at 21 DAH. The purpose of including a treatment with metal frames was to evaluate whether or not the metal frames themselves affected the crop response.

At the DeWitt site, the control treatment irrigation was terminated (but was not drained) 1 day after draining at the R7 stage. A summary of the different treatments at each location is given in Table 1.

The first experiment was grown on a Stuttgart silt loam soil within a 132-acre rice field approximately 3 miles southwest of DeWitt (DeWitt location). The second experiment was also grown on a Stuttgart silt loam soil within a 57-acre rice field at Gillett, Ark. The plots were 4-ft. by 8-ft. areas bordered by 14-gauge sheet metal 8 in. above the soil surface and driven into the soil 8 in. deep (the depth of the impervious layer). The experiment at Stuttgart was conducted on a DeWitt silt loam soil with field plots 34-ft. wide by 120-ft. long. Each plot at Stuttgart was bounded by its own normal, earth levees.

The model has three components: (1) prediction of reproductive growth-stage intervals with DD50 units; (2) prediction of maximum water use for each growth-stage interval; and (3) prediction of plant available water for a given soil at draining. The timing between reproductive stages of development was noted in the field for selected plants of several rice cultivars with the timing through their development noted. Subsequently, calculations of DD50 intervals were made (Watson et al., 2005; Clements et al., 2002). Maximum water-use values per day were derived from Lage et al. (2003) and were multiplied by the number of days for a given site and growth stage. The length of specific developmental periods at a given location was determined from the number of DD50 units required for a given stage of development and historical maximum and minimum temperatures at the site for that calendar period. Soil water available after draining was determined by multiplying the depth of the effective root zone by the inches of water available per inch of soil. Soil water-supplying properties can be estimated (among other sources) from Davis (2002). Beyrouty et al. (1996) determined that, although some roots extend to 16 in., greater than 90% of the roots are in the upper 8 in. Beginning at R9 and working backward, the amount of water to reach each previous stage of development was summed. First, the water used from R9 to R8, then the amount of water used from R9 to R7, then R9 to R6, etc. At a given reproductive growth stage, if the amount of water in the cumulative water-use column is less than or equal to the amount of soil water available at draining, it is safe to drain.

The goal of the program is to allow growers to save money by draining rice without reducing rice grain yield or milling quality. Consequently, the predictions are to be conservative to ensure the rice plant has enough water available so that yield and quality are not reduced. To improve safety, three assumptions are made: (1) no rainfall will occur after draining the rice field; (2) maximum water use by the crop at each growth stage; and (3) no water will be extracted below 8 in. even in the absence of an impervious layer at 8 in. Some rice roots, even with an impervious soil layer, do penetrate below this depth (Sharma et al., 1994; Beyrouty et al., 1996). We know that some of these three assumptions may not be true and, consequently, they add a measure of safety to the model's predictions. Plots were harvested by hand with a sickle and threshed with a stationary thresher. Rough-rice harvest moisture content, rough-rice yield, and milling quality were determined shortly after harvest for each plot. Subsequently, grain was dried in shallow metal pans at room temperature for one to 12 hours and stored in two plastic bags within each other at approximately 45°F until transported to Fayetteville for precision drying, and for determination of brown-, milled-, and head-rice yield. Data were subjected to analysis of variance.

RESULTS AND DISCUSSION

Water-use predictions cumulative to R9 backward indicate the safe stage of growth for draining rice would be R7 for all three locations (Table 2). Grain yields did not differ between controls and plots drained by growth stage predictions at the DeWitt and Stuttgart locations. At the Gillett location, the control without steel borders yielded more than either the control with borders or the plots drained by growth-stage predictions (Table 3). At the Gillett site, culms were counted from the harvested area and these data used for analysis of covariance with population as a covariant. The covariance analysis indicated the significant difference in rough-rice yields was the result of suboptimal population in the areas with steel borders and the unbordered areas. The analysis of covariance further revealed that, with the covariant taken into account, there was no significant effect of treatment at Gillett. There was no significant reduction in head-rice yields due to early draining using the computer program developed at any of the three locations where the study was conducted (Table 4).

Given the results of these experiments, it is reasonable to expect a minimum savings of one irrigation could be realized. Given this irrigation savings, cost savings of $3.97 to $18.82/acre could be realized by employing the program (Table 5).

SIGNIFICANCE OF FINDINGS

Water-pumping costs are a significant part of the costs of producing rice. The goal is to provide all the water needed to produce the maximal rough-rice and head-rice yield. The earlier draining permitted by using the output from the computer draining program resulted in no reductions in either rice-grain yield or milling quality. In addition, budget analysis revealed water savings from $3.97 to $18.82/acre depending upon water depth.

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Table 1. Dates of draining treatments for three experiments on draining rice conducted on the Arkansas Grand Prairie in 2006.

Draining treatments	DeWitt	Gillett	Stuttgart
Drain at R7[z]	19 July	7 August	7 August
21 DAH[y]	---	15 August	---
21 DAH - bounded	---	15 August	---
28 DAH	---	---	21 August
R7 + 1 day[x]	24 July	---	---

[z] Date (growth stage) at which one grain on main-stem panicle is yellow.

[y] DAH, days after heading.

[x] Treatment was drained at 21 DAH and plot was bounded by metal frames driven into soil.

[w] Irrigation was terminated July 20, but soil was saturated on July 24, similar to a recently drained field.

Table 2. Projections for crop-water use by Wells rice at three locations (DeWitt, Gillett, and Stuttgart) on the Arkansas Grand Prairie in 2006.

Rice growth stage[z] (RGS) interval	Maximum water use/day	Cumulative water use DeWitt	Gillett	Stuttgart
	(in.)			
R3-R4	0.256	4.65	5.47	5.42
R4-R5	0.236	3.88	4.47	4.47
R5-R6	0.209	3.00	3.39	3.39
R6-R7	0.189	2.42	2.68	2.68
R7-R8	0.118	1.49	1.54	1.54
R8-R9	0.079	0.91	0.80	0.82
Available soil moisture	-	1.54	1.54	1.72
Predicted Safe RGS	-	R7	R7	R7

[z] Rice Growth Stage (RGS) morphological markers: R3 - Panicle exertion from boot, tip of panicle is above collar of flag leaf on main stem; R4 - One or more floret on main stem panicle has reached anthesis; R5 - At least one caryopsis on the main stem panicle is elongating to the end of the hull; R6 - At least one caryopsis on the main stem panicle has elongated to the end of the hull; R7 - At least one grain on the main stem panicle has a yellow hull; R8 - At least one grain on the main stem panicle has a brown hull; R9 - All grains which reached R6 have brown hulls.

Table 3. Grain yield of Wells rice from draining experiments at three locations on the Arkansas Grand Prairie in 2006.

Teatment	Grain yield DeWitt	Gillett	Stuttgart
	(bu/acre)		
Drained by program predictions at Rice Growth Stage R7[z]	161.3	169.2	187.3
Control[y]	169.4	175	185.6
2nd Control[x]	--	212	--
CV (%)	7.68	11.43	6.56
Significance	NS[w]	*[v]	NS

[z] Rice Growth Stage R7 is when one grain on the main stem panicle has turned yellow.

[y] Controls were as follows: Cease adding irrrigation water on the days of draining at DeWitt, drain at 21 days after 50% heading at Gillett, and drain at 28 days after 50% heading at Stuttgart.

[x] The 2nd Control was done only at Gillett and consisted of a plot area which was not bounded by the metal frames as were the other two treatments.

[w] NS = not significant.

[v] The yield difference at Gillett was between the areas bounded by the metal frames and the areas not bounded by metal frames.

Table 4. Head rice yield of Wells rice from draining experiments at three locations on the Arkansas Grand Prairie in 2006.

	Head rice yield		
Teatment	DeWitt	Gillett	Stuttgart
	---------------------(%)----------------------		
Drained by program predictions at Rice Growth Stage R7[z]	51.3	55.9	61.9
Control[y]	53.4	57.4	62.0
2nd Control[x]	--	59.2	--
CV (%)	2.84	5.42	1.03
Significance	NS[w]	NS	NS

[z] Rice Growth Stage R7 is when one grain on the main stem panicle has turned yellow.

[y] Controls were as follows: Cease adding irrigation water on the days of draining at DeWitt, drain at 21 days after 50% heading at Gillett, and drain at 28 days after 50% heading at Stuttgart.

[x] The 2nd Control was done only at Gillett and consisted of a plot area which was not bounded by the metal frames as were the other two treatments.

[w] NS = not significant.

Table 5. Variable cost savings associated with a 3 acre-inch reduction in applied water for varying pump lifts.

	Pump lift (ft)					
Variable cost item	50	100	150	200	250	300
Diesel consumption (gal/acre-in)[z]	0.43	0.9	1.3	1.72	2.15	3.01
Fuel & lubrication cost ($/acre)[y]	3.27	5.7	8.5	11.4	14.2	17
Repairs & maintenance cost ($/acre)[x]	0.28	0.3	0.4	0.4	1.35	1.35
Labor cost ($/acre)[w]	0.43	0.4	0.4	0.43	0.43	0.43
Total cost savings ($/acre)	3.97	6.4	9.4	12.2	16	18.8

[z] Diesel consumption was varied by pump lift using an engineering formula supplied by Dr. Phil Tacker (University of Arkansas Extension Agricultural engineer).

[y] Fuel consumption for 3 acre-inches multiplied by $2.20/gal for on-farm diesel (2006 Arkansas rice budgets) plus $0.33/gal for engine oil.

[x] Derived from 2006 Arkansas rice budgets. Values for deeper pump lifts were adjusted upward to reflect greater repair expenditures for larger wells.

[w] Derived from 2006 Arkansas rice budgets. Assumes a labor wage of $8.12/hour.

RICE CULTURE

Seasonal Accumulation of ^{15}N-Labeled Nitrogen Fertilizer by Two Rice Cultivars Grown on an Arkansas Clay Soil

D.L. Frizzell, R.J. Norman, C.E. Wilson, Jr., N.A. Slaton, and P.K. Bollich

ABSTRACT

Rice (*Oryza sativa* L.) grown on a clay soil in a direct-seeded, delayed-flood system as used in the southern U.S. requires 30 to 60 lb/acre more nitrogen (N) fertilizer to achieve maximal grain yields compared to rice grown on silt loam soils. Seasonal N fertilizer accumulation studies are almost non-existent for rice grown on clay soils. Therefore, a two-year field study was conducted to evaluate uptake of fertilizer ^{15}N applied preflood to 'Wells' and 'Cocodrie' rice grown on a Perry clay (very-fine, smectitic, thermic, Typic Epiaquert). Aboveground plant samples were taken throughout the season for total dry matter, total N, and fertilizer ^{15}N accumulation. Grain yield was higher for Cocodrie during 2000 and Wells during 2001. Fertilizer ^{15}N accumulation patterns were dissimilar between study years. Fertilizer ^{15}N uptake in both cultivars was maximized at 50% heading during 2000. However, during 2001, peak ^{15}N uptake occurred at 21 or 28 days after flooding, which is comparable to previous fertilizer ^{15}N uptake studies of rice grown on silt loam soils. In 2001, the preflood-N fertilizer application had to be delayed for a week or two because of wet soil conditions from frequent rains. The resulting delay in preflood-N fertilizer application to larger rice plants with probably a large root biomass led to a rapid uptake of preflood-N fertilizer with an efficiency of around 70%. Consequently, delaying the preflood-N fertilizer and flood on clay soils a week or two past the 4- to 5-lf growth stage might result in increased root biomass and allow rice grown on clay soils to utilize fertilizer-N more efficiently.

INTRODUCTION

The dry-seeded, delayed-flooded rice (*Oryza sativa* L.) production system is commonly utilized in the southern U.S. rice belt. In this production system, rice plants emerge and grow upland until the 4- to 5-lf growth stage. At this time, a large nitrogen (N) fertilizer rate, termed preflood-N, is applied to a dry soil surface and a permanent flood established and maintained until just prior to harvest. This large preflood-N fertilizer application has been shown in University of Arkansas N-fertilizer rate studies to be a major component in determining rice-grain yield (Norman et al., 2001, 2003, 2005). These same studies have also shown that rice grown on clay soils requires 30 to 60 lb/acre more N fertilizer to achieve maximal grain yields compared to rice grown on silt loam soils. With approximately 40% of the rice in Arkansas grown on clay soils (Wilson and Branson, 2006), and with a 90 to 115% increase in urea fertilizer cost from 2000 to 2005 (Moss, personal communication, 2005), there is interest in knowing the reason additional N fertilizer is necessary to achieve maximal rice grain yield when grown on clay soils compared to silt loam soils. Although clay soils generally have higher N content than silt loam soils, it has been surmised that more N fertilizer is required on clay soils to meet the N needs of the rice plant because diffusion is slower in clay soils compared to silt loams (Trostle et al., 1998). Thus, more N fertilizer is required on clay soils to overcome diffusion constraints of the N fertilizer moving through the soil to the rice root.

The most widely used conventional cultivars, such as Wells, reach the time of transition from vegetative growth to reproductive growth, known as panicle initiation, approximately 21 days after establishment of the permanent flood, but Cocodrie begins panicle initiation approximately 14 days after flooding (Wilson et al., 2005). With Cocodrie reaching panicle initiation 5 to 7 days earlier than other popular conventional cultivars, there is concern this shortened time of vegetative growth would be detrimental to N uptake during the vegetative stage.

Seasonal N-accumulation studies using a single preflood-^{15}N application to delayed-flood rice grown on a Crowley or DeWitt silt loam have shown peak fertilizer-N uptake at 21 days after flooding (Wilson et al., 1989; Bufogle et al., 1997; Guindo et al., 1994a) and 28 days after flooding (Norman et al., 1992a). The only study utilizing a single preflood-^{15}N application to delayed-flood rice grown on a clay soil found a maximum fertilizer-N uptake by rice of 50.3% (Norman et al., 1992b). This study was sampled only at heading and did not establish seasonal N-uptake patterns. There appear to be no published studies examining the seasonal N-uptake patterns of dry-seeded, delayed-flood rice grown on a clay soil. With preflood-N application having a major influence in determining rice grain yield, seasonal N-uptake studies of currently grown cultivars are important. Therefore, a study was initiated to compare the seasonal N-uptake patterns of two prevalent rice cultivars, Wells and Cocodrie, grown on a southern U.S. clay soil utilizing a delayed-flood production system.

MATERIALS AND METHODS

The experiment was conducted during 2000 and 2001 at the University of Arkansas Southeast Research and Extension Center on a Perry clay (very-fine, smectitic, thermic, Typic Epiaquert) that previously had been cropped to soybean (*Glycine max* (L.) Merr). Two rice (*Oryza sativa*, L.) cultivars, Wells and Cocodrie, were seeded at a rate of 100 lb/acre with a 6-in. row spacing.

Several days prior to N fertilization and flood establishment, microplots were established by enclosing eight rows of rice of 30 in. in length in galvanized steel collars. The collars were driven 4 in. into the ground leaving 8 in. aboveground to minimize N fertilizer movement in the soil or floodwater. Nitrogen-15 (2 atom% ^{15}N)-labeled urea fertilizer was applied at a rate of 150 lb N/acre as a single preflood treatment to dry soil at the 4- to 5-lf growth stage. The preflood-N fertilizer application was delayed for over 2 weeks past the 4- to 5-lf growth stage in 2001 due to frequent rainfall and lack of a dry seedbed. Rice outside the collars was not fertilized with N to avoid addition of non-labeled N into the plots when water was added from the surrounding bay. The plots were flooded immediately after N fertilization to a depth of 4 in. and maintained by hand until 21 days after physiological maturity (78 days after flood establishment).

Plant samples were collected 7, 14, 21, 28, 42, 56, or 77 days after flooding (DAF) by removing all aboveground plant material from either the second and third or sixth and seventh rows of selected plots. All plant material was oven-dried at 60°C, dry weights were determined, and samples were ground to pass thru a 1-mm sieve. Samples taken at 28 DAF during 2001 were improperly dried and were excluded from N analysis. Samples were analyzed for N using the Kjeldahl digestion-distillation method and distillates analyzed for atom % ^{15}N at the University of Illinois on Nuclide/MAAS 3-60 RMS double collector mass spectrometer. Grain yield was determined by harvesting two center rows from each plot and then threshing with a small-plot thresher. Grain moisture was determined and all grain yields were expressed on a 12% moisture basis.

The study was designed as a split-plot with cultivars as the main plot and sampling date as the sub-plot. The study had four replications. The data were analyzed using Fisher's Least Significant Difference (SAS Institute, 2001).

RESULTS AND DISCUSSION

Grain Yield

Wells and Cocodrie had yields of 151 and 170 bu/acre in 2000, respectively, and in 2001 yields of 201 and 165 bu/acre, respectively (Table 1). These yields compare favorably with grain yield data reported in cultivar evaluation programs during this time, which showed a mean grain yield of 181 bu/acre for Wells and 169 bu/acre for Cocodrie (Moldenhauer et al., 2002).

Fertilizer N Accumulation

In 2000, N fertilizer accumulation of both cultivars increased significantly in the whole plant from 7 to 56 DAF to maximize at about 64% of the applied fertilizer N and remained constant from 56 to 77 DAF (Table 2). This uptake pattern is in contrast to earlier studies where preflood-N applied to rice at the 4- to 6-lf growth stage reached a peak N accumulation at 21 to 28 DAF on a Crowley silt loam soil (Bufogle et al., 1997; Guindo et al., 1994a; Norman et al., 1992a; Wilson et al., 1989). However, this N-uptake pattern does agree with individual study years of Bufogle et al., (1997) and Guindo et al., (1994b) during which peak fertilizer-N uptake occurred after heading. The relatively low N fertilizer uptake rate between N fertilizer application and panicle differentiation (28 DAF) appears to substantiate the laboratory study by Trostle et al, (1998), which showed greater ammonium-diffusion constraints in clay versus silt loam soils used for Texas rice production. The greater ammonium-diffusion constraints in clay soils versus silt loam soils would slow the N fertilizer accumulation rate by rice.

Although the N fertilizer uptake pattern is dissimilar to earlier studies on silt loam soils, the fertilizer accumulation of 64% does compare favorably to the above-mentioned studies. With fertilizer N uptake continuing to increase throughout 2000, it would appear that sufficient fertilizer-N remained available in the soil to meet plant-N requirements and optimize grain yield.

In 2001, Wells whole plant did not appear to reach maximal N fertilizer accumulation until 77 DAF, but the decline in N fertilizer accumulation between 14 DAF and 56 DAF probably indicates an analysis error for the 77 DAF sample date rather than a sudden release of fertilizer N from the N pool at physiological maturity (Table 2). Disregarding the 77 DAF samples, Wells obtained maximal whole-plant fertilizer-N uptake of 70.0% at 14 DAF (at ½-in. internode elongation), then remained relatively stable from 21 to 56 DAF. The same N-fertilizer accumulation pattern was seen in the Cocodrie whole plant with the exception of peak fertilizer uptake of 78.6% occurring at 21 DAF (½-in. internode elongation + 7 days) rather than at 14 DAF. During 2001, both cultivars had accumulated at least two times more fertilizer-N in the panicles at 50% heading than during 2000, but by heading + 21 days, fertilizer-N uptake was comparable between study years.

The 2001 study year appears to be in contrast to previous studies showing N fertilizer uptake at 21 to 28 days after flooding (Bufogle et al., 1997; Guindo et al., 1994a; Wilson et al., 1989; Norman et al., 1992a), but when growth stage is considered, previous and present studies are in agreement that peak uptake occurs at panicle differentiation (½-in. internode elongation; Table 2). The exception to this is Cocodrie, where peak uptake occurs after reproductive growth has begun. In comparison to 2000, 2001 showed a greater accumulation of fertilizer-N for both cultivars and a definite peak uptake period at, or just after, panicle differentiation. This could be attributed to the development of larger root systems prior to preflood-N and flood application in 2001 compared to 2000, but as root biomass was not measured, this is only speculation. Norman et al., (1992b) found increased fertilizer-N accumulation with delay in flood at both SEREC and RREC, but root biomass was also not measured in that study.

Other studies using midseason N fertilizer applications showed N was taken up in 3 days (Wilson et al., 1989), 7 days (Guindo et al., 1994a,b) or 14 days after application (Norman et al., 1992a), which suggests that older plants have greater capacity for fertilizer-N accumulation due to larger root systems.

SIGNIFICANCE OF FINDINGS

Grain yield was higher for Cocodrie during 2000 and Wells during 2001. Both study years compare favorably to the grain yields from cultivar evaluation programs of the same period.

During 2000, whole-plant fertilizer-N accumulation increased from 7 to 56 DAF and then remained constant between 56 and 77 DAF. This contrasts to earlier studies on silt loam soils in which fertilizer uptake was maximized at 21 to 28 DAF. During 2001, whole-plant fertilizer-N accumulation was maximized in Wells at panicle differentiation and in Cocodrie at panicle differentiation + 7 days which is in agreement with the time of peak uptake in earlier studies.

Since previous N fertilizer-rate studies have shown grain yield is determined by the preflood-N application, efficient N uptake by the rice plant prior to reproductive growth may be critical to achieving optimal fertilizer-N uptake rates on a clay soil. With the sharp increase in fertilizer N accumulation seen during the 2001 season when flooding was delayed beyond the recommended 4- to 5-lf growth stage, there may be potential for delaying preflood-N and permanent flood on a clay soil until the rice plant has had time to develop a more sufficient root biomass. This increased root mass might allow the rice plant to utilize fertilizer-N more efficiently and earlier in the season.

With such a small database of seasonal-N uptake of rice grown on clay soils, more studies are needed to address the differences in seasonal uptake patterns between clay and silt loam soils.

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Table 1. Influence of cultivar on grain yield at the Southeast Research and Extension Center near Rohwer, Ark., during 2000 and 2001.

	Grain yield	
Cultivar	2000	2001
	(bu/acre)	
Wells	151	201
Cocodrie	170	165
LSD$_{(\alpha=0.05)}$	12	24

Table 2. Influence of cultivar and sampling date on fertilizer-N uptake, shown as a percentage of N fertilizer applied, at the Southeast Research and Extension Center near Rohwer, Ark., during 2000 and 2001.

	Fertilizer N uptake								
	2000			2001					
Sample	Shoots	Panicles	Whole plant	Shoots		Panicles		Whole plant	
timing	mean	mean	mean	WLLS^z	CCDR	WLLS	CCDR	WLLS	CCDR
(DAF^y)	(% of applied N)								
7	6.0	---	6.0	20.9	22.6	---	---	20.9	22.6
14	14.4	---	14.4	70.0	61.8	---	---	70.0	61.8
21	27.4	---	27.4	68.5	78.6	---	---	68.5	78.6
28	39.9	---	39.9	---	---	---	---	---	---
42	45.2	---	45.2	62.5	70.2	---	---	62.5	70.2
56	60.4	3.7	64.1	49.3	58.8	7.3	11.7	56.6	70.5
77	36.3	28.3	64.6	48.8	30.9	32.5	26.4	81.3	57.3
LSD$_{(\alpha 0.05)}$ within cultivar	4.8^x	2.9	4.9	9.7		5.6		10.1	
LSD$_{(\alpha=0.05)}$ between cultivars				9.3		5.4		9.8	

[z] WLLS = ‘Wells’; CCDR = ‘Cocodrie’.

[y] DAF = days after flooding.

[x] Cultivar x sample date interaction not significant during 2000.

Influence of Row Spacing and Seeding Rate on Grain Yield of Hybrid Rice

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ABSTRACT

Recent interest by producers, researchers, and industry personnel concerning the use of grain drills utilizing 7-in. versus 10-in. row spacing have raised questions as to the optimal drill-row spacing for rice. With the increase in hybrid rice produced and the associated low seeding rates, questions arose regarding the response of these cultivars to row widths. The objective of this study was to determine the effect of row spacing and seeding rate on grain yield of hybrid rice. The rice hybrid RiceTec 'XL 723' was seeded at the Lake Hogue Research Farm during 2006 using 7-in. or 10-in. drill-row spacing or broadcast-seeding methods. Seeding rates of 10, 20, 30, and 40 lb seed/acre were used with each of the seeding methods. Results from 2006 indicated 7-in. row spacing produced approximately 10 bu/acre more grain than either the 10-in. row spacing or the broadcast-seeding methods. Rice-grain yield was similar between the 30 and 40 lb/acre seeding rates, but was significantly lower at the 10 and 20 lb/acre seeding rates.

INTRODUCTION

Hybrid rice is typically seeded at approximately 30 lb/acre compared to 67 to ll2 lb/acre for most conventional varieties. Despite the lower seeding rate, hybrids generally exhibit plant biomass visually comparable to most conventional varieties beginning at approximately midtillering and continuing throughout the growing season. This results because of the extensive tillering of hybrid rice. With the recent interest generated by producers and industry personnel concerning the use of grain drills utilizing 7-in. versus

10-in. row spacing, questions have also arisen concerning the optimal drill-row spacing for hybrid rice. With this in mind, a study was initiated in 2006 to examine the effect of drill-row spacing and seeding rates on grain yield of hybrid rice.

PROCEDURES

The study was conducted during 2006 on the Lake Hogue Research Farm in Poinsett County, southwest of Waldenburg, Ark., on a Hillemann silt loam (fine-silty, mixed, thermic, Albic Glossic Natraqualfs) that had previously been cropped to soybean *[Glycine max* (L.) Men]. The rice hybrid RiceTec XL723 was seeded on 4 April at rates of 10, 20, 30, and 40 lb/acre (Table 1) into 16-ft long plots utilizing 7- or 10-in. drill-row spacing or broadcast-seeding methods. Emergence of both the 7- and 10-in. drill-row spacing treatments was 16 April, and 29 April for the broadcast-seeding method. Stand density determinations were made on 11 May by counting plants per 3-row feet in the 7- and 10-in. drill-row treatments and counting plants in three 1-ft square areas of the broadcast-seeded treatments. All stand densities were reported as plants/ft^2. Grain yield was determined on a 12-ft-long section of each plot by harvesting the center five rows of 7-in. row-spacing plots, the center three rows of the 10-in. drill-row spacing plots, and the center 30-in. of the broadcast-seeded plots using a small-plot combine. The study was harvested 13 September, and grain yield was adjusted to 12% moisture content. Analysis of variance was performed using Fisher's protected Least Significant Difference method.

RESULTS AND DISCUSSION

Stand Density

Broadcast-seeding resulted in greater stand density than drill-seeding rice during 2006. (Table 2). Broadcast-seeding resulted in an average stand density of 9.6 plants/ft^2 compared to 5.6 and 5.2 plants/ft^2 for the 10- and 7-in. row spacings, respectively. This was unexpected due to the variability in incorporation of broadcast-seeded rice. Drill-seeded rice typically results in more uniform seeding depth and less seed exposed to the soil surface where dessication or bird predation can be significant. General observations suggest that the drill-seeded rice emerged more uniformly and more rapidly. While the broadcast-seeded rice emerged over a longer period of time, more rice emerged than the from drill-seeded rice.

Stand density generally increased from 4.7 to 9.3 plants/ft^2 as seeding rate increased from 10 to 40 lb/acre (Table 3). While increasing seeding rate is expected to increase stand density, the percentage of planted seed that emerged decreased as the seeding rate increased. Seeding rates of 10 lb/acre, which is approximately 4 seeds/ft^2, resulted in approximately 100% emergence. However, the percentage of planted seeds that emerged at the highest seeding rate was just over 50% (Tables 1 and 3).

Grain Yield

Row spacing did not significantly influence grain yield of Rice Tec XL 723 during 2006 (Table 2). However, these data do exhibit a strong tendency toward increased grain yield with the 7-in. drill-row spacing as compared to either the 10-in. drill-row spacing or the broadcast-seeding methods. Previous studies comparing row widths for conventional varieties suggested that narrow rows may be preferable to wider rows (Frizzell et al., 2006). Grain yields in the previous studies were consistently higher across locations and study years for conventional varieties seeded using the 7-in. drill-row spacing compared to 10-in. row spacing.

The influence of seeding rate on grain yield of Rice Tec XL723 hybrid rice was significant during 2006 (Table 3). Grain yield increased as seeding rate increased from 10 to 40 lb seed/acre but was not significant between the 30- and 40-lb seeding rates. This optimum seeding rate is consistent with recommended seeding rates developed by Rice Tec, Inc. Excellent yields achieved during this study demonstrate the ability of this hybrid to perform well at much lower seeding rates than conventional varieties. However, conventional varieties have also performed well at reduced seeding rates in recent studies.

SIGNIFICANCE OF FINDINGS

The data from this preliminary study suggest that RiceTec XL723 may produce higher grain yield when drill-seeded using 7-in. row spacing. However, the differences in row widths were not significant. More data are needed on multiple soil conditions to further evaluate the effects of row widths of hybrid rice. These data also suggests a seeding rate of approximately 30 lb/acre to maximize grain yield.

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Table 1. Seeding rate conversions for the current study.

Seeding rate	Seeding density
(lb/acre)	(seed/ft^2)
10	4
20	9
30	13
40	18

Table 2. Influence of seeding method on stand density and grain yield of RiceTec XL 723 hybrid rice during 2006 at the Lake Hogue Research Farm.

Row spacing	Stand density	Grain yield
(in.)	(plants/ft^2)	(bu/acre)
7	5.2	218.9
10	5.6	208.3
Broadcast	9.6	209.6
LSD$_{(\alpha=0.05)}$	1.6	NS[z]
p-value	<0.0001	0.2732

[z] NS = not significant.

Table 3. Influence of seeding rate on stand density and grain yields of RiceTec XL723 hybrid rice during 2006 at the Lake Hogue Research Farm in Poinsett County.

Seeding rate	Stand density	Grain yield
(lb/acre)	(plants/ft^2)	(bu/acre)
10	4.7	181.0
20	5.6	205.8
30	7.6	227.9
40	9.3	234.3
LSD$_{(\alpha=0.05)}$	1.8	16.5
p=value	<0.0001	<0.0001

Influence of Urea and Agrotain Applied to a Dry Clay Soil Several Days Prior to Flooding on the Grain Yield of Delayed-Flood Rice

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ABSTRACT

Agrotain has shown in previous studies on silt loam soils to be much less prone to ammonia volatilization loss and to result in higher rice-grain yields compared to urea when the flood cannot be applied immediately after nitrogen (N) fertilizer application. However, no research has been conducted to determine if Agrotain is superior to urea as an N source for rice grown on clay soils, which volatilize urea as ammonia slower and to a lesser degree than silt loam soils. Thus, a 2-year study on clay soil was conducted comparing urea and Agrotain applied 1, 5, 7, and 10 days prior to flooding on rice-grain yield. In both years of the study, urea and Agrotain resulted in similar rice-grain yields when the two N fertilizer sources were applied 1 and 5 days prior to flooding. However, Agrotain resulted in higher rice-grain yields compared to urea when the N sources were applied to the clay soil 7 and/or 10 days prior to flooding.

INTRODUCTION

The early N fertilizer application in delayed-flood rice culture (75 to 100% of the total N rate) should be applied as an ammonium or ammonium-forming N source onto dry soil immediately prior to flooding at around the 4- to 5-lf growth stage or beginning tillering. Once the preflood-N has been applied, flooding should be completed as quickly as possible. The floodwater incorporates the N fertilizer into the soil, which minimizes losses via ammonia volatilization and nitrification/denitrification as long as a flood is maintained. The flood should be maintained for at least 3 to 4 weeks to achieve maximal uptake of the preflood-applied N.

Urea is the N fertilizer most often used in rice production because of its high N analysis and lower cost-per-pound of N relative to other N fertilizers. Urea has many fine qualities, but it also has an undesirable characteristic in that its initial reaction when applied to soil is alkaline and thus, it is prone to ammonia volatilization losses if not soil-incorporated within a couple of days after surface application. Agrotain has shown in previous studies to be much less prone to ammonia volatilization loss and to result in higher rice-grain yields compared to urea when the N fertilizers were applied to a dry or wet silt loam soil 5 days or more prior to establishment of the permanent flood (Norman et al., 2004, 2006). Currently, all of the rice research in Arkansas with Agrotain has concentrated on silt loam soils. This is because silt loam soils are more prone to ammonia-volatilization loss of urea-N than clay soils (Griggs et al., 2005) and approximately 60% of the rice grown in Arkansas is grown on silt loam soils (Wilson and Branson, 2006). However, since there is a sizeable amount of rice acreage on clay soils and because urea is still prone to ammonia volatilization from clay soils, it was believed prudent to conduct some research to determine if Agrotain could be of benefit to rice grown on clay soils when the flood cannot be applied in a timely manner.

PROCEDURES

The study was conducted in 2005 and 2006 at the University of Arkansas Southeast Research and Extension Center (SEREC), Rohwer, Ark., on a Perry clay (Vertic Haplaquepts) having a soil pH of 5.7 and 6.0, respectively, at the time of measurements. The cultivar chosen was ‘Wells’, a long-grain, short-stature rice cultivar with excellent yield potential. Rice was seeded at 130 lb/acre in nine-row plots (7-in. spacing) of 15 feet in length on 21 April 2005 and 19 April 2006. The rice emerged on 12 May in 2005 and 29 April in 2006. The rice was grown upland until the 4- to 5-lf growth stage and then a permanent flood (2- to 4-in. depth) was applied on 15 June 2005 and 16 June 2006 and maintained until maturity. The treatments were arranged as a randomized complete block 3 (N rate) X 2 (N source) X 4 (application time) design factorial with four replications. Fertilizer N rates were 0, 100, and 150 lb N/acre and the preflood-N fertilizer sources were urea and Agrotain. The preflood-N fertilizer application times were 1, 5, 7, and 10 days prior to flooding. All preflood-N fertilizer applications were made to a dry soil surface.

At maturity, the plots were harvested (30 August 2005 and 28 August 2006) with a small-plot combine by cutting a 12-foot length from the center four rows of each plot. The grain was weighed, analyzed for percent moisture, and the reported grain yields expressed on a 12% moisture basis in bushels (bu)/acre. A bushel of rice weighs 45 pounds. Statistical analyses were conducted on the grain yield data with SAS and mean separations were based upon protected LSD where appropriate.

RESULTS AND DISCUSSION

There was no three-way interaction between N-fertilizer source, rate, and application time on rice-grain yield in 2005; however, there were three two-way interactions between the three parameters. A two-way interaction existed between N source and N rate (Table 1). Grain yield significantly increased for both N sources as N rate increased through the 150 lb N/acre rate. Significantly higher grain yields were achieved at the 100 and 150 lb N/acre rates when Agrotain was the N source compared to urea, although the differences lessened at the higher N rate.

The significant interaction between N fertilizer source and application time indicated that Agrotain and urea resulted in statistically similar grain yields when applied at 1 and 5 days before flooding (Table 2). However, when the flood was delayed for 7 and 10 days after N fertilizer application, Agrotain resulted in significantly higher grain yields compared to urea. In addition, Agrotain had statistically similar grain yields when applied up to 10 days before flooding as urea or when Agrotain was applied 1 day prior to flooding. These findings indicate that Agrotain has a place for use on clay soils when a week or greater time is required to flood a field.

The interaction between N fertilizer rate and application time demonstrates that the grain yield decreased as flood was delayed and that the grain yield decrease was greater for the 100 lb N/acre rate than for the 150 lb N/acre (Table 3). Thus, ammonia volatilization loss of the N fertilizers and the consequential grain-yield decrease from delaying the flood can be compensated for by increasing the N fertilizer rate. However, this is not an environmentally sound practice and probably is not a sound economic practice. The increase in cost of N fertilizer over the past few years makes using Agrotain more cost-effective than increasing the fertilizer-N rate if a flood cannot be applied in a timely manner on silt loam or clay soil.

There was a three-way interaction between N fertilizer source, rate, and application time on rice-grain yield in 2006 (Table 4). Grain yield increased as N rate was increased from 0 to 100 lb N/acre and 100 to 150 lb N/acre for each of the two N sources. When 100 lb N/acre were applied 1 and 5 days prior to flooding, the use of urea and Agrotain resulted in a similar rice-grain yield at both application times. However, rice-grain yield decreased significantly from 106 bu/acre when urea was applied 1 day prior to flooding to 91 bu/acre when urea was applied 10 days prior to flooding. Conversely, Agrotain applied at the 100 lb N/acre rate resulted in similar grain yields of around 110 bu/acre when the flood was delayed from 1 to 10 days after Agrotain application.

When urea and Agrotain were applied at the 150 lb N/acre rate 1 day prior to flooding, both resulted in similar grain yields of around 130 bu/acre (Table 4). However, as the time between N application and flooding was incrementally increased from 1 to 10 days, the rice-grain yield tended to steadily decrease when urea was the N source, but not when Agrotain was the N source. When 150 lb N/A was applied as urea and Agrotain 10 days before flooding, rice-grain yields of 118 and 131 bu/acre, respectively, were measured.

The 2005 and 2006 results comparing Agrotain and urea indicate Agrotain is superior to urea when the flood cannot be applied within a week or so after preflood-N application. Thus, from these data the recommendation in Arkansas will be that when rice is grown on a clay soil and the field cannot be flooded in a week or less after N fertilizer application, then it would be prudent to use Agrotain in place of urea.

SIGNIFICANCE OF FINDINGS

The 2005 and 2006 results with Agrotain and urea are quite similar. In both years of the study, urea and Agrotain resulted in similar rice-grain yields when the two N fertilizer sources were applied 1 and 5 days prior to flooding. However, Agrotain usually resulted in higher rice-grain yields compared to urea when the N sources were applied 7 and/or 10 days prior to flooding. Thus, from these two years of data, the recommendation in Arkansas will be that when rice is grown on a clay soil and the field cannot be flooded in a week or less after N fertilizer application, then Agrotain should be used in place of urea.

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Table 1. Influence of nitrogen fertilizer source and rate on rice-grain yields at the Southeast Research and Extension Center during 2005.

	Nitrogen source	
Nitrogen rate	Urea	Agrotain
(lb N/acre)	-------- [Grain yield (bu/acre)]	-----------
0	66	
100	116	128
150	139	145
$LSD_{(0.05)}$	6	

Table 2. Influence of nitrogen fertilizer source and timing on rice-grain yields at the Southeast Research and Extension Center during 2005.

	Nitrogen source	
Nitrogen timing	Urea	Agrotain
(days prior to flood)	-------- [Grain yield (bu/acre)]	-----------
1	115	116
5	110	113
7	105	114
10	98	111
$LSD_{(0.05)}$	7	

Table 3. Influence of nitrogen fertilizer rate and timing on rice-grain yields at the Southeast Research and Extension Center during 2005.

	Nitrogen rate (lb N/acre)		
Nitrogen timing	0	100	150
(days prior to flood)	---------------	[Grain yield (bu/acre)]	---------------
1	66	132	147
5		124	145
7		120	142
10		112	135
$LSD_{(0.05)}$		8	

Table 4. Influence of nitrogen fertilizer source, rate, and application timing on rice-grain yield at the Southeast Research and Extension Center during 2006.

Nitrogen	Nitrogen	Nitrogen application timing prior to flooding			
source	rate	1 Day	5 Days	7 Days	10 Days
	(lb N/acre)	-------------------	[Grain yield (bu/acre)]		--------------------
Control	0	43			
Agrotain	100	111	106	108	109
Urea	100	106	100	95	91
Agrotain	150	132	129	130	131
Urea	150	128	125	124	118
$LSD_{(0.05)}$		13			

RICE CULTURE

Grain Yield Response of Ten New Rice Cultivars to Nitrogen Fertilization

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ABSTRACT

The Variety x Nitrogen (N) fertilizer interaction 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. ‘Jupiter’, ‘Pace’, ‘Pirogue’,‘Presidio’, ‘Trenasse’, Clearfield ‘CL131’, Clearfield ‘CL171’, and the RiceTec hybrids ‘XL723’, Clearfield ‘CLXP729’, and Clearfield ‘CLXL730’ were the new rice varieties evaluated for N fertilizer response in 2006. Jupiter and Pace required 120 lb N/acre to achieve maximal grain yield when grown on silt loam soil and 150 to 180 lb N/acre when grown on clay soil. CL131, CL171, Pirogue, and Trenasse typically required 120 lb N/acre to achieve maximal grain yield when grown on silt loam soil and 150 lb N/acre when grown on clay soil. Presidio required 90 lb N/acre to achieve maximal grain yield when grown on silt loam soil and 120 to 150 lb N/acre when grown on clay soil. The three RiceTec hybrids achieved maximal grain on silt loam soil when 90 lb N/acre were applied preflood and on clay soil when 150 lb N/acre were applied preflood. Typically, rice varieties require 30 lb N/acre more on silt loam soils compared to clay soils to maximize yield; however, the hybrids in 2006 required 60 lb N/acre more when grown on clay soil to maximize yield. The late-boot N application helped reduce lodging of CLXP729 and CLXL730 where lodging was present.

INTRODUCTION

A major strength of the rice-soil fertility research program has been the delineation of N fertilizer response curves for promising new rice cultivars. This study measures the performance of the new cultivars over a range of N fertilizer rates on clay and silt loam soils and determines the proper N fertilizer rates across the array of soils and 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. Ten rice cultivars were studied in 2006 at two to four locations depending on seed supply and resources. Louisiana had three varieties in the studies: i) Jupiter is a semidwarf, medium-grain; ii) Pirogue is a semidwarf, short-grain; and iii) Trenasse is a semidwarf, long-grain. Pace is a short-stature, long-grain released by Mississippi and Presidio is a semidwarf, long-grain released by Texas. Clearfield CL131 and CL171 are Horizon AG rice varieties tolerant to the broad-spectrum herbicide imidazolinone (Newpath). CL131 is a semidwarf, long-grain developed from 'Cocodrie' and CL171 is semidwarf, long-grain developed from 'Wells'. RiceTec Clearfield CLXP729 and CLXL730 are long-grain, hybrid varieties tolerant to the broad-spectrum herbicide imidazolinone (Newpath). The other RiceTec hybrid, XL723, is a long-grain. The three hybrids typically achieve larger grain yields with similar to smaller amounts of N fertilizer compared to inbred rice varieties.

PROCEDURES

Locations where the Variety x N rate studies 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); Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs); and the Southeast Research and Extension Center (SEREC), near Rohwer, Ark., on a Perry clay (Vertic Haplaquepts). The experimental design utilized was a randomized complete block with four replications at all locations for all the rice cultivars studied. The split application scheme utilized for all cultivars, except the RiceTec hybrids, was a two-way split application method where the N fertilizer was split-applied at preflood and beginning internode elongation (BIE) in the following total-N (preflood N + BIE N) rate splits: 0 (0+0), 60 (30+30), 90 (45+45), 120 (75+45), 150 (105+45), 180 (135+45), and 210 (165+45) 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 two clay soils at the NEREC and SEREC received the 0 to 210 lb N/acre fertilizer rates with the 60 lb N/acre rate omitted. The clay soils at the NEREC and SEREC received the higher N rate of 210 lb N/acre and had the low N rate of 60 lb N/acre omitted, because the clay soils usually require more N fertilizer compared to the silt loams to maximize grain yields of the rice cultivars. The RiceTec hybrids had N fertilizer rates ranging from 90 to 180 lb N/acre applied in an assortment of split applications at preflood, BIE, and late-boot (LB). The rice was drill-seeded at a rate of 110 lb/acre in plots 9-rows wide (row spacing of 7 in.) and 15 ft. in length at all locations, except the RiceTec hybrids, which were seeded at rates ranging from 31 to 41 lb/acre on the silt loam soils and 41 to 62 lb/acre on the clay soils. All locations were seeded in mid to late April, except the RREC location which due to a poor stand had to be re-seeded in mid May. Plots were flooded at each location when the rice was at the 4- to 5-lf stage and remained flooded until the rice was mature. At maturity, 12 ft of the center four 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

Jupiter did not significantly increase in grain yield when more than 120 lb N/acre were applied on the silt loam soil at the LHRF (Table 1). Jupiter was able to maintain its grain yield when the N rate was increased from 120 to 150 lb N/acre at the LHRF, but displayed a significant grain yield decrease when the N rate was further increased to 180 lb N/acre. Jupiter did not significantly increase in grain yield when more than 150 lb N/acre were applied on the clay soils at the NEREC and the SEREC. Rice typically requires about 30 lb N/acre more when grown on clay soils compared to silt loam soils to achieve maximal yield. The grain yield of Jupiter appeared quite stable on the clay soils when the N rate was higher and lower than the N rate required to maximize grain yield. In addition, Jupiter had no trouble with lodging at any of the locations. The 2006 data along with the 2005 data (Norman et al., 2006) indicate Jupiter should probably have an N rate between 120 and 150 lb N/acre when grown on silt loam soils and 150 to 180 lb N/acre when grown on clay soils.

Pace did not yield very well at the two locations, the LHRF and the NEREC, where it was studied in 2006 and the data were quite variable with LSD's of over 15 bu/acre (Table 2). Pace achieved maximum numerical grain yield when 120 lb N/acre were applied to the silt loam soil at the LHRF and when 180 lb N/acre were applied to the clay soil at the NEREC. Pace had stable, but low yields, over several N rates higher and lower than the optimum. Even at the highest N rates, Pace displayed no signs of lodging at any of the locations. This was the first year Pace was in the Variety X Nitrogen Rate Study and it will need another year or two of study.

The maximum grain yield of Pirogue was only 153 bu/acre and did not significantly increas when more than 120 lb N/acre were applied on the silt loam soil at the LHRF (Table 3). Pirogue had maximal grain yields ranging from 178 to 190 bu/acre on the clay soils and these were achieved when 120 and 150 lb N/acre were applied to the clays soils at the NEREC and SEREC. Pirogue displayed a significant grain yield decrease when greater than the optimum N rate was applied to maximize grain yield at the LHRF and the SEREC even though there was no lodging or signs of disease. The grain yield of Pirogue was stable at the NEREC over the 120 and 150 lb N/acre range, but did decrease significantly in yield when 180 lb N/acre were applied. This may indicate that the N rate applied to Pirogue must be fairly exact for it to achieve full grain-yield potential. Lodging was not a problem for Pirogue at any of the N rates applied nor at any of the locations. This was the first year Pirogue was in the Variety X Nitrogen Rate Study and it will need another year or two of study.

Presidio also did not yield well at the LHRF and had a maximum grain yield of only 154 bu/acre (Table 4). Presidio displayed a low but maximum yield when 90 lb N/acre were applied to the silt loam soil at the LHRF and maintained this yield when up to 150 lb N/acre were applied. When grown on the clay soils at the NEREC and the SEREC, Presidio had slightly higher yields of 164 and 171 bu /acre, respectively. Presidio achieved maximal grain yield at the NEREC when 150 lb N/acre were applied and at the SEREC when 120 lb N/acre were applied. Presidio, like other varieties, requires about 30 lb N/acre more when grown on clay soils compared to silt loam soils to achieve maximal yield. Grain yields of Presidio on the clay soils at the NEREC and the SEREC declined slowly as the N rate was increased above the optimum. Presidio displayed no signs of lodging at any of the locations with the N rates applied. This was the first year Presidio was in the Variety X Nitrogen Rate Study and it will need another year or two of study.

Trenasse reached a maximal grain yield of 196 bu/acre when 120 lb N/acre were applied on the silt loam soil at the LHRF (Table 5). When Trenasse was grown on the clay soils at the NEREC and the SEREC, the variety did not produce as good grain yields as when grown on the silt loam soils at the LHRF. Trenasse achieved maximal grain yields of 178 and only 140 bu/acre at the NEREC and SEREC, respectively, when 150 lb N/acre were applied. The lower yields of Trenasse on the clay soils at the NEREC and SEREC were not due to any noticeable disease and lodging was not a problem. Trenasse did not have very stable yields when N was applied at a rate greater than the optimum, except when it had low yields at the SEREC. After two years of testing, Trenasse should probably have an N rate between 120 and 150 lb N/acre when grown on silt loam soils and 150 to 180 lb N/acre when grown on clay soils (Norman et al., 2006).

Grain yields of CL131 peaked on the silt loam soils at the LHRF and RREC when 120 lb N/acre were applied, but statistically did not significantly increase when more than 90 lb N/acre were applied to the silt loam soils (Table 6). The later planting–mid-May compared to mid-April–is the reason for the lower yields at the RREC compared to at the LHRF. When CL131 was grown on the clay soils at the NEREC and SEREC, CL131 achieved a maximized grain yield at both locations when 150 lb N/acre were applied. CL131 displayed a substantial yield decrease at the LHRF, NEREC, and the RREC when 30 lb N/acre more than required for optimal yield were applied. This indicates that CL131 has a rather narrow yield plateau when it comes to N fertilization. CL131 did not lodge at any of the locations. The 2006 data along with the 2005 data (Norman et al., 2006) indicate CL 131 should have 120 lb N/acre applied in a split application of 75 lb N/acre preflood followed by 45 lb N/acre at BIE when grown on silt loam soils and 150 lb N/acre (105 lb N/acre preflood + 45 lb N/acre BIE) applied when grown on clay soils to achieve maximal grain yield potential. Thus, CL131 requires less N fertilizer to reach maximal grain yield compared to other rice varieties.

CL171 achieved maximal grain yield on the silt loam soils at the RREC and LHRF when 120 lb N/acre were applied, but required 150 lb N/acre to maximize grain yields when grown on the clay soils at the NEREC and SEREC (Table 7). As mentioned earlier, rice varieties typically require 30 lb N/acre more N fertilizer to maximize yield when they are grown on clay soils compared to silt loam soils. Similar to CL131, CL171 had a lower maximal yield at the RREC (154 bu/A) compared to at the LHRF (174 bu/acre) due to the later than optimal planting at the RREC. When more N fertilizer was applied than required for CL171 to optimize yield, CL171 did not decrease in yield as much as CL131, except at the RREC. CL171 did not lodge at any of the locations with the N rates utilized. This is the first year CL171 has been in the Variety X Nitrogen Study and it will need to be in the study at least one and probably no more than two more years to accurately determine the proper N fertilizer rate.

XL723 reached grain yields of over 200 bu/acre at all three of the locations where it was studied in 2006 (Table 8). Grain yields of XL723 did not significantly increase on the two silt loam soils at the LHRF and RREC when more than 90 lb N/acre were applied in a single preflood application. Our current N recommendation for the RiceTec hybrids when grown on silt loam soils–of 90 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in grain yields of XL723 that were statistically similar to the maximum recorded at the RREC and was the maximum at the LHRF. The lower yields of XL723 at the RREC location were because of having to replant in mid-May. Grain yields of XL723 did not significantly increase on the clay soil at the SEREC when more than 150 lb N/acre were applied in a single preflood application. Our current N recommendation for the RiceTec hybrids when grown on clay soils–of 120 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in a grain yield for XL723 of only 167 bu/acre. The 2006 data clearly indicate that our preflood-N recommendation for the RiceTec hybrids when grown on clay soils is at least 30 lb N/acre too low. XL723 did not lodge at any of the locations in 2006.

Clearfield CLXP729 achieved statistically maximum grain yields on the silt loam soils at the RREC and LHRF when 90 lb N/acre were applied in a single preflood-N application (Table 9). All other N application rates and timings at the RREC and LHRF failed to cause a significant grain yield increase of CLXP729 over what was obtained with the 90 lb N/acre single preflood-N application on these silt loam soils. Our current N recommendation for the RiceTec hybrids when grown on silt loam soils–of 90 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in grain yields of XL723 that were statistically similar to the maximum recorded at the RREC and LHRF. The lower yields of CLXP729 at the RREC location were because of having to replant in mid-May. CLXP729 achieved a maximum grain yield on the clay soil at the SEREC when 150 lb N/acre were applied in a single preflood application. Similar grain yields were achieved by CLXP729 at the SEREC when 180 lb N/acre were applied in a single preflood-N application and when 150 lb N/acre were applied preflood followed by 30 lb N/acre at BIE or LB. There was some lodging of CLXP729 at the SEREC, but only when no LB N application was utilized. Our current N recommendation for the RiceTec hybrids when grown on clay soils–of 120 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in a grain yield for CLXP729 of only 186 bu/acre. CLXP729 was just not able to reach its maximal yield potential on the clay soil at the SEREC when 120 lb N/acre were applied preflood even when 30 lb N/acre were applied at IE and LB or even when the LB application was increased to 60 lb N/acre. As with XL723, the

2006 data for CLXP729 clearly indicate that our preflood-N recommendation for the RiceTec hybrids when grown on clay soils is at least 30 lb N/acre too low.

Clearfield CLXL730 achieved grain yields of 192 and 234 bu/acre at the RREC and LHRF, respectively, when 90 lb N/acre were applied in a single preflood application (Table 10). CLXL730 did not display a significant grain yield increase on the two silt loam soils when more than 90 lb N/acre were applied preflood or when extra N was added at IE and/or LB. However, the highest numerical yields on the silt loam soils were achieved by CLXL730 when 90 lb N/acre were applied preflood followed by 60 lb N/acre at LB. Our current N recommendation for the RiceTec hybrids when grown on silt loam soils–of 90 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in grain yields of CLXL730 at the RREC and LHRF of 191 and 225 bu/acre, respectively. The lower yields of CLXL730 at the RREC location were because of having to replant in mid-May. Grain yields of CLXL730 did not significantly increase on the clay soil at the SEREC when more than 150 lb N/acre were applied in a single preflood application. Similar grain yields were achieved by CLXL730 on the clay soil at the SEREC when 150 lb N/acre were applied preflood with or without 30 or 60 lb N/acre applied at LB or when 180 lb N/acre were applied in a single preflood application. CLXL730 lodged more than the other two hybrids at the SEREC and the LB N applications minimized the lodging. Our current N recommendation for the RiceTec hybrids when grown on clay soils–of 120 lb N/acre applied preflood followed by 30 lb N/acre at LB–resulted in a grain yield for XL723 of only 193 bu/acre. Again, the 2006 data for CLXL730 clearly indicate that our preflood-N recommendation for the RiceTec hybrids when grown on clay soils is at least 30 lb N/acre too low.

SIGNIFICANCE OF FINDINGS

Nitrogen-fertilizer response curves were developed for ten new rice varieties in 2006 and these response curves will be used to determine the proper N-fertilization rate to obtain maximal grain yield potential for each new variety. Jupiter, Pace, Pirogue, Presidio, Trenasse, Clearfield CL131, Clearfield CL171, and the RiceTec hybrids XL723, Clearfield CLXP729, and Clearfield CLXL730 were the new rice varieties evaluated for N fertilizer response in 2006. Most rice varieties required 120 lb N/acre to achieve maximal grain yield when grown on silt loam soils and 150 lb N/acre when grown on clay soils. The three RiceTec hybrids achieved maximal grain on the silt loam soil when 90 lb N/acre were applied preflood and on the clay soils when 150 lb N/acre were applied preflood. It is unusual for a rice variety to require 60 lb N/acre more when grown on clay soils compared to the silt loams to maximize yield. The late-boot N application helped reduce lodging of CLXP729 and CLXL730 where lodging was present.

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Table 1. Influence of nitrogen (N) fertilizer rate on the grain yield of Jupiter rice at three locations in 2006.

	Grain yield		
N fertilizer rate	LHRF[z]	NEREC	SEREC
(lb N/acre)		(bu/acre[y])	
0	87	79	44
60	130	--	--
90	154	154	141
120	174	184	184
150	177	192	192
180	154	188	203
210	--	177	183
$LSD_{(0.05)}$	11	9	16

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and SEREC=Southeast. Research and Extension Center, Rohwer, Ark.

[y] A bushel (bu) of rice weighs 45 lb.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Pace rice at two locations in 2006.

	Grain yield	
N fertilizer rate	LHRF[z]	NEREC
(lb N/acre)	(bu/acre[y])	
0	90	52
60	123	--
90	147	120
120	158	136
150	140	139
180	125	148
210	--	135
$LSD_{(0.05)}$	16	17

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

[y] A bushel (bu) of rice weighs 45 lb.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Pirogue rice at three locations in 2006.

	Grain yield		
N fertilizer rate	LHRF[z]	NEREC	SEREC
(lb N/acre)	----------	(bu/acre[y])	----------
0	87	79	44
60	130	--	--
90	154	154	141
120	174	184	184
150	177	192	192
180	154	188	203
210	--	177	183
$LSD_{(0.05)}$	11	9	16

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and SEREC = Southeast Research and Extension Center, Rohwer, Ark.

[y] A bushel (bu) of rice weighs 45 lb.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Presidio rice at three locations in 2006.

	Grain yield		
N fertilizer rate	LHRF[z]	NEREC	SEREC
(lb N/acre)	----------	(bu/acre[y])	----------
0	84	64	45
60	124	--	--
90	154	136	109
120	154	153	171
150	153	164	160
180	134	158	158
210	--	153	150
$LSD_{(0.05)}$	10	9	13

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and SEREC = Southeast Research and Extension Center, Rohwer, Ark.

[y] A bushel (bu) of rice weighs 45 lb.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Trenasse rice at three locations in 2006.

N fertilizer rate	Grain yield		
	LHRF[z]	NEREC	SEREC
(lb N/acre)	---------- (bu/acre[y]) ----------		
0	97	91	39
60	134	--	--
90	168	153	119
120	196	166	125
150	170	178	140
180	140	159	137
210	--	156	135
$LSD_{(0.05)}$	8	11	12

[z] LHRF = Lake Hogue Research Farm, Wiener, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; and SEREC = Southeast Research and Extension Center, Rohwer, Ark.

[y] A bushel (bu) of rice weighs 45 lb.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL 131 rice at four locations in 2006.

N fertilizer rate	Grain yield			
	LHRF[z]	NEREC	RREC	SEREC
(lb N/acre)	---------- (bu/acre[y]) ----------			
0	128	79	81	70
60	163	--	122	--
90	180	140	134	111
120	184	154	149	124
150	170	172	122	142
180	165	155	102	147
210	--	159	--	144
$LSD_{(0.05)}$	13	8	15	11

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

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL 171 rice at four locations in 2006.

N fertilizer rate	Grain yield			
	LHRF[z]	NEREC	RREC	SEREC
(lb N/acre)	--- (bu/acre[y]) ------------------------------------			
0	124	72	82	37
60	142	--	120	--
90	159	137	136	94
120	175	142	154	136
150	162	164	124	151
180	1151	156	105	147
210	--	159	--	140
LSD$_{(0.05)}$	11	8	16	14

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

Table 8. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec XP723 rice at three locations in 2006.

N fertilizer rate		Grain yield		
Total	Split[z]	LHRF[y]	RREC	SEREC
--------- (lb N/acre)--------------		------------------------ (bu/acre[x]) ------------------------		
0	0-0-0	133	121	69
90	90-0-0	239	205	--
120	120-0-0	243	201	149
120	90-30-0	231	204	--
120	90-0-30	246	207	--
150	90-30-30	226	198	--
150	150-0-0	232	195	198
150	120-30-0	239	201	177
150	120-0-30	232	199	167
150	90-0-60	245	209	--
180	120-30-30	--	--	181
180	180-0-0	--	--	210
180	150-30-0	--	--	207
180	150-0-30	--	--	205
180	120-0-60	--	--	178
LSD$_{(0.05)}$		20	16	13

[z] Split = nitrogen applied at preflood–beginning internode elongation–late boot.

[y] LHRF = Lake Hogue Research Farm, Wiener, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; SEREC = Southeast Research and Extension Center, Rohwer, Ark.

[x] A bushel (bu) of rice weighs 45 lb.

Table 9. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec CLXP729 rice at three locations in 2006.

N fertilizer rate		Grain yield		
Total	Split[z]	LHRF[y]	RREC	SEREC
--------- (lb N/acre)--------------		------------------------ (bu/acre[x]) ------------------------		
0	0-0-0	133	124	73
90	90-0-0	239	190	--
120	120-0-0	243	83	185^{33}[w]
120	90-30-0	231	192	--
120	90-0-30	246	193	--
150	90-30-30	226	188	--
150	150-0-0	232	155	218^{25}
150	120-30-0	239	188	189^{35}
150	120-0-30	232	184	186
150	90-0-60	245	195	--
180	120-30-30	--	--	198
180	180-0-0	--	--	215^{35}
180	150-30-0	--	--	212^{30}
180	150-0-30	--	--	218
180	120-0-60	--	--	199
$LSD_{(0.05)}$		13	12	13

[z] Split = nitrogen applied at preflood–beginning internode elongation–late boot.

[y] LHRF = Lake Hogue Research Farm, Wiener, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; SEREC=Southeast Research and Extension Center, Rohwer, Ark.

[x] A bushel (bu) of rice weighs 45 lb.

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

Table 10. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec CLXP730 rice at three locations in 2006.

N fertilizer rate		Grain yield		
Total	Split[z]	LHRF[y]	RREC	SEREC
--------- (lb N/acre)--------------		------------------------(bu/acre[x]) ------------------------		
0	0-0-0	155	125	75
90	90-0-0	234	192	--
120	120-0-0	228	184	186^{30w}
120	90-30-0	228	191	--
120	90-0-30	225	191	--
150	90-30-30	234	192	--
150	150-0-0	200	171	214^{55}
150	120-30-0	206	175	189^{30}
150	120-0-30	219	175	193
150	90-0-60	241	194	--
180	120-30-30	--	--	192^{45}
180	180-0-0	--	--	214^{65}
180	150-30-0	--	--	211^{50}
180	150-0-30	--	--	215^{35}
180	120-0-60	--	--	195^{5}
$LSD_{(0.05)}$		13	11	14

[z] Split = nitrogen applied at preflood–beginning internode elongation–late boot.

[y] LHRF = Lake Hogue Research Farm, Wiener, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; SEREC = Southeast Research and Extension Center, Rohwer, Ark.

[x] A bushel (bu) of rice weighs 45 lb.

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

Soil Properties and Carbon, Nitrogen, and Phosphorus Availability in White River Region Fields

M.C. Savin, P. Tomlinson, and R.J. Norman

ABSTRACT

About 40% of rice grown in Arkansas is produced in the White River Region; however, soil fertility remains a serious problem. Soil properties have been measured in fields typical of the region to determine if there are soil-quality parameters that are characteristic of these fields. The goal was to be able to target properties for further assessment to determine the degree to which they limit crop productivity. Soil samples were collected in the spring (preflood) and fall (post-harvest) of 2006. Microbial biomass carbon (C), dissolved organic C, inorganic nitrogen (N), and C and N cycling enzyme activities were statistically equal to or greater than those measured in the DeWitt silt loam (soil typical of the Grand Prairie Region). Total C and N and available phosphorus (P) were more variable than measured in the DeWitt soil. Bulk density was not greater in White River than the DeWitt soil, only one soil had a higher electrical conductivity, and while pH was higher in some White River soils, values ranged from 6.1 to 7.2. In general, while a greater range of values was measured among fields in the White River Region as compared to the DeWitt soil, most C, N, and P concentrations overlapped with, and were not consistently greater or less than, what was measured in the DeWitt soil. As a result, none of the measurements suggested a characteristic difference in White River Region soils.

INTRODUCTION

Although approximately 40% of the total rice crop in Arkansas is produced in the White River Region, rice yields are commonly lower than average yields in other systems such as the Grand Prairie. Problems common to the White River Region include low soil fertility, alkaline soils with seasonal salinity problems, weed control problems, heavy disease pressure, and variability within fields. Because of these problems soils have been managed intensively, and while there are productive counties in this region, the long history of intensive rice production has no doubt led to a reduction in soil quality. Crop yield potential is affected not only by the above-mentioned problems, but can be diminished when soil quality is reduced. Soil quality can be defined as the ability of a soil to perform essential ecosystem services (Karlin et al., 1997), in this case plant growth or specifically, rice crop production.

Soil properties were measured in 2005 (see Savin et al., 2006) and 2006 to characterize biological, physical, and chemical soil properties from fields typical of the White River Region. The ultimate goal is to be able to improve the soil quality of White River Region fields to enhance the soil fertility, consistently increase crop yields, and reduce variability within fields, thus alleviating three problems common to the White River Region. In this paper, we report properties related to C, N, and P in soils specifically selected for sampling in 2006 because yields have been below expected and cannot be explained easily due to disease, weed pressure, or management practices. Values for soil properties are compared among White River Region fields and to a DeWitt silt loam soil collected in the Grand Prairie Region. The objective was to determine whether properties can be targeted for future analysis and soil quality impovement.

PROCEDURES

Five growers' fields in the White River Region selected by Arkansas county extension agents were sampled to a depth of 10 cm in April or May of 2006 before fields were flooded. Two of those fields were sampled previously in 2005. The other three grower fields were specifically chosen because of yield problems that have not been easily explained. Four of the fields grew rice and were resampled after harvest in early October. Soils included a Foley-Calhoun (Fc) and Lafe silt loam, and Foley-Calhoun-McCrory (Fm) complex in Jackson County, and what was predominantly mapped as a Jackport silty clay loam and Henry silt loam in Poinsett County. In addition, fields (two in the spring and one in the fall) in Arkansas County at the Rice Research and Extension Center in Stuttgart (DeWitt silt loam) were sampled as soil typical of the Grand Prairie to provide a comparison to the White River Region soils.

Eight soil cores were collected from across a field and composited per replication and three replications were collected per field. There was one exception to the sampling design in spring 2006. One field was subdivided into plots that were sampled separately for each replication because of an experiment in progress (Henry silt loam). Plot boundaries were no longer marked during the fall sampling, so samples were composited from across the field, similar to the sampling protocol used in all other fields. In addition to the 2006 samples, soil had been sampled in ten fields in 2005 (eight White River Region fields and two DeWitt silt loam fields in Stuttgart) in the same manner described here (see Savin et al., 2006). Ranges of values for both spring and fall across both years are reported in this paper with White River Region soils separated from the Stuttgart DeWitt silt loam soils.

The following soil properties were measured. Bulk density was obtained by oven-drying a known volume of soil (5-cm dia, 10-cm length cores). Particle size distribution was measured using the hydrometer method (Arshad et al., 1996). Urease enzyme activity was measured by production of ammonium following incubation of soil with added urea (Tabatabai, 1994). The other three enzyme activities were based on the production of the colored compound *p*-nitrophenol after cleavage of a substrate (Parham and Deng, 2000; Tabatabai, 1994). Values for pH and EC were obtained using 1:10 (wt:vol) soil:water ratios and measured by electrode and pH meter and by conductivity meter. Microbial biomass C and N were obtained using the chloroform-fumigation-extraction method (Vance et al., 1987; Cabrera and Beare, 1993), with dissolved organic C (DOC) measured in the filtered, unfumigated soil extracts. Filtered 1:10 (wt:vol) soil:2 *M* KCl extracts were analyzed colorimetrically for nitrate and ammonium (Mulvaney, 1996) using a nutrient autoanalyzer (Skalar Instruments, Norcross, Ga.). Potentially mineralizable N was measured as the production of ammonium-N following a 7-day incubation at 40°C under waterlogged conditions (Bundy and Meisinger, 1994). Filtered and acidified water-soluble P (1:10 soil:DI water ratio) was measured colorimetrically (Self-Davis et al., 2000) on a nutrient autoanalyzer (Skalar Instruments, Norcross, Ga.). Mehlich-III-extractable P was analyzed on filtered extracts (1:10 soil:extract (wt:vol) ratio) (Mehlich, 1984) by inductively coupled plasma-emission spectroscopy (Spectro Analytical Instruments, Fitchburg, Mass.). Each property was compared among fields in 2006 in the spring and again in the fall using PROC GLM in SAS and least significant differences to separate means ($P < 0.05$).

RESULTS AND DISCUSSION

The range of values for properties measured among all soils collected in 2005 and 2006 in the White River Region was greater than in the DeWitt soil (Table 1). In 2006, all soils except one were classified as silt-loam by particle-size analysis. The predominantly Jackport silty clay loam was classified as a clay loam. Although there were differences among fields, pH in White River was equal to or higher than DeWitt soil and all values ranged from 5.6 to 7.2 (Table 2). Electrical conductivity (EC) was under 1.4 dS/m, and bulk density was 1.2 to 1.3 g cm^{-3} in all fields. While there were significant differences among fields in the fall, no White River fields had a higher bulk density than the Dewitt soil. Values were 1.0 and 0.1 % or less for soil C and N, respectively, with the lowest total C and N measured in Jackport soil and the highest in the Henry and Fm complex; these three soils represented the “problem” fields (Tables 2 and 3).

For C pools, most soils had similar-sized microbial biomass (C_{mic}), with one exception, the Fm complex. Biomass in that soil in the spring was more than twice the amount measured in other soils. Soils with greater microbial biomass are considered to be healthier than soils with lower biomass because microbes retain nutrients in a relatively labile form. However, in the fall C_{mic} was lower and not different among fields. Microbial biomass N (N_{mic}) concentrations tended to increase in White River soils from spring to fall, with N_{mic} being as high or higher in White River soil compared to the DeWitt silt loam in the fall (Table 3). Because C_{mic} did not increase, this suggests a shift away from fungal contributions towards more bacteria during the growing season. Because fields were flooded throughout summer, anaerobic bacteria could have been active while aerobic organisms such as fungi were inhibited.

In addition to immobilizing nutrients, microorganisms are the primary agents responsible for decomposition and nutrient cycling. Dissolved organic C was measured as an amount of substrate in soil solution (thus potentially available for decompostion by microbes). While the two fields with DeWitt soil were different than each other in the spring, DOC was not significantly different between White River and DeWitt soils, and there were no differences in DOC among any fields in the fall (Table 2). Inorganic N concentrations (nitrate plus ammonium) also tended to be lower in the fall (Table 3). One field with Dewitt soil had the highest inorganic N, but the lowest potentially mineralizable N (Table 3). In contrast, the other field with DeWitt soil had relatively low inorganic N, but among the highest potentially mineralizable N. This inverse relationship between inorganic N and potentially mineralizable N was not observed in the White River soil; however, inorganic N was not significantly lower than the Dewitt silt loam in the spring or fall.

Because nutrient concentrations provide a measure of the size of pools but not activity in the soil, enzymes were measured. Urease catalyzes the breakdown of urea (important following urea fertilization) and is presumed to be ubiquitous in surface soils while β-glucosaminidase (NAGase) is involved in the breakdown of chitin, an abundant polymer of amino sugars in soil. Urease activity was similar between the DeWitt and White River soils in the spring, but was markedly lower in the DeWitt soil in the fall (Table 3). Similar to available N concentrations, NAGase was significantly different among fields in the spring, but no fields had lower activity than the DeWitt soil and activity was similar across all fields in the fall.

There were more significant differences in P among fields in the spring and fall than C and N, and there were White River fields with significantly higher and lower Mehlich-III-extractable P (M-3 P) and water-soluble P (WSP) than in DeWitt soil (Table 4). There was a positive linear relationship between WSP and M-3 P (data not shown), but not between P availability and enzyme activity as soils with the lowest phosphatase did not necessarily have the lowest available P (Table 4). Furthermore, the DeWitt soil was significantly lower in alkaline phosphatase (microbially associated enzyme) in both spring and fall than all White River soils.

SIGNIFICANCE OF FINDINGS

This study was undertaken because rice is grown on silt-loam topsoil overlying clay layers in both the Grand Prairie and White River regions, but fields in the two regions do not perform the same. Our goal was to identify soil properties that could be targeted to improve soil quality to alleviate yield limitations in White River Region soils. After the 2005 sampling, it was determined that properties were just as variable among fields, even within the same soil type, as between ecological regions (Savin et al., 2006). Fields sampled in 2006 were chosen specifically because of unexplained rice yield problems. Similar to results in 2005, properties were variable among fields in 2006, and exhibited greater variability among White River Region soils than measured in the DeWitt (Grand Prairie) soil (Table 1). This is not unexpected because a greater number of fields were sampled in the White River Region. Despite the variability, in general, a similar range in values was measured for White River and DeWitt soils.

Appropriate methods to improve fertility and consistency of yields are more likely to be successful if limiting soil properties are improved. In this study, we quantified levels of several properties including some dynamic ones related to C, N, and P availability and cycling, and did not detect consistently lower (or higher) values in White River Region soils than in DeWitt soil. Futher analysis of how the interactions of several properties and processes combine to affect rice yields, and studies targeting the availability of micronutrients, may reveal limitations in regard to fertility problems.

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Table 1. Ranges of values measured for soil properties in spring and fall of 2005 and 2006 for White River soils compared to those in the DeWitt soil (representing the Grand Prairie region).

Property[z]	White River	Grand Prairie
pH	5.4 - 8.4	5.0 - 6.3
EC (dS m^{-1})	0.45 - 1.65	0.50 - 1.07
Bulk density (g cm^{-3})	1.10 - 1.41	1.07 - 1.34
Sand (%)	11 - 37	13 - 38
Silt (%)	38 - 75	50 - 71
Clay (%)	8 - 38	12 - 20
Total soil C (%)	0.48 - 1.74	0.67 - 0.92
C_{mic} (µg C g^{-1})	13.5 - 154.5	32.0 - 82.4
DOC (µg C g^{-1})	7.05 - 48.04	13.41 - 38.81
M-3 P (µg P g^{-1})	7.89 - 51.39	16.20 - 35.68
WSP (µg P g^{-1})	0 - 5.74	0 - 4.59
Alkaline Pase (µg nitrophenol g^{-1} hr^{-1})	23.83 - 92.29	0 - 27.14
Acid Pase (µg nitrophenol g^{-1} hr^{-1})	65.13 - 255.1	88.79 - 248.1
Total soil N (%)	0.05 - 0.13	0.07 - 0.11
N_{mic} (µg N g^{-1})	0.6 - 23.2	4.1 - 15.2
NO_3^- (µg N g^{-1})	0 - 17.62	0 - 25.12
NH_4^+ (µg N g^{-1})	0 - 3.92	0 - 6.11
Ni (µg N g^{-1})	0.2 - 19.5	0.22 - 19.53
Potentially min. N (µg N g^{-1})	2.4 - 36.2	3.0 - 26.3
Urease (µg NH_4^+-N g^{-1} hr^{-1})	5.59 - 35.38	1.08 - 19.67
NAGase (µg nitrophenol g^{-1} hr^{-1})	7.25 - 47.32	13.14 - 28.89

[z] Abbreviations for properties include: electrical conductivity (EC), microbial biomass carbon (C_{mic}), dissolved organic carbon (DOC), Mehlich-III-extractable phosphorus (M-3 P), water soluble phosphorus (WSP), phosphatase (Pase), microbial biomass nitrogen (N_{mic}), nitrate (NO_3^-), ammonium (NH_4^+), inorganic nitrogen (Ni), mineralizable nitrogen (min. N), and β-glucosaminidase (NAGase).

Table 2. Total soil C, microbial biomass C (C_{mic}), dissolved organic C (DOC), pH, electrical conductivity (EC), and bulk density in eight fields in three Arkansas counties in the spring (preflood) and fall (post-harvest) of 2006 (n=3).

	Total C		C_{mic}		DOC		pH		EC		Bulk density	
County/Soil[z]	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	--------(%)-------		---------------- (µg C g^{-1}) ----------------						--- (dS m^{-1}) ----		-----(g cm^{-3}) ---	
Arkansas 1/DeWitt	0.85bc[y]	NA[x]	51.9b	NA	22.52b	NA	6.0d	NA	0.51e	NA	1.22a	NA
Arkansas 2/DeWitt	0.87b	NA	50.6b	NA	33.62a	NA	5.6e	NA	0.76bc	NA	NA	NA
Arkansas3/DeWitt	NA	0.71b	NA	42.2a	NA	25.27a	NA	5.9c	NA	0.66b	NA	1.31a
Jackson 1/Fc[w]	0.77cd	0.72b	44.8b	60.6a	14.14b	13.28a	6.7a	7.2a	0.56de	0.68b	1.31a	1.24ab
Jackson 2/Lafe	0.70d	NA	46.0b	NA	24.20b	NA	6.2cd	NA	0.74bc	NA	1.27a	NA
Jackson 3/Fm	0.92b	0.92a	119.3a	51.8a	35.73a	24.24a	6.3bcd	6.1c	0.85b	0.71b	1.31a	1.25ab
Poinsett 1/Jackport	0.53	0.55c	47.4b	50.1a	18.61b	23.63a	6.5ab	7.2a	1.20a	1.37a	1.27a	1.18b
Poinsett 2/Henry	1.03a	1.00a	48.2b	64.3a	13.15b	15.19a	6.4bc	6.7b	0.65cd	0.71b	1.31a	1.28a

[z] The last three soils listed in the column were the poor-yielding producer fields.

[y] Different letters within a column indicate significant differences in that property among fields ($P < 0.05$).

[x] NA = not applicable.

[w] Fc soil is Foley-Calhoun and Fm soil is a Foley-Calhoun-McCrory complex.

Table 3. Total soil N, microbial biomass N (N_{mic}), inorganic N (nitrate plus ammonium), potentially mineralizable N (Pot. N_{min}), and urease and β-glucosaminidase (NAGase) activities for eight fields in three Arkansas counties in the spring (preflood) and fall (post-harvest) of 2006 (n=3).

	Total N		N_{mic}		Ni		Pot. N_{min}		Urease		NAGase	
County/Soil[z]	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	(%)		($\mu g\ N\ g^{-1}$)						($\mu g\ NH_4^+$-N $g^{-1}\ hr^{-1}$)		($\mu g\ g^{-1}\ hr^{-1}$)	
Arkansas 1 /DeWitt	0.09ab[y]	NA[x]	5.2c	NA	28.59a	NA	3.9d	NA	12.53b	NA	28.10c	NA
Arkansas 2 /DeWitt	0.09ab	NA	7.6ab	NA	6.69d	NA	22.4a	NA	14.31b	NA	19.28d	NA
Arkansas 3 /DeWitt	NA	0.08b	NA	6.1c	NA	3.12ab	NA	9.7a	NA	3.44c	NA	16.75a
Jackson 1 /Fc[w]	0.08b	0.07b	5.0c	9.2ab	4.67d	3.67a	12.4bc	8.9a	9.53b	17.28a	18.87d	14.52a
Jackson 2 /Lafe	0.09a	NA	6.2bc	NA	13.26c	NA	12.7bc	NA	11.16b	NA	27.75c	NA
Jackson 3/ Fm	0.10a	0.10a	9.2a	7.5bc	18.73b	1.50b	18.5a	16.9a	11.39b	12.39b	25.70c	21.10a
Poinsett 1 /Jackport	0.06c	0.06c	2.0d	7.0c	3.00d	1.94ab	6.2cd	7.2a	9.52b	19.91a	36.80b	14.12a
Poinsett 2 /Henry	0.10a	0.09a	6.6abc	10.0a	6.97d	3.19ab	16.2ab	10.1a	24.39a	17.96a	44.47a	19.07a

[z] The last three soils listed in the column were the poor-yielding producer fields.

[y] Different letters within a column indicate significant differences in that property among fields ($P < 0.05$).

[x] NA = not applicable.

Table 4. Mehlich-III P (M-3 P), water soluble phosphorus (WSP), and alkaline and acid phosphatase (Pase) in eight fields in three Arkansas counties in the spring (pre-flood) and fall (post-harvest) of 2006 (n=3).

	M-3 P		WSP		Acid Pase		Alkaline Pase	
County/soil[z]	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
	----(μg P g^{-1})----				----(μg nitrophenol g^{-1} hr^{-1})----			
Arkansas 1/DeWitt	27.04c[y]	NA[x]	1.39c	NA	236.69a	NA	10.32de	NA
Arkansas 2/DeWitt	16.48de	NA	1.81bc	NA	214.46ab	NA	0.00e	NA
Arkansas 3/DeWitt	NA	18.21c	NA	1.62a	NA	101.77c	NA	19.98d
Jackson 1/Fc[w]	37.93b	35.05a	3.22a	1.83a	169.49c	164.85b	55.54abc	79.22ab
Jackson 2/Lafe	13.70e	NA	0.42d	NA	241.55a	NA	50.37bc	NA
Jackson 3/Fm	10.17f	9.71d	0.18d	0.18c	214.21ab	200.27a	30.40cd	41.52c
Poinsett 1/Jackport	19.05d	16.08c	1.92b	0.87b	82.50d	67.36d	58.70ab	68.28b
Poinsett 2/Henry	39.32a	25.74b	1.93b	0.48c	201.24b	170.47ab	84.01a	84.77a

[z] The last three soils listed in the column were the poor-yielding producer fields.

[y] Different letters within a column indicate significant differences in that property among fields ($P < 0.05$).

[x] NA = not applicable.

[w] Fc is Foley-Calhoun and Fm soil is a Foley-Calhoun-McCrory complex.

Movement of Fertilizer Nitrogen Applied to a Dry Silt-Loam Soil During Four Days of Surfacewater Ponding

M.C. Savin, D.M. Miller, P. Tomlinson, K.R. Brye, and R.J. Norman

ABSTRACT

In a previous experiment urea nitrogen (N) moved deeper into silt-loam soil under ponded water than ammonium sulfate N. Because it can take up to a week to establish a flood, we extended the time that water was maintained on the soil surface from 12 hours to 4 days to determine if movement of N from the two fertilizers diverged to a greater extent with time. Urea or ammonium sulfate was dissolved on the surface of intact DeWitt silt-loam soil cores (approximately 4-in. length) that were immediately ponded with water for 12 to 96 hours. Nitrogen concentrations were measured in floodwater, leachates, and at 0.8-in. depth intervals in the soil cores. Ammonium sulfate-N concentrations were greatest at the surface 0.8 in. of soil, decreased with depth, and were not significantly affected by ponding time. In contrast, after 96 hours of ponding, urea concentrations were similar from 0 to 1.6 in. and did increase with time as measured at progressive 0.8-in. soil depth intervals. Ammonium-N was measured in floodwater and leachates of cores receiving fertilizer. Soil-N results are similar to those obtained from a previous experiment after 12 hours of flooding, suggesting that the immediate movement into soil is important for fertilizer-N and that the type of fertilizer-N impacts the depth of fertilizer movement within the surface 4 in. of soil during 4 days of surfacewater ponding.

INTRODUCTION

Rice-grain yield depends in large part on the preflood application of fertilizer-N (Wilson, Jr., et al., 2001). Nitrogen is applied onto dry soil at about the 4- to 5-lf growth stage, ideally with N in an ammonium form. The soil should be flooded immediately because the flood is used to move the N into the soil. If it remains on the soil surface, N can be lost as a result of volatilization or through sequential processes of nitrification followed by denitrification. Urea and ammonium sulfate are common ammonium-N fertilizers. Advantages of urea over ammonium sulfate include that it is widely available, relatively inexpensive, and has a large percentage (46% as compared to 21% in ammonium sulfate) of N per pound of fertilizer.

Previously, urea or ammonium sulfate was applied to dry DeWitt silt-loam soil cores (4-in. depth), which were flooded immediately (Savin et al., 2006). Nitrogen movement and distribution were measured for up to12 hours while a ponded-water depth of 2 in. was maintained on top of the cores. The immediate movement into soil was important and affected by the fertilizer source, with urea moving deeper into soil than ammonium sulfate. However, soil cores were ponded for only 12 hours. Because it can take up to 4 to 5 days to establish a flood, the experiment was repeated with time intervals ranging from 12 to 96 hours. The objective of this research was to measure the extent to which floodwater applied immediately after fertilization of a silt-loam soil incorporates fertilizer N into the surface soil. This experiment was conducted to reflect more realistically flood establishment times and to determine if results after 12 hours of ponding were representative of longer time intervals up to four days. It was hypothesized, based on the results of the previous experiment and the forms of N in the two fertilizers, that urea would move farther into the soil than ammonium sulfate and move deeper as flooding time was extended.

PROCEDURES

Fifty-two intact soil cores (2.8-in. dia., 4-in. length) kept inside plastic sleeves were collected from a DeWitt silt loam in a plot (1.2 x 2.5 yards) at the Rice Research and Extension Center at Stuttgart, Ark. (Table 1). Three additional samples were taken for bulk density, and chemical analyses. Soils for chemical analyses were dried, ground, and extracted for P and K concentrations by analyzing filtered 1:10 (wt:vol) soil:Mehlich-3 solution extracts by inductively coupled plasma spectrophotometry (SPECTRO CIROS ICP, Fitchburg, Miss.). Total C and N were determined following combustion at 2330°F (1100°C) (Elementar Variomax). Values for pH and electrical conductivity (EC) were determined at a 1:2 (wt:vol) soil:water ratio.

Nitrogen distribution following ponding was conducted for specified time intervals as previously described (Savin et al., 2006). Briefly, background inorganic-N concentrations in the cores (4 replications) were determined. Nitrogen (202 mg urea or 444 mg ammonium sulfate) was applied to the soil surface in the center of the cores at a rate of 90 mg N for each fertilizer to approximate an application of 180 lb/acre (200 kg/ha). Just enough water was added to dissolve the fertilizer, and then a flood was applied and maintained at a constant depth using Mariotte bottles. Cores (4 replications for a total of 32 cores) were ponded for time intervals of 12 , 24, 48, or 96 hours for each fertilizer. Background-N concentrations after each flood time interval, but with no fertilizer (4 replications for a total of 16 cores) were also determined. When the allotted time elapsed, the floodwater and any leachate that was produced were collected, and volumes were measured and kept at 39°F (4°C). Floodwaters and leachates were filtered before analysis of N as described below. All cores were capped and immediately placed in a -176°F (-80°C) freezer.

The frozen cores were cut at 0.8-in. depth intervals with a band saw. Moisture content and inorganic N were determined for each thawed and homogenized core section. Moisture content was determined gravimetrically after drying soil (5 g) at 223°F (105°C) for 24 hours. Inorganic N was extracted at a 1:10 (wt:vol) soil:extract ratio with 2 *M* KCl and filtrates were analyzed colorimetrically for nitrate and ammonium (Mulvaney, 1996) on a nutrient autoanalyzer (Skalar Instruments, Norcross, Ga.). It had been determined previously (Savin et al., 2006) that N in unaltered urea form was not measured by this method. Mean N concentrations and standard deviations were calculated for each depth and time interval. Concentrations were compared between fertilizers at different depths and ponding times in SAS using the general linear model and least significant differences to separate means ($P < 0.05$).

RESULTS AND DISCUSSION

Background nitrate levels before flooding were 13.94 ± 3.25 µg N/g in the surface 0.8 in. and declined to 8.12 ± 1.90 µg N/g at the 3.1 to 3.9 in. depth. Applying a flood to the cores significantly reversed the trend of nitrate concentrations with depth (data not shown). Flooding moved nitrate downward in the soil, so that nitrate-N levels were lowest at the surface 1.6 in., and increased progressively from 1.6 to 2.4, 2.4 to 3.1, and 3.1 to 3.9 in. Furthermore, nitrate concentrations were significantly affected by the interaction between time of ponding and soil depth ($P = 0.001$). Concentrations after ponding water for 96 hours were different than all shorter time intervals, such that the prolonged maintenance of a flood left little nitrate except at the 3.1 to 3.9 in. soil depth. Mean nitrate values remained within the range of 1 to 13.6 µg N/g at all 0.8-in. depth intervals. Floodwater nitrate concentrations were less than 1 µg N/mL throughout the 96 hours of incubation. Leachate volumes were variable across all cores and leaching times, and leachate was collected from only six cores that did not receive fertilizer. Nitrate concentrations in leachate after12 hours were negligible, but ranged from 28 to 46 µg N/mL after 24 hours and 111 to 121 µg N/mL after 48 hours of ponding. No leachate was collected from "blank" cores leached for 96 hours. Therefore, while background levels of soil nitrate did not increase during incubations up to 96 hours, flooding moved nitrate down the soil column.

Similar to nitrate, flooding without N fertilizer additions did not result in increased soil ammonium concentrations. Prior to flooding, background ammonium levels were 5.60 ± 1.56 µg N/g in the surface 0.8 in. and declined to 1.56 ± 0.74 µg N/g at the 3.1- to 3.9-in. depth. Floodwater ammonium-N concentrations were less than 1.5 µg N/mL throughout the 96 hours of incubation, and leachate ammonium-N concentrations were less than 2.5 µg N/mL. Duration of ponding from 12 to 96 hours did not affect ammonium concentrations (*P* = 0.62), but depth was significant to concentrations measured in soil. Ammonium-N at the 0- to 0.8- and 0.8- to 1.6-in. depths was significantly higher than the 2.4- to 3.1- and 3.1- to 3.9-in. depths (*P* = 0.0001). Ammonium-N continued to range from 5.40 down to 1.60 µg N/g throughout 96 hours of incubation when no fertilizer was applied. The nitrate and ammonium concentrations in this study were similar to those reported for a DeWitt silt loam in Savin et al. (2006), and demonstrated that N cycling processes in the soil itself were not contributing to increased inorganic-N levels during the experiment.

Ammonium sulfate represents an alternative form of fertilizer and the N breakdown product of urea. Similar to background ammonium-N concentrations, ponding duration was not a significant factor (*P* = 0.71) affecting N concentrations in soil receiving ammonium sulfate fertilizer. Soil ammonium-N concentrations after 12 hours were statistically indistinguishable from 24, 48, and 96 hours of flooding. Additionally, nitrate in the floodwater was always less than 1 µg N/mL until 48 hours and less than 2 µg N/mL at 96 hours. This is in contrast to urea fertilizer where the range of nitrate concentrations in floodwater increased through time; concentrations were less than 2 µg N/mL at 12 hours, less than 4 µg N/mL at 24 hours, up to 11 µg N/mL at 48 hours, and up to 31 µg N/mL at 96 hours. Ammonium-N in floodwater ranged from 2.8 to 58 µg N/mL throughout the experiment for both fertilizers, but there was a wider range of ammonium concentrations measured in leachate (0.6 to 547 µg N/mL) for ammonium sulfate than was measured in leachate of urea (60 to 107 µg N/mL). Similar to background cores, nitrate concentrations in leachate suggested a trend of increasing concentration with time, although interpretations of data are speculative because of lack of cores with leachate and variability in leachate volumes. Nitrate concentrations in leachate ranged from 1.3 to 39 µg N/mL at 12 hours, 19 to 69 µg N/mL at 24 and 48 hours, and 36 to 344 µg N/mL at 96 hours. In urea cores, nitrate in leachate ranged from 6.0 to 47 µg N/mL at 24 hours to 87 to 140 µg N/mL at 48 hours.

Although time was not significant, soil depth was significant for ammonium sulfate fertilizer (Table 2). Ammonium-N concentrations at 0- to 0.8-in. depth were 288 µg N/g and decreased by almost half with each successive 0.8-in. depth interval, except at the 1.6- to 2.4-in. depth where one core had a markedly high ammonium-N concentration. Concentrations in individual cores ranged from 37.39 to 137.17 µg N/g at the 1.6- to 2.4-in. depth, except for 584.02 µg N/g measured in one 48-hour core, which may have resulted from a "hotspot" rather than from fertilizer applied to the soil. Despite measurable decreases in ammonium-N with every 0.8-in. depth interval, the 0.8- to 1.6- and 1.6- to 2.4-in. depths were not statistically different from each other, and the 2.4- to 3.1- and 3.1- to 3.9-in. depths were statistically indistinguishable (Table 2). These results were similar to a previous study where fertilizer-applied cores were flooded for up to 12 hours and ammonium-N decreased within the surface 2.4 in. of soil (Savin et al., 2006).

For ammonium-N measured after urea additions, both time (*P* = 0.03) and depth (*P* < 0.0001) significantly affected how much N was measured, but the time × depth interaction was not significant (*P* = 0.06). Nitrogen was not different between the 0- to

0.8- and 0.8- to 1.6-in. depths or the 2.4- to 3.1- and 3.1- to 3.9-in. depths (Table 2). Nitrogen at the 1.6- to 2.4-in. depth was different than for concentrations at all other depths. By combining concentrations across ponding times, it appears that ammonium-N derived from urea and ammonium sulfate differ mostly in the surface 1.6 in. (Table 2). Lower concentrations were measured at the 0- to 0.8-in. depth following urea application as compared to ammonium sulfate (Table 2). Whereas ammonium sulfate had significantly lower N at 0.8- to 1.6-in. compared to the surface 0.8 in., that was not true for urea-applied N (Table 2). There was a trend of increasing ammonium-N farther into the cores with time throughout the 0.8-in. depth intervals of urea cores (Fig. 1). Results after 24 and 96 hours were significantly different than those measured after 12 hours. These results of greater movement of urea-applied N are similar after 96 hours of ponding to what was measured previously in Savin et al. (2006) after 12 hours of ponding.

SIGNIFICANCE OF FINDINGS

Fertilizer-N movement into the surface 4 in. of silt-loam soil under ponding was measured previously, but only for up to 12 hours (Savin et al., 2006). This experiment continued measurements of N movement from surface-applied urea or ammonium sulfate with ponding durations up to 96 hours. Because it can take days to flood rice fields, time of ponding to allow N movement from the surface into the soil under flooded conditions needed to be extended from hours to days. Interestingly, concentrations of fertilizer-derived N measured after 12 hours in 2005 (Savin et al., 2006) were similar to concentrations measured after 96 hours of ponding in 2006. This is not surprising for ammonium sulfate given that ponding time did not significantly influence the results, but time was a significant factor affecting N concentrations for urea-N. However, the lack of difference between years in the values and shape of the curves depicting N distribution with depth from both fertilizers is striking. These data suggest that N may move into soil at slightly different rates depending on antecedent and existing soil conditions, and may even reach 2.4 to 3.1 in. in as short as 12 hours, but that the data obtained after 12 hours in 2005 were representative of fertilizer N movement up to 96 hours of ponding in soil cores in 2006.

Movement of urea-N is not restricted to the same extent as ammonium sulfate-N. Ammonium can be converted to nitrate under oxidized conditions at the soil surface, which can then be lost through denitrification after moving into the anaerobic zone. Thus, accumulation of ammonium-N at the surface is not necessarily desired. Urea-N accumulated in the surface 2.4 in. of soil after two days of a flood. Urea-N concentrations were lower below 2.4 in., but did increase through time showing that urea continued to move deeper throughout the 4-day incubation. Despite differences between the two fertilizers in concentrations measured at the 0.8-in. soil depths, both nitrate and ammonium were measured in leachate from both fertilizers, while only nitrate was measured in leachate from soil not receiving fertilizer. No nitrate greater than 2 μg N/mL was measured in the floodwater of ammonium sulfate, while the range of nitrate concentrations, although variable, did increase with time in urea cores. These data suggest that type of fertilizer

N affects movement within the soil, but that despite greater movement of urea in soil, mechanisms for N loss are a concern for both fertilizers.

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Table 1. Selected properties of a DeWitt silt-loam soil (n = 3) collected from the Rice Research and Extension Center near Stuttgart, Ark.

pH	EC	P	K	C	N	Bulk density
	(umhos/cm)	------------- (µg/g)	-------------	-------------(%)	----------------	(g/cm^3)
5.6 (0.1)[z]	337.3 (8.5)	49.6 (3.7)	115.5 (4.4)	0.73 (0.01)	0.08 (0.01)	1.31 (0.02)

[z] Standard deviations are in parentheses ( ).

Table 2. Ammonium-N following application of ammonium sulfate (AS) or urea to silt-loam soil and ponding of water up to 96 hours (n = 16).

	NH_4-N	
Soil depth	AS	Urea
(in.)	--------------- (µg N/g)	-----------------
0 - 0.8	287.74 a[z]	153.80 a
0.8 - 1.6	157.83 b	181.22 a
1.6 - 2.4	112.15 b	100.72 b
2.4 - 3.1	54.73 c	54.18 c
3.1 - 3.9	26.89 c	32.89 c

[z] Different letters within a column indicate significant differences ($P < 0.05$).

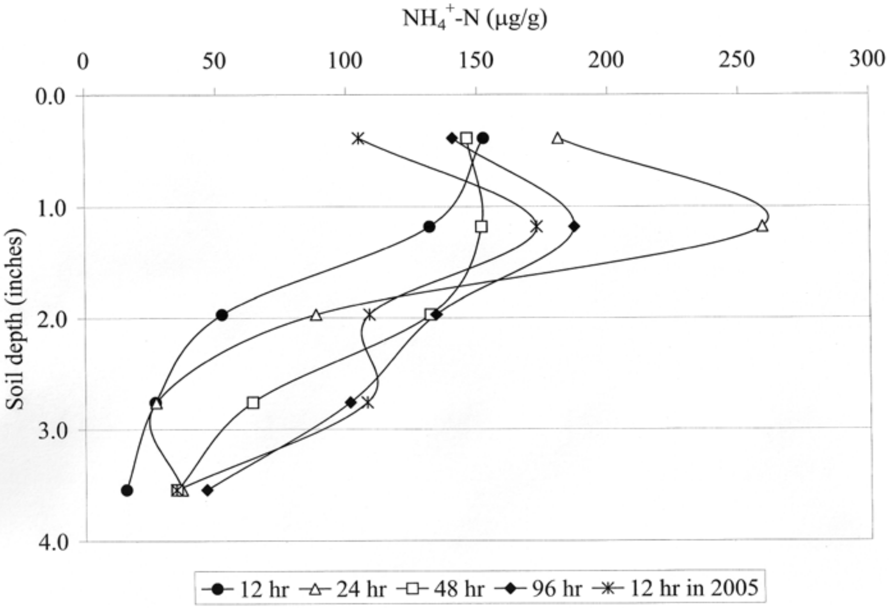

Fig. 1. Ammonium (NH_4^+-N) derived from urea (90 mg N) applied to the surface of soil cores containing DeWitt silt loam and ponded with 2 in. of water for 12, 24, 48, or 96 hours.

RICE CULTURE

Rice and Soybean Response to Annual Potassium Fertilization Rate

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

ABSTRACT

The balance between nutrient inputs as fertilizer and removals by the harvested portion of the crop plus soil properties and management are needed to evaluate the sustainability of recommended fertilizer rates using various fertilization philosophies. A long-term potassium (K) fertilization study was initiated at the Pine Tree Branch Station (PTBS) in 2000 and cropped to rice and soybean. After seven crops, data indicate when <60 lb K_2O/acre/year was applied, soil-test K declined and K nutrition became a yield-limiting factor for rice and soybean with soybean yields being more sensitive to K deficiency than rice yields. Over the last 4 years, rice and soybean yields have tended to be the greatest when >60 lb K_2O/acre/yr were applied.

INTRODUCTION

Fertilizer rate recommendations are correlated and calibrated using data from trials that are conducted for a single year across numerous sites and years. Data from such trials are quite useful in determining how accurate soil tests are at predicting the need for phosphorus (P) and K fertilizers and calibrating the fertilizer rates that are needed to maximize crop yields for specific soil properties. However, fertilization trials that are conducted for a single year across numerous sites reveal little about how the annual fertilization rate influences the yields of subsequent crops and how soil-test K responds to fertilization across time. The balance between nutrient inputs as fertilizer and removals by the harvested portion of the crop plus soil properties and management are needed to evaluate the sustainability of recommended fertilizer rates using various fertilization philosophies.

Growers often question the sustainability of recommendations made using the '*fertilize the crop*' philosophy that recommends fertilization only when a positive crop yield response is expected. Consistently high crop yields combined with potential nutrient-loss pathways may remove more P and K than is recommended for application. A negative nutrient balance (annual loss/removal > input) can slowly reduce a soils' fertility level and make subsequent crops more susceptible to nutrient deficiencies and ultimately reduce the soils' productivity, especially for poorly buffered soils and when soil samples are submitted for analysis once every 3 or 4 years. The primary objectives of this project were to evaluate the effect of different, annual K-fertilization rates on rice and soybean yields and soil-test K across time.

PROCEDURES

A K-fertilization trial was established in 2000 at the Pine Tree Branch Station on a Calhoun silt loam. In May 2000, plot boundaries were established and a composite soil sample consisting of 6 to 8, 1-in. diameter soil cores (0- to 4-in. depth) was collected from each plot to evaluate initial soil properties and uniformity of soil-test K among plots. Soil samples were oven-dried at 55°C, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil weight:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in Mehlich-3 extracts were determined using inductively coupled plasma spectroscopy (ICPS). Each year a composite soil sample was taken from each plot and processed as described previously. Annual soil samples were always taken in February or March. Selected soil-chemical property means for each year are listed in Table 1.

Each individual plot measured 16-ft long by 25-ft wide, which allowed for planting four strips per treatment with a 6-ft wide small-plot drill. Phosphorus fertilizer was applied annually at a rate of 50 lb P_2O_5/acre. Zinc (Zn) fertilizer (10 lb Zn/acre) was applied in 2000, 2004, and 2006 before rice was grown and boron (B) fertilizer (1 lb B/acre) was applied before soybean was seeded in 2003 and 2005. In 2000, 2002, 2004, and 2006 'Wells' rice was drill-seeded (7.5-in. drill spacing) at 100 lb seed/acre. In 2001, 2003, and 2005, soybean was seeded in 7.5- or 15-in.-wide rows (Table 2). Rice was seeded into a conventionally tilled seedbed in 2000. To minimize soil and K movement among plots, all crops planted from 2001 to 2004 and 2006 were established in untilled seedbeds (i.e., no-till). Tillage was performed in 2005 to remove combine tire tracks from the 2004 rice harvest. Management with respect to seeding rate, irrigation, and weed control was performed following University of Arkansas Cooperative Extension Service recommendations for rice and soybean.

Muriate of potash (KCl, 60% K_2O) was broadcast to the soil surface shortly before or after planting at rates of 0, 30, 60, 90, and 120 lb K_2O/acre each year from 2000 to 2005. Rates were increased to 0, 40, 80, 120, and 160 lb K_2O/acre in 2006. Rates will be identified by the initial K rates (applied in 2000) throughout the paper. Potassium fertilizer rates were arranged as a randomized complete block with eight replications.

At maturity, rice and soybean yields were determined by harvesting the middle 3- to 5-ft of each drill pass in four 12- to 14-ft long strips from each K rate. Grain moisture contents were adjusted to 12% moisture for rice and 13% for soybean for statistical analysis of yield data.

Plant samples were collected in all years, except 2004, to monitor plant-K uptake. For rice, whole, aboveground plants in a 3-ft section of the first inside row were harvested near panicle differentiation, dried, weighed for dry matter, ground to pass a 2-mm sieve, digested, and analyzed by ICPS for nutrient concentrations. For soybean, whole plants were sampled in 2001 and 2003 (2-linear ft of row) and trifoliate leaves (20) in 2005 and processed as described for rice samples.

Analysis of variance procedures were conducted by year with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's protected Least Significant Difference method at a significance level of 0.10. Linear regression was performed on data means to delineate trends.

RESULTS AND DISCUSSION

Soil-Test K

Initial soil samples taken in 2000 showed that soil-test K was uniform among treatments before K fertilizer treatments were applied (Table 3). Based on the annual soil-test K of the unfertilized control, the recommended (revised recommendations, 2006) K-fertilizer rates were 90 lb K_2O/acre for rice in 2000, 120 K_2O/acre for soybean in 2001, 60 lb K_2O/acre for rice in 2002, 60 lb K_2O/acre for soybean in 2003, 90 lb K_2O/acre for rice in 2004, 120 lb K_2O/acre for soybean in 2005, and 90 lb K_2O/acre for rice in 2006. The recommended rates of K fertilizer for all other treatments were identical to the unfertilized control in all years except 2001, 2004, and 2006 when lower K-fertilizer rates would have been recommended for the 90 and/or 120 lb K_2O/acre/year rates.

Soil-test K in the unfertilized control fluctuated somewhat among years, ranging from a low of 65 ppm in 2006 to a high of 103 ppm in 2003 (Table 3). Following application of K treatments, the range of soil-test K among annual K rates generally increased each year and varied from 12 ppm in 2001 to 32 ppm in 2006. Soil receiving the two lowest rates (0 and 30 lb K_2O/acre) of K fertilizer always contained the lowest soil-test K values and the highest soil-test K was always from one of the two highest K application rates (90 or 120 lb K_2O/acre). Each year, soil-test K increased linearly as annual K rate increased with 4 to 12 lb K_2O/acre required to increase Mehlich-3 soil-test K by 1 ppm. Soil samples collected in spring 2006 showed that application of 60 lb K_2O/acre had maintained the initial soil-test K and rates >60 lb K_2O/acre increased soil-test K by about 1 ppm per every 4 lb K_2O/acre/year. Data show that building soil-test K by application of K rates greater than the crop removal rate is possible, albeit slow.

Yield Response

During the first two complete rice-soybean rotations, only soybean yields in 2001 were significantly increased by K fertilization (Table 4). Although not statistically significant, consistent, numerical yield increases were observed during 2002 and 2003. However, rice and soybean yields were significantly increased by K fertilization during the third crop-rotation cycle (2004 to 2005) and in 2006. In both 2004 and 2005, application of 120 lb K_2O/acre produced the greatest rice and soybean yields. Across time, rice yields declined 2.5%/year when 0 lb K_2O/acre/yr was applied and remained constant (≥95% of maximum yields) at rates ≥30 lb K_2O/acre/yr. Similarly, soybean yields declined by 4.5 and 3.4%/yr when 0 and 30 lb K_2O/acre/yr were applied annually.

The average yields across the 4 years for rice were 152, 160, 164, 164, and 168 bu/acre (LSD0.10 = 9 bu/acre) for 0, 30, 60, 90, and 120 lb K_2O/acre, respectively. The average yields across the 3-years for soybean were 39, 42, 45, 46, and 47 bu/acre (LSD0.10 = 4 bu/acre) for 0, 30, 60, 90, and 120 lb K_2O/acre, respectively. Averaged across years, yield data suggest that ≥30 lb K_2O/acre/yr and ≥60 lb K_2O/acre/yr allowed production of near maximal rice and soybean yields, respectively. The minimum K rate needed to produce near maximal yields, 30 lb K_2O/acre for rice and 60 lb K_2O/acre for soybean, closely matched the K removal rate by the mean yields for rice (0.18 lb K_2O/bu) and soybean (1.4 K_2O/bushel) during this 7-year period. Potassium removal in harvested grain largely explains the decline, maintenance, and increase in soil-test K among K rates.

Tissue-K Concentrations

Each year, K concentrations in rice (panicle differentiation) and soybean tissues (R2) increased as K application rate increased (Table 5). Also, rice tissue-K concentrations in the unfertilized control tended to decrease across time, indicating less soil-available K. The tissue-K data when considered with yield data provide insight concerning the tissue-K concentrations, which can be considered deficient and sufficient for crop growth. Ideally, whole-plant K concentrations for rice at panicle differentiation should be above 2.0%.

SIGNIFICANCE OF FINDINGS

The data provide strong evidence that soybean yield is more sensitive to K deficiency than rice, suggesting that K-fertilizer recommendations should be targeted to maintain soybean yields. Data collected from this study were used as an aid to revise fertilizer recommendations for silt-loam soils used for rice and soybean production. The data indicate that annual applications ≥60 lb K_2O/acre were needed to produce high annual rice and soybean yields as well as maintain soil-test K. Annual K-fertilizer rates >60 lb K_2O/acre tended to produce the greatest crop yields during the third rotation cycle and were needed to gradually build soil-test K. The study will be continued to monitor rice and soybean yields, crop K nutrition, soil-test K, and other crop growth and management considerations (e.g., stand, vigor, disease, lodging, etc.) in future years.

ACKNOWLEDGMENTS

The authors wish to thank the Pine Tree Branch Experiment Station personnel for their assistance in establishing and conducting these trials. Research was funded from grants by the rice check-off program, soybean check-off program, and Fertilizer Tonnage Fees in Arkansas and by a grant from the Foundation for Agronomic Research through the Potash and Phosphate Institute.

Table 1. Selected soil chemical property means of the annual potassium (K) fertilizer rate test site conducted at the Pine Tree Branch Station from 2000 to 2005.

		Mehlich-3-extractable soil nutrients[z]							
Year	Soil pH	P	Ca	Mg	Na	S	Mn	Zn	Cu
	(1:1)[y]	---------(mg/kg)---------							
2000	6.9	15	1424	272	58	11	109	2.6	0.9
2001	7.2	6	1439	292	58	24	58	4.9	0.6
2002	7.7	15	1763	314	51	7	125	4.8	1.0
2003	7.5	15	1672	310	47	12	119	6.2	1.2
2004	7.8	19	1695	311	39	8	95	3.5	1.1
2005	7.3	17	1718	280	51	13	109	3.3	0.9
2006	7.7	23	1799	323	28	11	363	3.3	0.7

[z] P = phosphorus; Ca = calcium; Mg = magnesium; Na = sodium; S = sulphur; Mn = manganese; Zn = zinc; and Cu = copper.

[y] Soil pH measured in a 1:1 soil:water ratio.

Table 2. Selected agronomic information for crops planted in long-term potassium (K) fertilization study.

Year	Crop planted	Cultivar	Drill spacing	Plant date
			(in.)	(day / month)
2000	Rice	Wells	7.5	17 May
2001	Soybean	Caviness	7.5	22 June
2002	Rice	Wells	7.5	16 April
2003	Soybean	Caviness	15.0	29 May
2004	Rice	Wells	7.5	11 May
2005	Soybean	Armor 53K3	15.0	12 May
2006	Rice	Wells	7.5	13 April

Table 3. Soil-test potassium (K) (measured in February or March each year) as affected by annual K application rate in a multi-year study conducted at the Pine Tree Branch Station from 2001 to 2006.

Annual K Rate	2000 Rice	2001 Soybean	2002 Rice	2003 Soybean	2004 Rice	2005 Soybean	2006 Rice
(lb K_2O/acre)	[mg Mehlich-3-extractable K/kg soil (ppm)]						
0	78	80	99	103	80	68	65
30	80	83	109	104	82	69	71
60	83	85	114	107	87	72	76
90	83	85	122	121	106	88	90
120	80	92	110	114	110	86	97
LSD0.10	NS	6	11	NS	7	7	8
P-value	0.7336	0.0328	0.0289	0.2446	0.0001	0.0001	0.0001
C.V., %	9.3	8.7	11.9	15.2	9.0	10.8	11.5
Linear regression (means)[z]							
Slope	--	0.087*	0.117	0.13*	0.280*	0.183*	0.277*
r^2	--	0.8667	0.4394	0.6590	0.9000	0.8149	0.9692

[z] * denotes coefficient was significant at the 0.10 probability levels.

Table 4. Rice and soybean yields as affected by annual potassium (K) application rate in a multi-year study conducted at the Pine Tree Branch Station from 2000 to 2006.

Annual K Rate	2000 Rice	2001 Soybean	2002 Rice	2003 Soybean	2004 Rice	2005 Soybean	2006 Rice
(lb K_2O/acre)	(bu/acre)						
0	136	42	176	32	139	41	157
30	137	46	180	34	148	47	177
60	140	46	180	35	153	52	180
90	139	46	185	39	152	53	181
120	138	48	187	35	160	56	187
LSD0.10	NS	3	NS	NS	7	2	8
P-value	0.9680	0.0490	0.3297	0.4733	0.0011	0.0001	0.0001
C.V., %	5.3	6.5	5.7	20.6	5.9	6.5	5.2

[z] Annual K fertilizer rates were changed to 0, 40, 80, 120, and 160 lb K_2O/acre/yr in the spring of 2006.

Table 5. Rice (whole plants at panicle differentiation stage) and soybean (whole plant or trifoliate leaves at R2 stage) tissue-potassium (K) concentrations as affected by annual K application rate in a multi-year study conducted at the Pine Tree Branch Station from 2000 to 2006.

Annual K Rate	2000 Rice	2001[z] Soybean	2002 Rice	2003[z] Soybean	2004 Rice	2005[z] Soybean	2006[y] Rice
(lb K_2O/acre)	(% K)						
0	2.36	1.50	1.79	1.07	--	1.48	1.63
30	2.65	1.47	1.98	1.25	--	1.72	2.14
60	2.90	1.53	2.10	1.33	--	1.96	2.45
90	3.00	1.69	2.46	1.62	--	1.96	2.94
120	3.14	1.62	2.54	1.69	--	2.13	3.09
LSD0.10	0.19	NS	0.21	0.16	--	0.13	0.25
P-value	0.0001	0.3828	0.0001	0.0001	--	0.0001	0.0001
C.V., %	5.2	15.6	11.3	13.9	--	8.0	12.1

[z] Whole, aboveground soybean plants sampled in 2001 and 2003. Recently matured trifoliate leaves sampled in 2005.

[y] Annual K fertilizer rates were changed to 0, 40, 80, 120, and 160 lb K_2O/acre/yr in spring of 2006.

Rice Response to Phosphorus and Potassium Fertilization

N.A. Slaton, R.E. DeLong, R.J. Norman, C.E. Wilson, Jr., and B.R. Golden

ABSTRACT

Phosphorus (P) and potassium (K) must often be applied to maintain the productivity of cropped soils and prevent deficiencies of these nutrients from limiting crop yields. Fertilization trials were conducted with K at four sites, P at two sites, and a multi-nutrient trial established in a commercial field during 2006. Rice grain yield was increased by 10 to 16% by application of 25 to 100 lb P_2O_5/acre on an Alligator clay with very low soil-test P. Rice yields responded similarly to P source, triple superphosphate or diammonium phosphate, averaged across P rates. Significant yield increases attributed to K fertilization were not measured at any of the four sites that had 'Medium' or 'Optimum' soil-test K levels. The multi-nutrient trial established in a grower's field showed that no fertilizer treatment increased grain yields compared to the control, which received only nitrogen (N) applied by the cooperating grower. However, all treatments receiving extra preflood-N or poultry litter (preplant) had numerically higher grain yields than treatments receiving P, K, Zinc (Zn), and boron (B) fertilizers.

INTRODUCTION

Phosphorus and K are essential macronutrients that must often be applied to maintain the productivity of cropped soils and prevent deficiencies of these nutrients from limiting crop yields. Deficiencies of P and K are sporadically observed in rice (*Oryza sativa* L.) and soybean [*Glycine max* (Merr.) L.] fields in Arkansas. Generally, rice grown on alkaline soils is susceptible to and shows P-deficiency symptoms during the seedling to tillering stages. In contrast, K-deficiency symptoms typically appear following panicle differentiation. Potassium-deficient rice has been documented on soils with a wide range of chemical properties in Arkansas, but deficiencies are most common on silt and sandy loams with pH <7.0 that have low soil-test K concentrations. Although P and K deficiencies of rice occur every year, they are relatively uncommon and research studies have not consistently shown significant rice yield increases from P and K fertilization, especially for soils that have a 'Medium' level of soil-test K.

Soil samples submitted to the University of Arkansas soil-test lab show that 54% of Arkansas soils cropped to rice have soil-test K <110 ppm (DeLong et al., 2006). Data show that when soil-test K is <110 ppm K, fertilization will often increase rice yields with the magnitude and likelihood of yield increases becoming greater as soil-test K declines (Slaton et al., 2006). The importance of accurate soil test-based fertilizer recommendations is greater than ever because of increased fertilizer prices and the adoption of precision agriculture and variable-rate application technology. The primary objectives of these studies were to evaluate rice growth and yield responses to P and K fertilization rates on soils in eastern Arkansas to aid in developing accurate fertilizer recommendations and diagnostic nutrient concentrations that can be used to diagnosis K deficiencies of rice.

MATERIALS AND METHODS

In 2006, P-fertilization trials were established at two sites and K-fertilization trials were established at four sites. One additional study that included P and K fertilizer treatments was established in a Poinsett County field, which investigated rice response to various fertilizer nutrients including additional N (preflood), Zn, and B. Selected soil and agronomic information is listed for each site in Table 1. Studies were established in grower fields as well as on the Pine Tree Branch Station (PTBS) near Colt, Ark.; Rice Research Extension Center (RREC) near Stuttgart, Ark; and the Lake Hogue Research Farm (LHRF) near Weiner, Ark. The cooperating grower fields were in Poinsett (2 fields) and Prairie counties. Growers omitted P and K fertilizer from the part of the field designated for research.

For each site, 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, soil water pH was determined in a 1:2 soil weight-water volume mixture by electrode, and subsamples of soil were extracted using the Mehlich-3 method. Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma spectroscopy (ICPS). Selected soil-chemical properties for each experiment site are listed in Table 2. Soybean was the previous crop grown (in 2005) at all sites.

A long-grain cultivar was drill-seeded into conventionally tilled seedbeds at all sites. 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- to 8-ft wide and 16-ft long with a 1- to 2.5-ft wide alley surrounding each plot.

Phosphorus Trials

Phosphorus rates of 0, 25, 50, and 100 lb P_2O_5/acre were applied as triple superphosphate (46% P_2O_5) and diammonium phosphate (18-46-0) to the soil surface before or shortly after emergence at two sites, Poinsett-East and PTBS. If needed, K (60 lb K_2O/acre as muriate of potash) and/or Zn fertilizers (10 lb Zn/acre as $ZnSO_4$) were also broadcast to the soil surface several weeks before flooding. At the cooperating-grower field site, N, pest control, and flooding were managed by the grower. At maturity, the middle four or five rows of rice from the center of each plot were harvested with a plot combine for grain yield determination. Harvest moisture content and weight of the harvested rice were determined immediately and yields were adjusted to 12% moisture for statistical analysis.

All experiments were arranged in a randomized complete block design with a 2 × 4 factorial treatment structure and four replicates per treatment. Locations were analyzed separately. Mean separations were performed by Fisher's protected Least Significant Difference method at a significance level of 0.10.

Potassium Experiments

Potassium rates of 0, 40, 80, 120, and 160 lb K_2O/acre as muriate of potash (60% K_2O) were applied to the soil surface at or before rice emergence at four sites. Phosphorus (50 lb P_2O_5/acre as triple superphosphate) and Zn fertilizers (10 lb Zn/acre as $ZnSO_4$) were also broadcast to the soil surface before flooding. At the PTBS, RREC, and LHRF, 120 lb N/acre as urea were applied at the 5-lf stage and followed by flooding. At all grower field sites, N and flooding were managed by the cooperating growers. Whole-plant samples were harvested from a 3-ft row section in the first inside row near the panicle-differentiation stage and at the late-boot to early-heading stage. Plant samples were processed and harvest was performed as described previously for the P-rate trials.

For all experiments, K rates were arranged as a randomized complete block design. Each treatment was replicated six or eight times. Locations were analyzed separately. Mean separations were performed by Fisher's Protected Least Significant Difference method at a significance level of 0.10. All statistical analyses were performed with SAS version 9.1.

Multi-Nutrient Trial

Various fertilizer treatments were applied to a grower's field in Poinsett County (Poinsett-West) in an attempt to help the grower identify whether lower-than-expected grain yields were attributed to plant nutrition. The treatments included N, P, and K fertilizers applied alone at various rates; N, P, K, Zn, and B applied in combination at various rates; and pelleted poultry litter applied to the soil surface at 3,000 lb/acre shortly after seeding (Table 3). All P, K, Zn, and B inorganic fertilizers were applied before rice emergence. Nitrogen (40 lb N/acre) treatments were always applied preflood as a combination of ammonium sulfate and urea (20 lb N/acre from each). All plots received the same N management as the surrounding field (applied by the grower). The preflood-N treatments represented additional preflood-N above what the grower applied. Whole-plant samples were collected from three treatments that received 50 lb P_2O_5/acre plus 0, 80, and 140 lb K_2O/acre at the late-boot stage for dry-matter accumulation and tissue analysis.

At maturity, the middle four or five rows of rice from the center of each plot were harvested with a plot combine for grain yield determination. Harvest moisture content and weight of the harvested rice were determined immediately and yields were adjusted to 12% moisture for statistical analysis.

The experiment was arranged as a randomized complete block design with five replicates per treatment. Mean separations were performed by Fisher's protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Phosphorus Trials

Soil pH was >7.0 and soil-test P was 'Optimum' (36 to 50 ppm) at PTBS and 'Very Low' (<16 ppm) at Poinsett-East (Table 2). The Poinsett-East site, a clayey soil, would have received a recommendation for 120 lb P_2O_5/acre and PTBS would have received a recommendation for 0 lb P_20_5/acre. The interaction between P sources and P_2O_5 rate or the main effect of P source had no significant influence on grain yield. Rice grain yield was increased 10 to 16% by P fertilization on this clayey soil that had a history of P deficiency. All treatments receiving P produced statistically similar yields that were greater than the unfertilized check (Table 4). At PTBS, the unfertilized control-yield was the numerically lowest among treatments, but was not statistically lower.

Potassium Rate Trials

Soil-test K concentrations were 'Medium' (90 to 130 ppm) at LHRF, Prairie, and RREC sites and 'Optimum' (131 to 175 ppm K) at the PTBS (Table 2). Potassium fertilization was recommended for all sites except the PTBS, however little or no positive yield increase was expected at the sites testing 'Medium.' Visual symptoms of K deficiency were not expressed at any of the test sites.

Potassium fertilization had no influence on rice dry-matter accumulation by the panicle-differentiation growth stage at any site (Table 5). By early heading, significant differences in dry-matter accumulation among K rates was measured only at the PTBS, the site with the greatest soil-test K. Rice receiving no K had the least dry matter, which increased numerically as K rate increased to 120 lb K_2O/acre.

Despite the lack of significant differences in dry-matter accumulation at most sites, whole-plant K concentrations generally increased as K-fertilizer rate increased at each site for samples collected at panicle differentiation (Table 6). Tissue-K concentrations of rice receiving no K fertilizer were always >2.2%, which is considered sufficient. By early heading, only rice grown at PTBS showed no significant difference in K concentrations among K rates. The lack of a consistent and significant increase in K concentration at PTBS was attributed to the K being diluted by the significant increase in dry matter. At the other three sites, which had similar dry matter among K rates, rice K concentrations increased as K rates increased. At all sites, rice receiving no K had tissue-K concentrations >1.5%, which are considered sufficient for early heading.

Significant, positive yield increases from K fertilization were not measured at any site (Table 7). Although significant differences among K rates occurred at the PTBS, the unfertilized control yield was not different from any treatment that received K fertilizer.

Multi-Nutrient Response

Rice yields were not significantly affected by any of the fertilizer treatments (Table 3). Despite the lack of significant differences, there were some interesting trends in the data. Preplant-incorporated poultry litter (~120 lb total-N/acre) and treatments that included extra preflood-N always produced higher numerical yields than treatments receiving no extra N (above N applied by the grower). These data suggest that rice yields in this field would benefit from a slightly greater preflood-N rate. Analysis of whole plants from selected treatments that received the same N and P fertilizer rates showed that K nutrition was adequate (>1.64%). The soil-test P, K, and Zn concentrations were all considered 'Optimum' or 'Above Optimum' and soil-test recommendations correctly recommended that only N be applied to this soil when cropped to rice.

SIGNIFICANCE OF FINDINGS

Soil-test recommendations for K correctly suggested that rice yields at four research sites would be affected only nominally or not at all by K fertilization, with the recommended K fertilizer serving to replace K removed by an above-average rice yield (i.e., maintain soil K fertility). Soil test-based P-fertilizer recommendations correctly predicted rice response to P fertilization at two sites. Although current soil test-based P and K fertilizer recommendations are not always accurate, these data show that the recommendations often correctly identify nutrient-deficient soils and appropriately classified crop response to soils with 'Medium' or greater soil-test K levels. Continued research and verification of soil test-based recommendations will further improve our knowledge of crop response to fertilization and enable us to refine recommendations to aid in maximizing crop yields and net profits.

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Table 1. Agronomic and field information for field sites used to evaluate rice response to phosphorus (P) and potassium (K) fertilization on silt loam soils during 2006.

Site[z]	Nutrients tested	Cultivar	Soil series	Plant date[y]
				(day/month)
LHRF	K	Wells	Hillemann	13 April
Prairie County	K	Cheniere	Calloway	16 May
Poinsett-East	P	Wells	Alligator	5 April
Poinsett-West	many	Wells	Henry	17 April
PTBS	P & K	Wells	Calhoun	13 April
RREC	K	Wells	Dewitt	15 May

[z] LHRF = Lake Hogue Research Farm; PTBS = Pine Tree Branch Station; and RREC = Rice Research and Extension Center.

[y] Estimated or actual seeding date.

Table 2. Selected soil chemical characteristics of sites used to evaluate rice response to phosphorus (P) and potassium (K) fertilization on silt loam soils in 2005.

Trial / site[z]	Soil pH[y]	Mehlich-3-extractable soil nutrient concentrations[x, w]								
		P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
		[mg/kg (ppm)]								
Phosphorus trials										
PTBS	7.3	44 (4)	141	1618	306	14	218	202	3.8	1.1
Poinsett-East	7.8	9 (4)	221	4565	1033	9	212	60	3.1	0.9
Potassium trials										
LHRF	6.5	10	104 (9)	962	171	11	157	124	3.5	0.7
Prairie	7.4	45	121 (12)	1295	168	19	269	28	2.8	0.9
PTBS	7.3	38	151 (30)	1697	319	12	183	210	1.4	1.1
RREC	5.5	33	116 (15)	835	128	11	368	126	14.1	0.7
Multi-nutrient trial										
Poinsett-West	6.6	45 (2)	133 (4)	1289	268	28	260	21	8.9	1.1

[z] LHRF = Lake Hogue Research Farm; PTBS = Pine Tree Branch Station; and RREC = Rice Research and Extension Center.

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

[x] Mehlich-3 extraction procedure (1:10 extraction ratio). Ca = calcium; Mg = magnesium; S = sulfur; Fe = iron; Mn = manganese; Zn = zinc; and Cu = copper.

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

Table 3. Grain yield as affected by fertilizer treatment for a test conducted on a silt loam soil at the Poinsett-West site during 2006.

Fertilizer/amendment rate[z]						Grain
N	P	K	Zn	B	Litter	yield
(lb N/acre)	(lb P_2O_5/acre)	(lb K_2O/acre)	(lb Zn/acre)	(lb B/acre)	(lb/acre)	(bu/acre)
40	50	80	10	0	0	199
40	50	80	10	1	0	195
0	0	0	0	0	3000	195
40	0	0	0	0	0	194
0	50	80	10	0	0	189
0	50	0	0	0	0	187
0	0	140	0	0	0	183
0	0	0	0	0	0	183
0	50	80	0	0	0	181
0	50	140	0	0	0	181
0	0	80	0	0	0	178
$LSD_{0.10}$						NS
(C.V., = 7.9%) *P*-value						0.3796

[z] N = nitrogen; P = phosphorus; K = potassium; Zn = zinc; and B = boron.

Table 4. Effect of phosphorus (P)-fertilizer rate, averaged across P sources, on rice grain yield for studies conducted in 2006.

P fertilizer	Site	
rate	PTBS[z]	Poinsett-East
(lb P_2O_5/acre)	--------------------- (bu/acre)	--------------------------
0	203	144
25	211	159
50	214	164
100	209	167
LSD0.10	NS[y]	13
P-value	0.3470	0.0257

[z] PTBS = Pine Tree Branch Station.

[y] NS = not significant at the 0.10 level.

Table 5. Effect of potassium (K) rate, by location, on rice dry matter accumulation at the panicle differentiation (PD) and late-boot to early heading stages for studies conducted in 2006.

K	Site			
rate	PTBS[z]	RREC	LHRF	Prairie
(lb K_2O/acre)	(lb dry matter/acre)			
PD				
0	2898	2913	4256	2802
40	3669	2922	3696	2767
80	3560	3198	3990	3044
120	3729	3322	3938	3126
160	4170	3213	3932	2868
$LSD_{0.10}$	NS	NS	NS	NS
P-value	0.1322	0.8431	0.4322	0.4635
Late boot				
0	9463	12164	11914	11455
40	10991	10696	12747	12518
80	11620	12584	11978	12067
120	13221	12338	11336	12608
160	12486	12248	11359	12507
$LSD_{0.10}$	1563	NS[y]	NS	NS
P-value	0.0026	0.3759	0.4984	0.9193

[z] PTBS = Pine Tree Branch Station; RREC = Rice Research and Extension Center; and LHRF = Lake Hogue Research Farm.

[y] NS = not significant at the 0.10 level.

Table 6. Effect of potassium (K) rate, by location, on whole-plant K concentrations at the panicle differentiation (PD) and late boot to early heading stages for studies conducted in 2006.

K rate	Site			
	PTBS[z]	RREC	LHRF	Prairie
(lb K_2O/acre)	(% K)			
PD				
0	2.28	2.63	2.48	2.55
40	2.45	2.58	2.71	2.80
80	2.64	2.89	2.86	2.77
120	2.51	2.78	3.02	3.02
160	2.93	3.07	3.15	3.06
$LSD_{0.10}$	0.20	0.14	0.17	0.17
P-value	0.0001	<0.0001	<0.0001	0.0002
Late boot				
0	1.78	1.95	1.57	1.84
40	1.85	1.97	1.57	1.84
80	1.90	2.00	1.65	1.89
120	1.92	2.14	1.70	1.97
160	1.84	2.22	1.81	1.98
$LSD_{0.10}$	NS[y]	0.14	0.11	0.09
P-value	0.3133	0.0097	0.0056	0.0216

[z] PTBS = Pine Tree Branch Station; RREC = Rice Research and Extension Center; and LHRF = Lake Hogue Research Farm.

[y] NS = not significant at the 0.10 level.

Table 7. Effect of potassium (K) rate, by location, on rice grain yield for studies conducted in 2006.

K rate	Site			
	PTBS[z]	RREC	LHRF	Prairie
(lb K_2O/acre)	(bu/acre)			
0	209	158	155	187
40	208	162	156	168
80	202	173	152	183
120	212	164	154	190
160	192	164	154	191
$LSD_{0.10}$	12	NS[y]	NS	NS
P-value	0.0722	0.1449	0.9270	0.3974
C.V., %	6.8	6.0	4.6	11.3

[z] PTBS = Pine Tree Branch Station; RREC = Rice Research and Extension Center; and LHRF = Lake Hogue Research Farm.

[y] NS = not significant at the 0.10 level.

Determining the Potential of Furrow-Irrigated Rice Using a 3- and 5-Day Irrigation Schedule in a Rice-Production System

D.O. Stephenson, IV, C.E. Wilson, Jr., P. Tacker, and S.W. Lancaster

ABSTRACT

A field study was initiated to evaluate a 3- and 5-day furrow-irrigation schedule in a rice-production system. Averaged across furrow-irrigation schedules, 'XL723' height was greater than 'Cybonnet' in July and August of the growing season; however, panicle number was greater for Cybonnet than XL723. Yield components (spikelets, total kernels, and total filled kernels/panicle) and rough-rice yields were greater for XL723 than Cybonnet. Percent head and total rice were greater for Cybonnet compared to XL723. Furrow-irrigation schedule did not influence rice heights or panicle number. Yield components, rough-rice yields, and milling percentages were greater following the 3-day schedule than the 5-day schedule. The effect of soil moisture logger location on rice height was minimal; however, yield components observed at the 200-ft location were greater than the 400-ft location. No differences in rough rice yield were observed between the 200- and 400-ft locations, but head and total rice percentages were greater at the 200-ft location. Rice location on the raised beds did not influence heights or yield components. Panicle number was greater for rice seeded on top of a raised bed compared to shoulder or furrow rice. Averaged across factors, soil moisture did not reach a detrimentally dry level due to rainfall amounts totalling 18.5 in. during the growing season.

INTRODUCTION

Rice (*Oryza sativa*) in the United States is predominately grown with flood-irrigation. In this system, the crop is usually flooded at approximately the V-4 (4-lf) growth stage (Counce et al., 2000) and a continuous flood is typically maintained until physiological maturity. Vories et al. (2002) stated that producers and researchers have investigated the possibility of producing rice in a row-crop culture with other irrigation methods rather than a continuous flood and that potential benefits include water and energy savings, simplified flushing of the soil early in the growing season, savings in levee construction and destruction, and easier harvest due to soil drying.

Furrow-irrigated rice-production systems have recently begun to receive increased attention among rice producers and media outlets. Furrow-irrigation can generally saturate the soil and may be similar to flood-irrigation (Vories et al., 2002). Nitrogen fertilizer application timings and rates in furrow-irrigated rice have been investigated (Bollich et al., 1988; Hefner and Tracy, 1991; Wells et al., 1991). Vories et al. (2002) observed a 15.6% yield reduction in furrow-irrigated rice compared to flood-irrigated rice. Unfortunately, little information is available concerning the timing of furrow-irrigation. Therefore, research was initiated to investigate furrow-irrigation schedules on rice yield, yield components, and the effect of soil moisture.

PROCEDURES

Research was initiated at the Northeast Research and Extension Center (NEREC) in Keiser, Ark., in 2006 on a Sharkey clay loam (very-fine, smectitic, thermic Chromic Epiaquert). A factorial arrangement of treatments in a randomized complete block design with four replications was used. The first factor consisted of two rice cultivars (RC), a conventionally bred cultivar Cybonnet and a hybrid XL723. The second factor consisted of two furrow-irrigation schedules (FIS), 3-day (3-d) and 5-day (5-d). Plot size was 25.33-ft wide (eight 38-in. raised beds) by 600-ft long. A raised bed/hipping implement was used to establish raised beds parallel to the slope of the field site for drainage. Pest management was based on Arkansas Cooperative Extension Service recommendations. Soil fertility management consisted of 230-lb nitrogen (N)/acre applied as urea (45% N) on 15 June. To prevent volatilization of the urea, 0.18-oz Agrotain/lb N was applied to urea prior to application. No phosphorus or potassium fertilizer was applied.

Cybonnet and XL723 were direct-seeded into the top, shoulder, and furrow of the raised beds at 90- and 30-lb/acre, respectively, using a 7.5-in. row spacing on 16 May. WatchDog Soil Moisture Loggers connected to two Watermark Soil Moisture Sensors were installed on 14 June at 200- and 400-ft of each 600-ft furrow-irrigated plot to record variation in soil moisture within each plot during the growing season. A sensor was installed in the top and on the shoulder of a raised bed to a 4-in. depth in the center of each plot to record variation in soil moisture within raised beds.

An irrigation-water flow meter was installed to record water usage by the 3-d and 5-d FIS. Poly-pipe was attached to the flow meter and placed at the high end of the experimental area to facilitate the FIS treatments. Rice was direct-seeded over the entire 25.33-ft plot width; however, only 12.67-ft (four 38-in. raised beds) of each plot were furrow-irrigated to prevent cross-contamination of irrigation water from each plot. Following each FIS, irrigation water was allowed to drain from the field site. Similar to a flood-irrigation rice-production system (Counce et al. 2000), FIS irrigations were scheduled to begin when rice reached the V-4 growth stage. During the growing season, the 3- and 5-d FIS were terminated when 1-in. or greater of rainfall was collected, because this amount typically saturated the soil at NEREC and each FIS was begun anew 2 days following each rainfall event.

During the growing season, rice plant heights were recorded periodically. At maturity, panicle number/3-row-ft, yield components, rough rice yield, and milling yield (percent head and total white rice) were determined. Yield components were determined by collecting five panicles within 5 ft of the 200- and 400-ft soil moisture logger locations (SMLL) in each plot to determine the total number of spikelets, kernels, and filled kernels/panicle. Rough rice yields were collected by harvesting four, 3.13- by 25-ft segments around the 200- and 400-ft SMLL with a mechanical harvester. All data were collected near each SMLL for comparison to soil moisture data.

Data were subjected to ANOVA using PROC MIXED (SAS, 2006) with replication as a random variable. Rice heights, soil moisture data, rough rice yield, milling yield percentages, and yield components were analyzed separately. Rough rice yield was converted to 12% moisture prior to analysis. Main effects and all possible interaction means were separated with Fisher's protected LSD test at 0.05 probability level.

RESULTS AND DISCUSSION

Analysis of data indicated no interaction of RC, FIS, or SMLL; therefore, main effects are presented. Following seeding, rice was flush-irrigated on 24 May, 2 June, and 12 June to aid in stand establishment and herbicide activation. Irrigation water amounts were not recorded for each flush-irrigation. Both cultivars reached the V-4 growth stage on 16 June; however, 5.2-in. of rainfall were collected from 18-21 June, which caused soil saturation. Therefore, both FIS were begun on 26 June (1st to 2nd tiller rice).

XL723 height was greater than Cybonnet on 20 July and 23 August (Table 1). Panicle number/3-row-ft for Cybonnet (60.5) was greater than XL723 (53.7); however, XL723 was observed with a greater number of spikelets, kernels, and filled kernels/panicle than Cybonnet (Table 2). Rough rice yield of Cybonnet and XL723 was 98 and 139.7 bu/acre, respectively, and head and total rice percentages for Cybonnet were greater than XL723 (Table 3). Yields were less than those observed by the University of Arkansas-Cooperative Extension Service Rice Performance Trials, which found that Cybonnet averaged 176 bu/acre and 64 to 71% head rice-total rice and XL723 averaged 215 bu/acre and 62 to 71% head rice-total rice from 2004 through 2006 when grown in a continuous flood (UA-CES, 2006a).

The FIS did not influence rice heights on either date or panicle number/3-row-ft (Table 1). However, all measured yield components were greater following the 3-d FIS compared to the 5-d FIS (Table 2). Averaged across RC, the 3-d FIS yielded 123.3 bu/acre of rough rice compared to 114.4 bu/acre for the 5-d FIS (Table 3). Head rice percentage following a 3-d FIS was 61.6% compared to the 5-d FIS (60.7%); however, no differences were detected for total rice.

Rice heights were greater at the 200-ft SMLL (28.5-in.) compared to the 400-ft SMLL (27.6-in.) on 20 July, but no difference was observed on 23 August (Table 1). Panicle number was greater at the 400-ft SMLL compared to the 200-ft SMLL. All yield components were greater at the 200-ft SMLL compared to the 400-ft SMLL (Table 2). Rough rice yield was similar at the 200- and 400-ft SMLL, indicating that location of rice in a furrow-irrigation rice field may not affect the potential yield (Table 3). However, milling percentages were greater from samples collected at the 200-ft SMLL compared to the 400-ft SMLL.

Rice location on the raised beds did not influence heights on either date with an averaging of 28.1- and 43.1-in. on 20 July and 23 August, respectively (Table 1). Rice located on the top of the raised beds developed more panicles (65.63) than either the shoulder or furrow rice (51.66 and 54.09, respectively). However, differences were not observed for any yield component measured (Table 3).

Soil moisture was recorded as kiloPascals (kPa) in which the greater the kPa, the dryer the soil. Rice cultivar and SMLL did not influence soil moisture (Table 4). Averaged across RC and SMLL, the greatest kPa recorded was 22.8 for both FIS (Table 4). This may have been due to the 18.5 in. of rainfall recorded at the experimental area during the 2006 growing season; therefore, soil moisture may have not influenced any measurable variable. The 3-d FIS was initiated 23 and 22 times for Cybonnet and XL723, respectively, with a total irrigation water usage of 22.9 and 20.4 acre-inches. For the 5-d FIS, Cybonnet and XL723 were irrigated 15 and 14 times, respectively, for a total irrigation water usage of 14 and 11.4 acre-inches. XL723 required one less 3- and 5-d furrow-irrigation to reach physiological maturity compared to Cybonnet. Typical, seasonal irrigation-water usage for a flood-irrigation rice production on a clay soil in Arkansas is 36 acre-inches (UA-CES, 2006b).

SIGNIFICANCE OF FINDINGS

One-year of research indicates that irrigation water usage possibly can be decreased in a furrow-irrigated rice-production system compared to traditional flooded-rice at NEREC. However, rough rice yields and milling percentages may be depressed compared to flooded-rice. Due to the amount of rainfall collected at the experiment site, little differences between the two FIS were seen. Decreased yields may have been due to numerous factors, such as planting date and N fertilizer application timing. Further research is needed to determine the potential of furrow-irrigation as a component of a rice-production system.

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Table 1. Main effect of rice cultivar, furrow-irrigation schedule, soil moisture logger location, and rice location on raised bed on 20 July and 23 August plant height and panicle number/3-row-ft at physiological maturity.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture logger location		Rice location on raised bed		
	Cybonnet	XL723	3-d[z]	5-d	200-ft	400-ft	Top	Shoulder	Furrow
	(in.)								
20 July	27.1	29.0	28.0	28.2	28.5	27.6	28.9	27.0	28.2
LSD (0.05)[y]	0.9		NS[y]		0.9			NS	
23 August	37.2	48.9	43.4	42.8	42.9	43.3	43.4	43.1	42.6
LSD (0.05)	0.7		NS		NS			NS	
	(no.)								
Panicle number/ 3-row-ft	60.5	53.7	59.3	55.0	51.1	63.1	65.6	51.7	54.1
LSD (0.05)[x]	4.6		NS		4.6			7.7	

[z] d = days.

[y] NS = not significant at the 0.05 probability level.

Table 2. Main effect of rice cultivar, furrow-irrigation schedule, soil moisture logger location, and rice location on raised bed on and spikelet, kernel, and filled kernel per panicle.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture logger location		Rice location on raised bed		
	Cybonnet	XL723	3-d[z]	5-d	200-ft	400-ft	Top	Shoulder	Furrow
	(no.)								
Spikelet/panicle	11.5	12.1	12.1	11.5	12.2	11.3	12.0	11.7	11.6
LSD (0.05)	0.3		0.3		0.3			NS[y]	
Kernel/panicle	97.1	111.7	106.7	102.1	106.9	101.8	105.4	104.1	103.6
LSD (0.05)	3.7		3.7		3.7			NS	
Filled kernel/panicle	88.6	101.5	97.3	92.8	97.1	93.1	95.5	94.8	94.9
LSD (0.05)	3.5		3.5		3.5			NS	

[z] d = days.

[x] NS = not significant at the 0.05 probability level.

[x] LSD (0.05) = least significant difference at the 0.05 probability level.

Table 3. Main effect of rice cultivar, furrow-irrigation schedule, and soil moisture logger location on rough rice yield and percent head and milled rice yield.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture logger location	
	Cybonnet	XL723	3-d[z]	5-d	200-ft	400-ft
	(bu/acre)					
Rough rice yield	98.0	139.7	123.3	114.4	120.1	117.6
LSD (0.05)[y]	4.5		4.5		NS[x]	
	(%)					
Head rice yield[w]	64.5	57.8	61.6	60.7	61.5	60.8
LSD (0.05)	0.5		0.5		0.5	
Milled rice yield	70.2	69.3	69.7	69.8	70.2	69.4
LSD (0.05)	0.3		NS		0.30	

[z] d = days.

[y] LSD (0.05) = least significant difference at the 0.05 probability level.

[x] NS = not significant at the 0.05 probability level.

[w] Head rice yield = [whole (head) rice : total white rice] X 100

Table 4. Main effect of rice cultivar, furrow-irrigation schedule, and soil moisture logger location on maximum, minimum, and average soil moisture readings.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture logger location	
	Cybonnet	XL723	3-d[z]	5-d	200-ft	400-ft
	(kPa[y])					
Maximum	19.8	20.9	17.9	02.8	20.5	20.2
LSD (0.05)[x]	NS[w]		1.4		NS	
Minimum	8.9	8.1	6.0	10.9	8.6	8.4
LSD (0.05)	NS		0.9		NS	
Average	14.1	13.1	11.1	16.1	13.6	13.6
LSD (0.05)	NS		1.0		NS	

[z] d = days.

[y] kPa = kiloPascal where a greater number indicates dryer soil conditions.

[x] LSD (0.05) = least significant difference at the 0.05 probability level.

[w] NS = not significant at the 0.05 probability level.

Rice Irrigation-Water Management for Water, Labor, and Cost Savings

P. Tacker and W. Smith

ABSTRACT

Field demonstrations of rice irrigation methods were conducted in 12 Arkansas counties with 20 producers on 27 different fields. A field comparison of MIRI (Multiple Inlet Rice Irrigation) to conventional irrigation on four sets of fields showed an average of 16% less water pumped on the MIRI fields over the season. Three of the MIRI fields had diesel-powered irrigation wells, which made any savings more significant due to the increase in diesel fuel prices. One demonstration included a location where the irrigation tubing ran upslope three levees to more effectively deliver water to a high area in a field. The irrigation tubing was used to successfully flush two rice fields early in the season and then it was used for MIRI on the fields for the remainder of the season. A comparison of furrow-irrigation to conventional flood irrigation was also conducted. Multiple inlet stops were included in field tours conducted in Poinsett, St. Francis, and Cross counties.

INTRODUCTION

Multiple-inlet rice irrigation offers several potential advantages over the conventional irrigation method: (1) reduced cold-water rice, labor, runoff, and pumping cost; (2) improved water management and conservation; and (3) improved herbicide and nitrogen fertilizer efficiency. The mechanics of this system need to be introduced to growers and adequately evaluated on production-size fields with varying soil, water, and topographical conditions. This can be done best through on-farm demonstrations in various rice-producing areas of the state.

Many growers operate several pumping units that are often spread over a large area with several miles separating them. Managing these units becomes time and labor intensive. This can result in someone spending a lot of time driving and laboring to determine if the pumping units are working properly. Many times a pumping unit may shut off soon after it is has been checked. When this happens critical pumping time is lost and the crop may suffer. A unit that provides a method for remote monitoring of pumps can be used to address this problem. The pump monitor can send a text message to a cell phone or pager or it can send an e-mail to a computer indicating that the water has stopped. This could save valuable pumping time and possibly reduce the amount of time and labor required for checking pump units. The pump monitors also have the ability to remotely shut a pumping unit down if needed. Efforts are ongoing to work with producers and the company manufacturing the pump monitors to look for future on-farm demonstration possibilities. This will help determine the practicality, dependability, and affordability of this technology in agriculture.

An accurate measurement of pump flow is critical to effective water management. Few growers know the actual flow delivered by their pump units or how to determine it. The plumb-bob method and/or a flow meter are two practical approaches for measuring pump flow. On-farm demonstrations offer the opportunity to instruct growers on how to use the two methods. This provides very useful information to the grower involved.

On-farm demonstrations cannot be conducted on every farm. However, experience and information gained on one farm is often applicable to other farms in the same area. The extension staff involved in on-farm demonstrations will become better able to advise rice growers on irrigation-water management. In time, demonstrations can be conducted in all rice-producing areas to address specific water-management problems and concerns.

PROCEDURES

On-farm irrigation demonstrations are coordinated with interested county extension agents and growers. When possible, the demonstrations are conducted in designated and pending critical groundwater-usage areas. Priority is also given to opportunities that allow for comparison of a conventionally irrigated field to a field that is irrigated with multiple inlets.

Measurements are made to determine water savings, cost savings, and other impacts of different irrigation-water management efforts including MIRI, remote pump-monitor systems, and pump flow measurement. Information and experience gained from on-farm irrigation demonstrations are distributed through field tours, meetings, presentations, and publications.

RESULTS AND DISCUSSION

Project investigators and county extension agents worked directly with 20 producers in 12 counties on 27 different field demonstrations of rice irrigation methods

(Table 1). Many of the counties are either designated or pending designation as critical groundwater-usage areas. Field tours that included multiple-inlet fields were conducted in three counties; Poinsett, St. Francis, and Cross.

Four field comparisons of MIRI to conventional rice irrigation were conducted in Poinsett and Cross counties (Table 2). The producer involved with the Poinsett County MIRI field that showed a 13% water savings commented that it was his easiest rice field to keep flooded this season when it had always been one of the most difficult to manage during previous seasons. The other Poinsett County comparison that showed only 8% less water pumped on the MIRI field used a type of multiple-inlet approach to irrigation on the conventional field. Once the top levees of the conventional field were flooded, the water was directed to the bottom levees by way of a flume ditch down the side of the field. The MIRI field had a relatively low irrigation flow and long levees, so the tubing was run down the high side of the field and then across the center of the field to aid in getting water to the far side of the field. These conditions probably contributed to only showing an 8% pumping reduction but the 8% savings is still significant. The Cross County producer that achieved 22% water savings had used MIRI on another field where he thought he had saved water but the data from this comparison helped support what he suspected.

A producer in Jackson County had been very resistant to using MIRI on his farm because his experiences with using irrigation tubing had not been very encouraging. We helped with the installation in one field and he also used MIRI in two other fields. On one of the fields he actually ran the tubing up-slope over 3 levees in order to put water directly to a high point in the field. He was satisfied with how it worked but he still made the comment: “I still don’t like fooling with the tubing but now I see how it has helped so I guess I will have to use more of it.” A Craighead County producer who had a comparison in 2005 contacted us to advise him on using MIRI in five of his rice fields for the 2006 season. In Randolph County, we worked with a producer on installing irrigation tubing in two fields early in the season so he could use it to flush the fields. We explained how to use the adjustable gates to apply the water to only three levees at a time so he could flush the field in sets. He was very pleased with how it worked and felt that it helped him get across the field faster and he was able to continue using it for MIRI of the fields for the season. A comparison of furrow-irrigated rice to conventionally irrigated rice showed that both required essentially the same amount of irrigation water. The experience from this season will be used to determine how to conduct comparisons for the 2007 season.

Flow measurements were conducted on several wells used for MIRI demonstrations. The producers were interested in how to measure flow and they were appreciative of having this information but most were disappointed to find that their wells were pumping less than they thought. A Greene County producer was assisted with determining the quality of his irrigation water and the possible impact it might have had on the early failure of the column pipe in a well that is only five-years old. Water samples from other wells were compared to the failed well and the new well that was drilled.

Evaluations of remotely monitored pump installations were conducted through coordination with the company and producers on several different farms. The evaluations have resulted in the company making improvements on the installation of the monitoring equipment. This has also led to the application of the technology to monitor the depth of fuel in diesel tanks at the irrigation wells so the grower can better schedule refilling of the tanks to avoid untimely delays and lost pumping time. Discussions have also caused the consideration of the potential for using the technology to monitor the advance of water across the rice field as another notification that the grower can use to better manage the irrigation water. The cooperators seem to have a positive opinion of the technology and its application to agriculture and have provided valuable feedback that is being used to inform other producers about the technology.

Experience from this year's work indicates that there is still a lot of potential for other growers to implement MIRI and pump unit monitors if demonstrations can continue to be conducted. There are still certain areas and counties in the state that have not yet adopted MIRI and even fewer are familiar with the technology for remotely monitoring pumps and other agricultural operations.

SIGNIFICANCE OF FINDINGS

Many Arkansas rice growers are experiencing increasing difficulty in effectively managing their irrigation water. Contributing factors are declining water tables, reduced pumping capacity, increased production acres, lack of skilled/dependable labor, decreased irrigation-equipment efficiency, increasing pumping costs, and extended drought periods. All of these factors cannot be controlled, but there are water-management efforts that many growers could implement to reduce the impact of many of these factors. On-farm demonstrations are very effective in encouraging growers to implement different water-management recommendations that address these factors.

Cooperating growers involved in on-farm demonstrations learn irrigation-water management techniques for reducing water use, labor, and pumping cost. The field experience and information gained from the demonstrations are provided to other growers through field tours, meetings, and publications.

ACKNOWLEDGMENT

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Table 1. Rice Irrigation Field Demonstrations - 2006 Season.

County		Fields	Farmers
Arkansas		2	1
Craighead		4	2
Crittenden		1	1
Cross		4	4
Jackson		3	2
Lincoln		1	1
Lonoke		2	2
Poinsett		2	2
Prairie		2	1
Randolph		2	1
St. Francis		3	2
White		1	1
Total	**12**	**27**	**20**

Table 2. Results of multiple inlet rice irrigation (MIRI) field comparison studies - 2006.

Poinsett County	
Farm A	13% less water for season with MIRI
Farm B	8% less water for season with MIRI
Cross County	
Farm A	19% less water for season with MIRI
Farm B	22% less water for season with MIRI

Rice-Kernel Dimensional Variability Trends

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

ABSTRACT

This study assessed trends in kernel dimensional variability of 'Bengal', 'Cypress', and 'Drew' rice varieties. Rice was harvested from Stuttgart and Keiser, Ark., during the autumns of 1998, 1999, and 2000, over a range of harvest moisture contents [HMCs (Moisture contents are expressed on a wet basis)]. Brown-rice kernel dimensions decreased with HMC beginning at 24%. Kernel dimensional distributions were usually single-modal and near normal. Brown-rice kernel dimensional standard deviation (SD) was significantly affected by HMC and location. Kernel dimensional SD generally was linearly related to HMC. Among kernel dimensions, thickness had the greatest shrinkage with decreasing HMC, followed by length and then width. Among varieties, Bengal had the greatest kernel shrinkage with decreasing HMC, followed by Drew, and then Cypress.

INTRODUCTION

Uniformity of rice kernel dimensions is very important because most post-harvest processes (hulling, milling, sizing, puffing, and cooking) are reliant on one or more kernel dimensions. For example, kernel thickness affects fissuring during pre- and post-harvest processes; thick kernels from bulk rice, often being lower in MC, are more susceptible to fissuring than thinner, higher MC kernels (Jindal and Siebenmorgen, 1994). Fissured kernels usually break during milling and thus reduce milling quality. Additionally, fractionated rice varieties Francis and Wells and a hybrid 'XL8CF' showed higher protein and total lipid contents for thin, followed by medium and thick brown-rice kernels (Wang et al., 2004). Among kernel dimensions, thickness has been most successfully tied to other kernel properties. Wadsworth et al. (1982) stated that grouping rice kernels by thickness could be an effective method for reducing MC variation; thus possibly improving rice drying and milling quality. Matthews et al. (1982) speculated that thicker kernels, having lower MC, were more susceptible to fissures. Sun and Siebenmorgen (1993) found that the thickest and thinnest kernel fractions from samples had significantly higher percentages of fissured and broken kernels, respectively, than the intermediate thickness fractions. Thinner kernels, generally being less mature and of lower mechanical strength, are more susceptible to breakage than thick kernels during milling.

It is believed that kernel development is affected by other factors during the filling process that could cause dimensional variation. These factors include diseases, the environment during kernel development, and production management practices such as fertilizer and irrigation applications. A controlled-environment growth-chamber study showed that rice plants exposed to high nighttime temperature during kernel development produced a greater number of thinner and empty kernels at harvest; this corresponded to a significant head rice yield (HRY) reduction (Counce et al., 2005). Hoshikawa (1993) showed that higher temperatures at the ripening stage of early-planted rice affected brown-rice kernel shape and size.

The above-mentioned works have indicated the existence of kernel size variability and the importance of kernel dimensional distributions, especially thickness, in milling. However, little work has been done to systematically quantify the variation in individual kernel dimensions based on variety, location, and year. This study was conducted to measure trends in kernel dimensions as affected by these variables.

MATERIALS AND METHODS

Panicles of rice varieties Bengal (medium-grain), Cypress, and Drew (long-grains) were collected from foundation seed fields at the University of Arkansas research and extension centers near Keiser and Stuttgart, Ark., at HMCs that ranged from 12% to 24% during the autumns of 1998, 1999, and 2000 (Table 1). In 2000, only Bengal and Drew samples were collected from Keiser because of frost damage to Cypress. Each lot comprised at least 200 hand-harvested panicles (approximately 2 kg of grain). Immediately after harvest, five panicles were randomly selected from each 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 individual kernel MCs was taken to be the lot HMC. An image analysis system (RIA IA, Satake Co., Hiroshima, Japan) was used to measure individual rough- and brown-rice kernel dimensions. Five panicles were randomly selected and prepared for rough-rice kernel dimensional measurements and another five panicles for brown-rice measurements; the kernels from each panicle were grouped and measured separately. The number of kernels on a panicle varied from 40 to 200.

Kernels were stripped from panicles and cleaned by hand. Any empty kernels and foreign matter were discarded. To produce brown rice, kernels were dehulled manually using tweezers. Brown-rice dimensional measurements were indicative of the kernel dimensions devoid of the air spaces that could be present within a rough-rice kernel. For this reason, analysis of brown-rice kernels was given more emphasis. After sample preparation, rice kernels were placed onto the feeding device of the image analyzer, which individually positioned kernels onto an illuminated screen where two cameras captured kernel images. The first camera captured images of the kernel from the top view for kernel length and width measurements, while the second camera captured images of the kernel from the side view to measure thickness. Images were then digitized and analyzed to calculate kernel dimensions. Statistical analyses were performed using JMP® (JMP® ver. 5, SAS Institute, Cary, N.C.). For each variety, analysis of variance and effect tests were performed to address the effect of the independent variables on kernel dimensions.

RESULTS AND DISCUSSION

Kernel Dimensional Distributions and Shrinkage at Harvest

Figure 1 shows the individual brown-rice kernel dimensional distributions from panicles of Bengal, Cypress, and Drew harvested at Stuttgart in 1998; two HMCs were selected representing high (22% to 24%) and low (13% to 15%) HMCs. The individual brown-rice kernel dimensional distributions for all varieties were single-modal and were generally near normal. Modes for Bengal width and thickness were usually greater than for Cypress and Drew.

For all varieties, kernel dimensions were affected by HMC as shown by a mode shift in the distributions to smaller kernel dimensions as HMC decreased (Fig. 1). This is also shown in Figure 2, which illustrates changes in the average kernel dimensions with HMC for Bengal, Cypress, and Drew in 1998, 1999, and 2000 at Stuttgart, Ark. Figure 2 shows that the average kernel dimensions decreased as HMC decreased. The reductions in dimensions presented in Figures 1 and 2 represent the shrinkage that kernels incurred while drying on panicles in the field.

As shown in Figure 2, the rate of kernel dimensional change with HMC varied among varieties and years. The average length of Drew kernels decreased faster with changes in HMC in 2000 than in 1998 and 1999. For Bengal, the average kernel length decreased faster in 1999 and 2000 than in 1998. Kernel-width shrinkage rates for Cypress and Drew were similar for all years; Bengal had less kernel-width shrinkage in 2000 than in 1998 and 1999. Kernel thickness shrinkage rates with HMC followed a similar trend as width shrinkage in that Cypress and Drew shrinkage rates were similar for all years while Bengal thickness shrinkage with HMC was less in 2000 than in 1998 and 1999.

The average kernel lengths for all varieties tended to be greater in 1998 than in 1999 and 2000. The average kernel width for Bengal was greater in 1998 than 1999 and 2000 at HMCs greater than 16%. For Cypress, wider kernels were observed in 2000 than in 1998 and 1999. Bengal brown-rice kernels were thicker in 1998 than in 1999 and 2000 at all HMC levels. For Drew, the average kernel thickness was greater in 1999 than in 1998 and 2000. Average kernel dimensions were thus affected by year and speculated to be affected by the environment, possibly the ambient temperature during kernel development.

Brown-Rice Kernel Dimensional Variation

Standard deviation provides a measure of the individual kernel dimensional variation from the mean. Kernel thickness SD was given emphasis over length and width SDs because the former is significantly correlated to breaking force as found by Siebenmorgen and Qin (2005). Kernel thickness SD was directly and linearly related to HMC for both locations. Location had a significant effect on brown-rice kernel thickness SDs ($P = 0.001$); Bengal, Cypress, and Drew thickness SDs were as great or greater at Stuttgart than at Keiser for all years. The generally lower kernel thickness SDs for Keiser samples could imply an advantage in milling performance. Siebenmorgen and Qin (2005) indicated that samples harvested from Keiser in 2001 had more uniform kernel thickness and breaking force distributions than did Stuttgart samples; it was also shown that Keiser samples had consistently higher HRYs than rice harvested from Stuttgart. Thus, for whole-grain processing such as breakfast cereals, if uniformity of kernel dimension is of importance Cypress grown in Keiser, Ark., would be a good choice for this purpose because of its lower dimensional variability.

There was no significant difference in width SDs across location; however, there were apparent trends of slightly higher SDs at Stuttgart (data not shown). In general, for all varieties, there was greater variation in kernel dimensions from Stuttgart than Keiser, except for Drew kernel length where Stuttgart samples had lower SDs than that of Keiser. Environmental factors could contribute to the variation in kernel dimensions across locations. Hoshikawa (1993) indicated that phosphorus content and temperatures during kernel development of japonica rice significantly affected the biosynthesis of rice starch. Hoshikawa (1993) and Counce et al. (2005) showed that kernel development was hampered by low or high nighttime temperatures during kernel filling.

Kernel Shrinkage During Field Drying

Brown-rice kernel length, width, and thickness shrinkage rates were calculated using the average initial kernel dimension at a given HMC and after drying in the field to approximately 12% MC as follows:

$$\text{Shrinkage rate} = \frac{(\text{Kernel dimension at HMC - Kernel dimension at HMC}_{12})}{(\text{Kernel dimension at HMC})} \times 100\% \qquad (1)$$

where: a) *kernel dimension at HMC* refers to the kernel dimension (length, width, or thickness) at any HMC as predicted by the regression equations derived from Figure 2; and, b) *kernel dimension at* HMC_{12} refers to the kernel dimension (length, width or thickness) at 12% HMC as predicted by the regression equations derived from Figure 2.

Figure 3 shows trends in kernel dimensional shrinkage incurred through field drying from any HMC to 12% HMC for 1998, 1999, and 2000 at Stuttgart and Keiser. The kernel dimensional shrinkage rates in all years were greatest in the thickness dimension, followed by the width and then the length. These results corroborated the findings of Sun et al. (2002) that shrinkage was greater in kernel thickness than in length and width. Bengal had consistently greater kernel thickness shrinkage rates at Stuttgart than at Keiser across years. Cypress followed a similar trend except in 1999, where thickness shrinkage was greater at Keiser than Stuttgart. For Drew, kernel thickness shrinkage was greater at Stuttgart than at Keiser in 1999 and 2000. Among varieties, Bengal had the greatest kernel thickness shrinkage.

SIGNIFICANCE OF FINDINGS

Rice kernel dimensions affect the performance of various post-harvest processes. Results of this study will provide fundamental information on kernel dimensional variability trends to be used as a reference for improving rice kernel dimensional property and variety selection for end-use processing.

ACKNOWLEDGMENTS

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Table 1. Summary of samples collected at various harvest moisture contents (HMCs) for Bengal, Cypress, and Drew rice from Keiser and Stuttgart, Ark., in 1998, 1999, and 2000.

Year	Variety	Location	Number of HMCs HMC Range (%)
1998	Bengal	Keiser	7; 12.1 - 24.1
		Stuttgart	6; 12.7 - 24.6
	Cypress	Keiser	6; 11.0 - 22.3
		Stuttgart	7; 12.6 - 23.4
	Drew	Keiser	6; 12.1 – 23.0
		Stuttgart	7; 12.6 - 24.5
1999	Bengal	Keiser	6; 14.0 - 22.4
		Stuttgart	5; 14.1 - 22.4
	Cypress	Keiser	6; 12.8 – 22.0
		Stuttgart	6; 13.2 - 22.3
	Drew	Keiser	7; 12.9 - 23.4
		Stuttgart	7; 12.2 - 23.1
2000	Bengal	Keiser	6; 12.0 – 24.0
		Stuttgart	6; 12.0 - 23.6
	Cypress	Keiser	No samples
		Stuttgart	5; 13.7 - 22.6
	Drew	Keiser	6; 13.9 - 23.7
		Stuttgart	5; 14.5 - 24.4

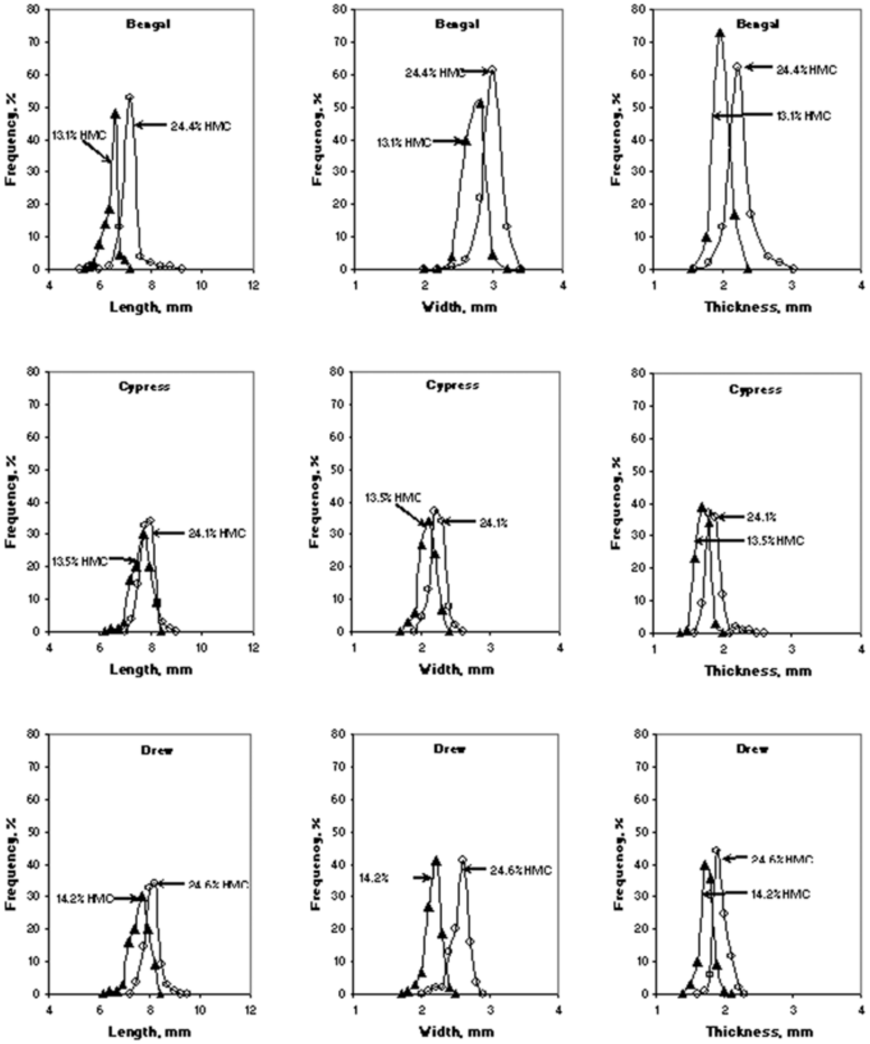

Fig. 1. Individual brown rice kernel dimensional distributions for rice varieties Bengal, Cypress, and Drew harvested at the indicated harvest moisture contents (HMCs) at Stuttgart, Ark., in 1998. Each curve represents pooled kernel dimensions from five panicles.

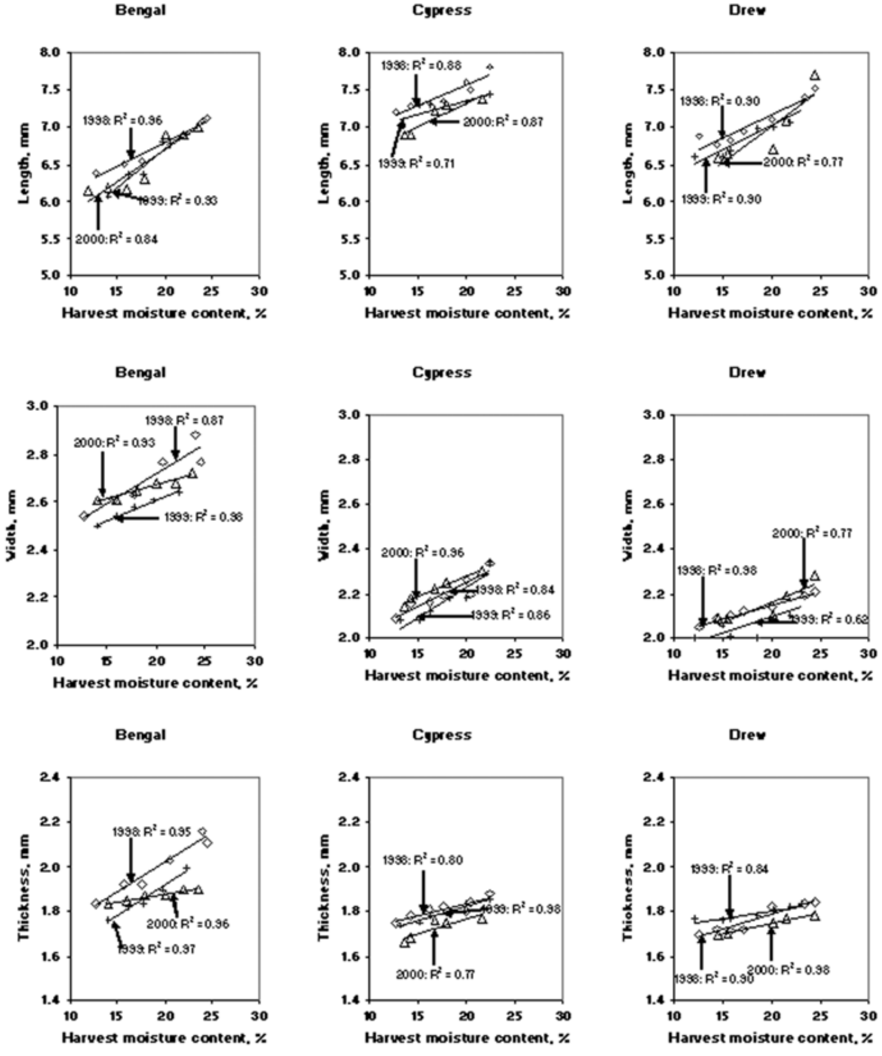

Fig. 2. Average brown rice kernel dimensions for rice varieties Bengal, Cypress, and Drew harvested in 1998, 1999, and 2000 at Stuttgart, Ark. Each data point represents the average of kernel dimensions from five panicles.

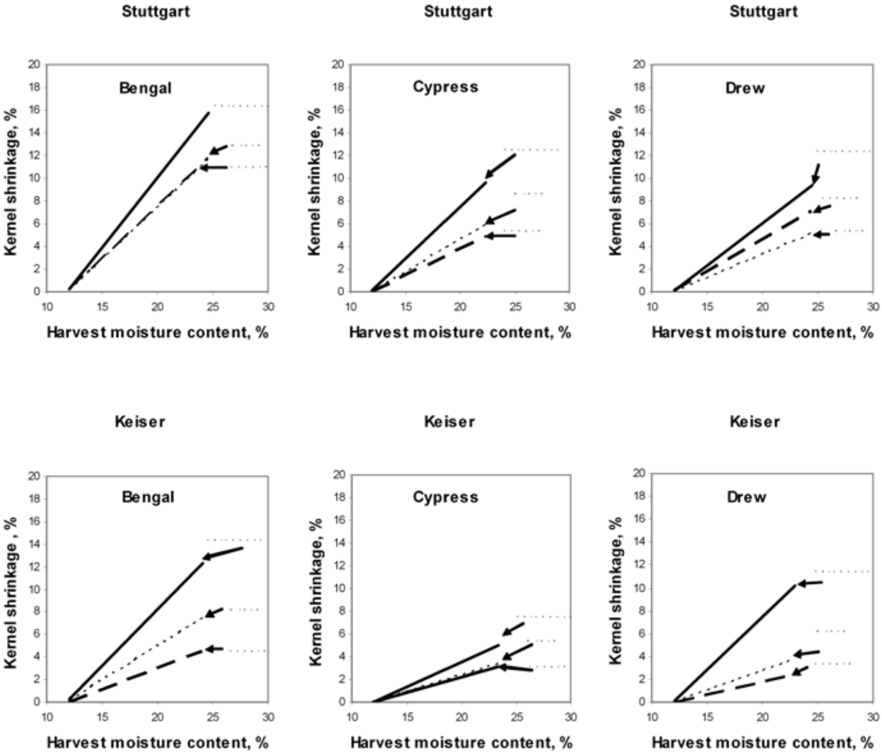

Fig. 3. Average brown rice kernel dimensional shrinkage due to moisture content change for rice varieties Bengal, Cypress, and Drew harvested at different moisture contents at Keiser, Ark., in 1998. Each data point represents the average shrinkage of kernels as calculated using equation 1 and regression equations derived from Fig. 2.

Texture Profile and Volatile Compound Analyses of 'Koshihikari' and 'Basmati' Rice Prepared in Different Rice Cookers

R.J. Bryant, G. Jones, and C. Grimm

ABSTRACT

'Koshihikari' and Basmati', two premium rices from Japan and Pakistan, respectively, were evaluated for volatile compounds and textural characteristics using three different cooking methods. Samples were analyzed for hardness, adhesiveness, and cohesiveness using the Texture Analyzer and for volatiles using the GC-MS. A trained sensory panel evaluated the samples for six textural attributes: stickiness-to-lips, hardness, cohesiveness, tooth packing/tooth stickiness, cohesiveness of mass, and roughness. Of the volatiles identified by SPME/GC/MS, dodecanal and hexanal were present in greater amounts in the samples prepared in the Hitachi cooker, whereas, acetone and naphthalene were present in greater amounts in the samples prepared in the National cooker. The Texture Analyzer showed that both rices prepared in the National cooker were the hardest with the "stove top" preparation being the softest. The sensory panel was unable to detect any significant difference ($P>0.05$) in rice texture due to preparation methods.

INTRODUCTION

Rice is consumed with little processing (dehulled, milled, and cooked). However, studies have shown that different cooking methods, such as oven cooking; small, medium, and large amounts of water; or steaming, can affect the texture and flavor of rice (Juliano, 1985). To date, little research has been conducted to show what effect different cookers have on the texture and flavor of rice. Consumers generally adjust their cooking methods to obtain the desired cooked rice texture and researchers generally standardize their methods and compare their results with others. Juliano and Perez (1983) looked at factors affecting cooked rice hardness using an excess-water method and a rice cooker method. In the rice cooker method, they cooked the rice in the amount of water that would be absorbed by the rice, however, they did not use a rice cooker. Juliano and Sakurai (1985) and Webb (1985) published reviews on the preparation of cooked rice. They reported on the effect of water-rice ratio, type of energy used (electric, gas, microwave), type of heating cycles (one- or two-stage, or microcomputer-controlled) and cooking times as they affect hardness. However, no one has reported the effect various cooker types would have on the volatile compounds and texture of cooked rice. Therefore, we tested an aromatic Basmati, and a non-aromatic Koshihikari, rice using two different types of cookers and a "stove top" method to determine if there were differences in volatile compounds and physical characteristics of the cooked rice.

PROCEDURES

Koshihikari rice was grown at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark. Rice was dehulled using a Satake Testing Husker and milled using a McGill No. 2 mill. Rice was stored in a ziplock bag at 4°C until time of evaluation. Basmati rice from Pakistan was purchased as milled rice at a speciality market and stored at 4°C until time of evaluation.

The rice was cooked using two types of rice cookers: a National rice cooker (Model SR-1HZC-18N, Matsushita Electric Industrial Co. Ltd, Osaka, Japan); a Hitachi rice cooker (Model RD-4053, Thailand); and a 2.8 L saucepan with lid, which was used on an electric stove to simulate conventional "stove-top" cooking. For the rice cookers, the amount of time the red (cooking) light was on was consider as the cook time. The temperature at the bottom of each rice cooker was tested at four different locations around the edge (facing the controls they were: back, front, right, and left) and in the center using a dual channel digital thermometer (Model 15-078-39, Fisher Scientific, Houston, Texas) containing 2 ultra-fast response type-K thermocouple naked bead probes with teflon insulated 4' leads. The thermometer was calibrated against National Institute of Standards and Technology Traceable Instrumentation. The temperature of the saucepan was not taken since it used excess boiling water and, therefore, the temperature would remain constant.

Instrumental

Each rice was prepared using methods culturally practiced. Koshihikari rice (300 g) was washed with an equal amount of filtered deionized water until the water was clear. After washing, the rice was drained and weighed, then filtered water was added until the rice-to-water ratio was 1:1.5. Rice was soaked for one hour and cooked using the same water. Basmati rice was cooked using a rice:water ratio of 1:2. No rinsing or soaking was done with the Basmati rice. Rices were cooked using the conventional "stove top" (2.8 L saucepan with lid), National rice cooker and Hitachi rice cooker. When rice was cooked using conventional "stove top" method, the amount of water used was kept at the same ratio as above. The rice was added after the water came to a boil and then cooked for 20 min. Each rice cooker was allowed to cook at its factory-set program. At the completion of the cooking period, the rice was allowed to rest for 15 minutes before testing.

Texture Profile and Sensory Analysis

The texture profile analysis was conducted using the Texture Analyzer (Model TA-XT2*i*, Texture Technologies, Inc., Scarsdale, N.Y.). Five grains were placed in a single layer and compressed using a 2-in.-diameter stainless steel cylinder. Pre-test speed was 2.0 mm/sec, test- and post-test speeds were 1.0 mm/sec. Samples were compressed 95%, held for 1 second, released and compressed again to complete the two-cycle compression test (Bourne, 1982). Samples were analyzed for hardness, adhesiveness, and cohesiveness.

Five panelists were trained in descriptive analysis techniques according to the Spectrum method (Sensory Spectrum, Chatham, N.J.). Eleven two-hour training sessions were necessary to train panelists in the testing procedures for cooked rice. Six attributes were used to describe the textural properties of rice: stickiness-to-lips, roughness, hardness, and cohesiveness, tooth packing/tooth stickiness, and cohesiveness of mass. Attributes were defined and evaluated according to Munoz (1986) and Meilgaard et al. (1991). When necessary, standards were added to the scale to fit the needs of a rice texture profile panel. The panel used a 15-cm line scale, anchored at both ends, to evaluate attribute intensities. Samples were coded with a 3-digit random number and presented in a warmed custard cup covered with a watch glass. Six samples were evaluated at each session.

GC-MS Analysis

Cooked rice grains were analyzed by placing 3g of rice directly into a 10 ml vial. 2,4,6-Trimethylpyridine (TMP; Sigma-Aldrich, St. Louis, Mo.) was employed as the internal standard by adding 2 µl aliquots of a 1-ppm solution to each sample, thus effectively placing 2 ng of TMP in each vial. The standard was placed on the inside of the glass vial just below the neck. Following preparation, samples were placed in an autosampler tray and maintained at room temperature until analyzed. Samples were preheated for 25 min at 80°C prior to sampling. Collection of volatile compounds was accomplished using a 15-min adsorption period at 80°C while shaking the sample. The Solid Phase Microextraction (SPME) fiber employed was a 1-cm 50/30 divinylbenzene/carboxen/polydimethylsiloxane stableflex fiber (Supelco, Bellefonte, Pa.). A CTC SPME autosampler equipped with a heated sample shaker and a needle heater for thermal cleaning of the SPME fiber was employed (Leap Technologies, Carrboro, N.C.).

Samples were desorbed for 5 minutes on an HP 5973 GC/MS system (Agilent Technologies, Palo Alto, Calif.), The injector temperature was held constant at 270°C. The GC oven temperature was held for 1 min at 50°C, then increased to 250°C at 10°C/

min. A 30-m, 0.25-mm, DB-5 capillary column was used with helium as the carrier gas under a constant flow of 40 cm/s. The total GC cycle time consisted of a 30-min run and a five-minute cool-down period.

Statistical analysis was preformed using SAS System for Mixed Models (Littell et al, 1996).

RESULTS AND DISCUSSION

The temperature profile for each cooker is shown in figures 1 and 2. The Hitachi cooker (Fig. 1), which had a one-step heating cycle, reached 100°C between 6 to 10 min. depending on the position. It held 100°C until 17 min. and then quickly rose to 140°C at which time the warm cycle was initiated. After 15 min. on the warm cycle the temperature was still above 100°C. The National cooker (Fig. 2), which had a two-step heating cycle, went to 60°C in one minute and held it for 9 min. It then went to 65°C for 7 min. and then to 100°C in 2 min. After 5 min. the temperature began to quickly rise to 140°C; however, it quickly returned to 105°C (within 2 min.) and held that temperature for 5 min. then dropped to 100°C for 4 min. The cooker then began a slow cool-down and went to warm at 40 min. into the run. The temperature at that time was 97°C. The National cooker held the temperature to within 5 degrees and each position was close in time and temperature and the heating appeared to be cycling. In the Hitachi cooker, due to continuous heating, each position had a different temperature at a given time except when they all reached 100°C. It must be pointed out that in our study the amount of time the red (cooking) light was on after the start button was depressed was consider as the total cook time. However, a rise in temperature over 100°C would indicate total water absorption which relates to the rice being fully cooked. Therefore, when the temperature began to rise, the Hitachi cooker, which was made out of aluminum and had a high very temperature (>100°C) for a longer period of time, tended to scorch the rice near the heating element, whereas, the National cooker, which had a coating on it and remained cooler, did not scorch. The scorched rice in the Hitachi cooker could become a problem if the scorching became severe or if the rice was allowed to sit longer and/or if it was stirred. Using cookers with a coating on them would alleviate this problem; however, the high temperature may still be of concern.

Koshihikari rice was analyzed for volatile compounds using SPME/GC/MS. Of the 130+ volatiles identified using this method (Grimm et al., 2002), only dodecanal and hexanal were present in greater amounts in the samples prepared in the Hitachi, whereas, acetone and naphthalene were present in greater amounts in the samples prepared in the National (Table 2).

Dodecanal and hexanal are representative of lipid oxidation products and can be enhanced by high temperatures, which was found to be the case with the Hitachi cooker (Fig. 1). Acetone and naphthalene have been found in rice not cooked in rice cookers (Bullard and Holguin, 1977; Grimm et al, 2002) and the high levels found in the National cooker could be due to the low volatility of these compounds and longer cooking time (Fig. 2).

There was a significant difference ($P<0.05$) due to the method of cooking for all attributes evaluated with the Texture Analyzer, except for cohesiveness of Koshihikari and adhesiveness of Basmati (Table 1). The National cooker produced harder rices and the "stove top" gave the softest rices. There was no significant difference ($P>0.05$) in hardness between the National cooker and the Hitachi cooker for both rice varieties. Koshihikari prepared on the "stove top" was significantly ($P<0.05$) less adhesive than that prepared in Hitachi cookers, whereas, there was no significant difference ($P>0.05$) in adhesiveness for any of the Basmati samples (Table 1). There was no significant difference ($P>0.05$) in cohesiveness for Koshihikari. There was a significant difference ($P<0.05$) between the National cooker and the "stove top" for Basmati, with the National cooker being most cohesive and the "stove top" being the least. The difference in texture could be due to the time required to cook the rice, 19 min. for the Hitachi cooker vs 40 min for the National cooker. However, it would be expected that the rice cooked in the National cooker would be softer not harder as the data showed.

The sensory panel evaluated each sample in triplicate for six attributes: stickiness-to-lips, roughness, hardness, and cohesiveness, tooth packing/tooth stickiness, and cohesiveness of mass. They were unable to detect any significant difference ($P>0.05$) in the attributes based on the preparation methods.

SIGNIFICANCE OF FINDINGS

This study showed that the heating profile of rice cookers are different and can have an effect on texture and volatiles. Therefore, if comparisons are made, it is important that the method and type of cookers used be taken into consideration. Since there are many different models of cookers available, the cooking profile and the material they are made of may be different, thus, each cooker should be tested before its use in a study.

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Table 1. Textural profile analyses of Koshihikari and Basmati rices.[z]

Sample	Hardness	Adhesiveness	Cohesiveness
	(N)	(N.s)	
Koshihikari			
Hitachi cooker	37.1 ab	4.0 a	5.5 a
National cooker	40.2 a	3.9 ab	5.6 a
"Stove top"[y]	33.8 b	3.3 b	5.4 a
Basmati			
Hitachi cooker	45.6 a	0.46 a	6.0 ab
National cooker	48.2 a	0.51 a	6.4 a
"Stove top"	41.8 b	0.63 a	5.5 b

[z] Values represent mean of triplicate analyses; mean comparisons followed by the same letters in the same column in the same sub-heading are not significantly different ($P<0.05$).

[y] "Stove top" = 2.8 L covered saucepan.

Table 2. Comparison of selected volatile compounds observed in 'Koshihikari' rice cooked in two different rice cookers.

		Hitachi cooker		National cooker	
Compounds	Retention times	Area counts avg.[z]	RSD	Area counts Avg.	RSD
	(min.)	(N=3)	(%)	(N=3)	(%)
Acetone	1.58	36,083	10.9	133,028	9.9
Hexanal	3.79	750,664	3.7	574,691	6.2
(E)-2-heptanal	7.25	757,499	7.1	179,709	5.8
Benzaldehyde	7.43	132,919	50.3	166,756	10.0
Hexanoic acid	7.85	36,072	76.1	14,474	93.4
2-pentylfuran	8.14	412,152	50.1	457,762	1.0
Dichlorobenzene	8.86	569,991	50.1	570,451	16.7
Undecane	11.27	18,548	52.9	19,497	9.3
Nonanal	11.40	907,790	36.4	502,432	4.6
Napthalene	13.12	9,448,117	8.0	24,666,632	71.5
2-butyl-2-octenal	15.59	18,013	16.8	15,241	7.5
Tetradecane	15.87	4,134	49.2	7,050	50.8
Dodecanal	15.98	25,660	28.0	15,540	8.4

[z] Due to the reproducibility of SPME, the RSD can be high for some compounds under the conditions analyzed.

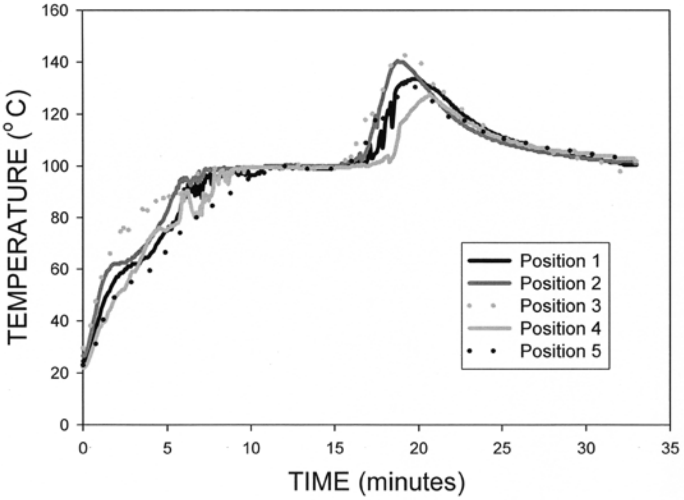

Fig. 1. Temperature profile of the Hitachi Cooker. (Each position is an average of two analyses). Facing the controls: Position 1 = back; Position 2 = front; Position 3 = right side; Position 4 = left side; Position 5 = center.

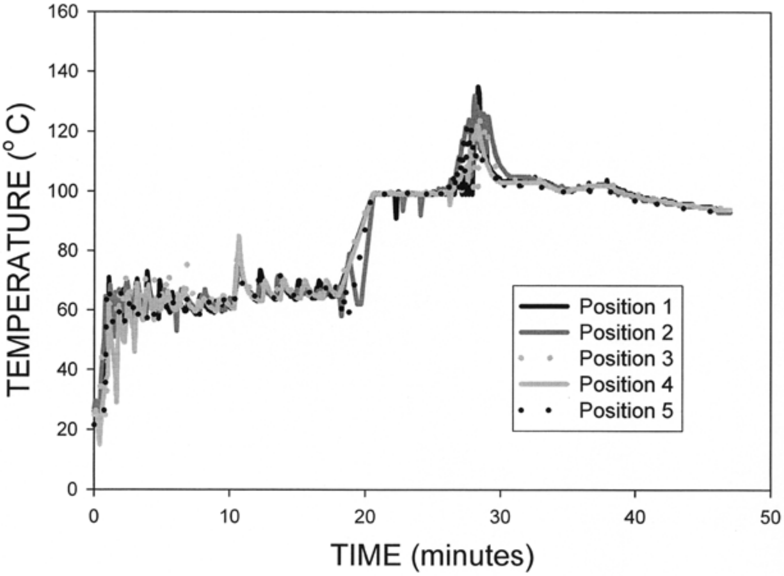

Fig. 2. Temperature profile of the National Cooker. (Each position is an average of two analyses). Facing the controls: Position 1 = back; Position 2 = front; Position 3 = right side; Position 4 = left side; Position 5 = center.

Effects of Nighttime Temperatures During Kernel Development on Rice Physicochemical Properties

N.T.W. Cooper, T.J. Siebenmorgen, and P.A. Counce

ABSTRACT

Rice quality can inexplicably vary from one lot to another and from year to year. One cause could be the variable temperatures experienced during the nighttime hours of rice kernel development. During the fall of 2004, a controlled temperature study was conducted using large growth chambers, testing nighttime temperatures of 18, 22, 26, and 30°C from 12 am until 5 am throughout kernel development, using rice cultivars 'Cypress', 'LaGrue', 'XP710', 'XL8', 'M204', and 'Bengal'. As nighttime temperature increased, head rice yields (HRYs) significantly decreased for all cultivars except Cypress and Bengal, for which HRYs did not vary among nighttime temperature treatments. Kernel mass did not vary among temperature treatments for any cultivar. The number of chalky kernels increased with an increase in nighttime temperature for all cultivars but Cypress.

INTRODUCTION

Rice is primarily consumed as an intact kernel, and therefore production quality is largely measured by HRY, which is the mass percentage of rough rice kernels that remain as head rice. Broken rice is worth only 50 to 60% of the value of head rice, meaning that a reduction in HRY can result in severe economic repercussions to rice producers. It is of major concern that HRY is maximized.

HRY can vary inexplicably from year to year and often from field to field, making it difficult for producers to predict yearly income and for processors to maintain a consistent end product. Moreover, in a given year, HRY can be uniform in one cultivar but variable in another, signifying that some cultivars are more resistant to quality variation. Environmental temperatures during kernel development may play an integral role in causing the observed, unexplained fluctuations in rice grain quality (Cooper et al., 2006).

A controlled temperature study was conducted to better understand the causes of HRY and processing quality variations. The objective was to quantify the effects of nighttime temperature during kernel development on rice physical and chemical properties.

PROCEDURES

One-hundred and ninety-two plants of each of six rice cultivars, chosen based on their observed milling characteristics (Table 1), were grown in a greenhouse until the grain-filling stage of kernel development, or when one kernel on the plant mainstem filled to the end of its caryopsis with starch. Once this developmental stage was reached, the plants were transferred into one of four phytotrons (large growth chambers), each of which contained four beds. Six experimental units were placed in each of the four beds; each experimental unit comprised 12 plants of one cultivar. The daytime temperature profile was identical in all four phytotrons, but the temperatures between 12 pm and 5 am were controlled at 18, 22, 26, or 30°C, comprising the experimental treatments of this study. The daytime temperature profile was typical of the rice-growing regions of the United States.

Once the rice kernels had reached between 17 and 20% moisture content (MC), rice panicles were hand-harvested and threshed with a single-panicle thresher (Hege-Maschinenbrau D7112, Hans-Ulrich, Waldenberg, Germany). After harvest, the rice samples were dried to 12% MC on screened trays in a chamber maintained at 23°C and 57% relative humidity. Samples were stored in Ziploc™ bags at 4°C prior to the physical and chemical tests. In order to obtain enough rough rice to complete all physical and chemical tests, the rice of each cultivar from experimental units in the two blocks (beds) at the front of each phytotron and the two blocks at the back of each phytotron were pooled. The pooled blocks were then analyzed as replications.

Rough rice samples were milled for 30 sec in a 35 g-capacity laboratory rice mill (modified #2 McGill mill, Rapsco, Brookshire, Texas) with a 2.04 kg load on the mill chamber. Once milled, the samples were aspirated (Grain Blower, Seedburo Equipment Co, Chicago, Ill.) for 30 sec in order to remove loose particles of bran. HRY was measured using an image analysis system (2312 Grain Check, FOSS North America, Eden Prairie, Minn.). Head rice was then separated from broken kernels using a sizing device (Seedburo Equipment Co, Chicago, Ill.).

Degree of milling (DOM), as surface lipid content (SLC), was determined using a lipid extraction system (Soxtec Avanti 2055, FOSS North America, Eden Prairie, Minn.) following the procedure of Matsler and Siebenmorgen (2005) with modifications in sample size (use of 3 g of head rice, instead of 5 g) due to the limited amount of sample.

HRYs were adjusted for differing SLCs based on the method of Cooper and Siebenmorgen (2007), using equation 1.

$$HRY_{adjusted} = HRY_{sample} - 9.4\ (SLC_{sample} - SLC_{standard})$$

where

- $HRY_{adjusted}$ = the HRY of a rice lot, adjusted for differences in SLC between the sample SLC and the desired, specified SLC, (%);
- HRY_{sample} = the HRY of a sample with a given DOM (SLC_{sample}), (%);
- SLC_{sample} = the SLC of a sample, (%); and
- $SLC_{standard}$ = the predetermined, specified SLC of a standard or processing application, (%).

This method maintains that HRY changes by 9.4 percentage points (pp) for every pp change of SLC. In this study, the chosen $SLC_{standard}$ was 0.5%.

The grain mass of 200 rough rice kernels of each cultivar/temperature treatment replication was determined using an analytical balance. Chalkiness was determined through visual examination of duplicate 15 g portions of head rice (roughly 750 kernels) of each cultivar/temperature treatment replication. Rice kernels with opaque regions totaling 50% of the kernel or greater were classified as chalky (USDA, 1997); the chalky kernels were then weighed and chalkiness expressed as the mass percentage of chalky kernels to the total, 15 g mass of head rice.

Data were analyzed with JMP software (JMP 6.0, SAS Software Institute, Inc., Cary, N.C.). Students' t-tests were used to compute differences between means at $p<0.05$. Statistical differences were computed within each cultivar group only.

RESULTS AND DISCUSSION

Although the rice samples were milled for the same duration and in the same laboratory mill, the DOM was not consistent. Surface lipid content varied from 0.20 to 0.38 for Cypress, 0.18% to 0.25% for LaGrue, 0.34 to 0.70% for Bengal, 0.42 to 0.57% for M204, 0.23 to 0.48% for XL8, and 0.26 to 0.46% for XP710. As such, the HRY values were adjusted for the SLC of the samples according to equation 1 in order to equitably compare the HRYs among temperature treatments within each cultivar. Figure 1 shows the HRYs resulting from the milling and adjustment analyses. The milling procedure yielded some $HRY_{adjusted}$ values that were above 70%, values that are rarely observed in commercial milling. However, the rice produced through this experiment had been harvested, threshed, and dried using the gentlest means possible in order to isolate the effects of nighttime temperature and to exclude any HRY differences due to processing techniques, therefore high HRYs resulted.

The $HRY_{adjusted}$ of rice hybrids XL8 and XP710 decreased as nighttime temperature increased. Differences of 23 pp and 7 pp were observed in the $HRY_{adjusted}$ values of XL8 and XP710, respectively, grown at 18°C and at 30°C nighttime temperatures. The long-grain cultivars generally reacted to changes in nighttime temperature as was predicted by their reputed milling quality (Table 1). Cypress, which is generally known as a consistently stable milling cultivar, showed a decrease in $HRY_{adjusted}$ only at 26°C, but was otherwise stable across the other tested temperatures. For LaGrue, a cultivar which is generally known as having variable milling characteristics, $\text{HRY}_{\text{adjusted}}$ decreased steadily with increased nighttime temperature. The medium-grain cultivars did not react to the temperature treatments as expected from their observed pre-study milling quality. Though Bengal has been alleged to have variable milling quality, Bengal $\text{HRY}_{\text{adjusted}}$ was consistent across all nighttime temperatures. In fact, Bengal $\text{HRY}_{\text{adjusted}}$s were very high, exceeding 74% across all temperature treatments. Conversely, cultivar M204 is generally known for its predictable processing quality and yet $\text{HRY}_{\text{adjusted}}$ steadily decreased as nighttime temperature increased. M204 is predominantly grown in California, U.S., where the climate exhibits little temperature variability during the rice-growing season. Therefore, it is possible that this cultivar's response to higher nighttime temperature was not previously observed as its usual growing temperature does not vary by a large amount.

Studies have shown that as daytime and mean daily temperature increased, grain mass decreased (Yoshida and Hara 1977, Sato and Takahashi 1971). However, Yoshida and Hara (1977) noted that grain mass did not vary significantly with changes in nighttime temperature for a japonica and an indica rice cultivar. Similarly, in this study, the rough rice 200-kernel mass did not significantly change in response to nighttime temperature variation for any cultivar or hybrid. The average rough rice 200-kernel mass values for each cultivar were, 4.2, 4.5, 4.3, 4.1, 5.1, and 4.5 g for XL8, XP710, LaGrue, Cypress, M204, and Bengal, respectively.

Chalkiness is an undesirable aesthetic and processing characteristic of rice. Figure 2 shows the effect of nighttime temperature on the chalkiness of the tested cultivars. The chalkiness of hybrid XL8 increased significantly with nighttime temperature, from 23% at 18°C to 34% at 30°C. The chalkiness of XP710, LaGrue, and M204 also increased with increased nighttime temperature. There was no significant difference in the chalkiness of Cypress rice grown at any nighttime temperature. Bengal samples consisted of between 0.6 and 2.0% chalky kernels, the lowest amount of all tested cultivars. Bengal rice grown at 18°C was significantly less chalky than Bengal rice grown at 22°C nighttime temperature.

SIGNIFICANCE OF FINDINGS

Milling quality, adjusted for the SLC of the milled rice samples, decreased with increased nighttime temperature for both tested hybrids, XL8 and XP710, long-grain cultivar LaGrue, and medium-grain cultivar M204. The $\text{HRY}_{\text{adjusted}}$s of cultivar Bengal were not significantly affected by changes in nighttime temperature, whereas those of Cypress only decreased at the 26°C nighttime temperature. Chalkiness generally increased as nighttime temperature increased, but particularly for the hybrid cultivars.

ACKNOWLEDGMENTS

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Table 1. Cultivars and hybrids evaluated in the nighttime temperature evaluation study, chosen based on their observed milling characteristics.

Cultivar	Rice type	Observed Characteristics, Pre-Study
Cypress	Long-grain variety	Consistent milling quality
LaGrue	Long-grain variety	Variable milling quality
M204	Medium-grain variety	Commonly cultivated in western U.S., predictable milling quality
Bengal	Medium-grain variety	Commonly cultivated in southern U.S., variable milling quality
XP710	Long-grain hybrid	New hybrid, unestablished milling quality
XL8	Long-grain hybrid	Established hybrid; good milling quality

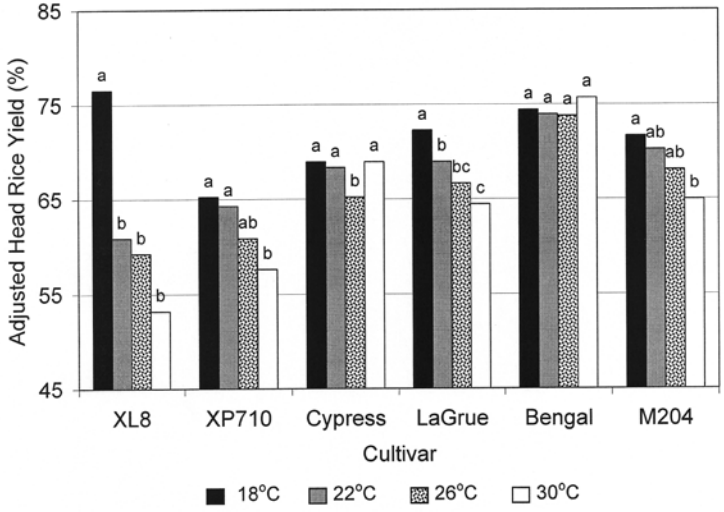

Fig. 1. Head rice yields of the indicated cultivars, adjusted for degree of milling using Equation 1. A standard surface lipid content of 0.5% was used as a basis of comparison. Means within each cultivar denoted with the same letter were not significantly (P>0.05) different.

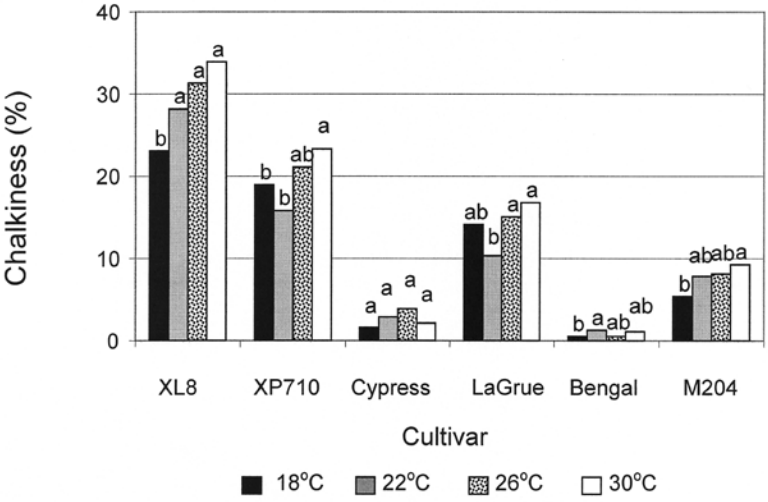

Fig. 2. Chalkiness of the indicated cultivars grown at 18, 22, 26, and 30°C nighttime air temperatures. Chalkiness was expressed as the mass percentage of 15 g of head rice, performed in duplicate. Means within each cultivar denoted with the same letter were not significantly (P>0.05) different.

Effect of Broken Rice Kernels on Cooked-Rice Texture and Rice-Flour Pasting Properties

M. Saleh and J.-F. Meullenet

ABSTRACT

Two long- and two medium-grain rice cultivars were used in this study. Dried rough rice was milled and broken kernels were separated. Rice samples were prepared by combining whole kernels with either 0, 4, 15, or 35% of broken kernels. Cooked-rice texture and rice-flour pasting properties were determined. Results indicated that rice with greater proportions of broken kernels was significantly ($P<0.05$) harder and stickier once cooked. Moreover, rice flour made from broken kernels had significantly ($P<0.05$) lower peak and breakdown viscosities, and greater setback. These results were ascribed to differences in the kinetics of rice moisture uptake during cooking resulting from differences in physical dimensions and chemical composition between broken and whole kernels.

INTRODUCTION

Rice is largely consumed as cooked, milled whole kernels, which are produced by de-hulling and milling processes, by removing the most outer layers of the rough rice kernel. During the rice milling process, portions of damaged, chalky, and broken rice kernels are usually separated and rice eventually graded based upon several criteria, among which is the percentage of broken kernels in milled rice (United States Standards for Rice, GIPSA). In addition, milled rice economic value is dependent on the proportion of broken rice kernels in the bulk (Monsoor et al., 2004). Hence, rice kernel breakage during cultivation and processing has been studied extensively. Factors such as environmental relative humidity and temperature, kernel moisture content (MC) during drying, and stresses during milling all can cause fissures and cracks and eventually breakage during rice milling (Lloyd and Siebenmorgen, 1999, Siebenmorgen and Jindal, 1986; Siebenmorgen et al., 1998). Variations in kernel dimensions have also been reported to affect rice fissure and breakage once milled (Sun and Siebenmorgen, 1993).

From the chemical standpoint, although broken and whole rice kernels have similar starch yields and protein contents, broken kernels have been reported to have significantly greater SLC and rate of lipid hydrolysis than whole kernels (Monsoor and Proctor, 2003; Wang et al., 2002).

In the United States, rice is usually graded based on its physical properties into 6 U.S. No. grades. Although the basic grading requirements are critical to the rice industry and for consumer appeal, differences among grades in cooked-rice texture have not been documented. This study was conducted to evaluate the effect of the proportion of broken rice kernels in milled rice samples on cooked-rice texture and the resulting rice-flour pasting properties.

PROCEDURES

Rice Sampling

Two medium- ('Bengal' and 'Medark') and two long- ('Wells' and 'CL-161') grain rice cultivars were harvested at MCs ranging from 19.0 to 26.0% [wet basis (wb)] from several locations in Arkansas. Rice was brought to the University of Arkansas rice processing program laboratories where it was cleaned, air dried (i.e., ambient temperature) to a MC of ~12.5% (wb). Dried rough rice was then stored at 22°C ±3 for two months before milling.

Rice Milling and Sample Preparation

Initially, 150 g of rough rice were de-hulled using a de-husker (THU-35, Satake, Hiroshima, Japan) and milled for 30 seconds using a McGill No. 2 mill (RAPSCO, Brookshire, Texas). A double-tray sizing device was used to separate whole from broken kernels. Broken rice kernels were further segregated visually to separate chalky and other unbroken kernels. Treatments were created by mixing whole and broken rice kernels in ratios of 0, 4, 15, and 35% broken kernels. Rice SLC was determined in duplicate using a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, Minn.) according to AACC method 30-20 (AACC, 1997) by modifying the washing duration from 30 min to 20 min using petroleum ether as described by Matsler and Siebenmorgen (2005).

Rice Cooking and Instrumental Texture Measurements

A water to rice ratio of 2:1 (w/w) was used for rice cooking. Rice was cooked using a miniature rice cooker consisting of a glass-cooking vessel with a glass top and a heating mantle (TM 102, Glas-Col, Terre Haute, Ind.) controlled by a temperature controller (89000-10, Eutech Instruments Pte Ltd, Singapore) for 20 minutes. The maximum cooking temperature was set at 98.5±1°C. Cooked rice was conditioned for 5 minutes and kept warm (50°C) using a temperature-controlled mantle during the texture measurements. The cooking conditions were identical for all rice samples to eliminate differences in cooked rice textural properties due to the cooking method. Cooked-rice textural attributes were determined by a uniaxial single-compression method using a TA-XT2 plus Texture Analyzer (Texture Technologies Corp., Scarsdale, N.Y./Stable Micro Systems, Godalming, Surrey, England). Ten whole, cooked-rice kernels placed on a non-lubricated flat aluminum plate were compressed using a 50-Kg load cell to leave a gap between two compression plates at the bottom of the compression cycle of 0.3mm. Although whole kernels do not represent the bulk for treatments containing broken kernels, the objective of this study was mostly to determine the impact of broken kernels on the water uptake of intact kernels. However, future studies will also report on the bulk texture properties. Textural attributes were obtained using the Texture Exponent software [Stable Microsystems, version 1,0,0,92 (2000) Surrey, England]. The maximum compression force was used as an indicator of cooked-rice hardness while the adhesion energy measured during the upward travel of the compression plate was used as an indicator of cooked rice stickiness. Samples were cooked in duplicate and five measurements were taken for each cook.

Rice Flour and Pasting Properties Measurements

A cyclone sample mill (Udy, Fort Collins, Colo.) fitted with a 100-mesh sieve was used for grinding the rice samples to produce rice flour. A Rapid Visco-Analyzer was used for measuring the pasting properties of rice flour made from rice samples containing various proportions of broken kernels. Approximately 3 grams of rice flour was mixed with 25 ml of distilled water; the slurry was mixed at 50°C for one minute at 160 rpm before being heated from 50°C to 95°C at a heating rate of 12°C/minute. The hot paste was held at 95°C for 2.5 min and then cooled down to 50°C at a cooling rate of 12°C/minute and typical RVA parameters were extracted.

Moisture Content During Cooking

The moisture content of the rice samples containing various percentages of broken kernels, as well as that of 100% broken kernels, was determined during cooking. Rice samples were cooked in duplicate for various intervals (i.e. 0, 5, 10, 15, and 20 minutes) after which triplicate measurements of cooked-rice moisture content were taken. Approximately five grams of cooked rice were incubated in a drying oven at 130°C for 24 hours.

RESULTS AND DISCUSSION

Texture Properties

Results indicated that cooked-rice hardness was greater ($P<0.05$) in samples containing greater amounts of broken kernels (Table 1). Hardness values ranged from 91.2 to 99.2, 93.0 to 103.0, 84.7 to 93.7, and from 105.5 to 113.8 N for Bengal, 161-CL, Medark, and Wells, respectively. Rice samples containing 35% of broken kernels were significantly ($P<0.05$) stickier than those samples having lower proportions of broken kernels (Table 1). Our results indicated that variation in rice physical dimensions foremost impacted cooked-rice texture properties. This agrees with Saleh (2006) who indicated that thin rice kernels tend to uptake proportionally more water than thick kernels. In a similar manner, broken rice kernels hydrate more rapidly than whole kernels (Figure 1) thus probably changing the water uptake kinetics of whole kernels. The rapid absorption of water by broken kernels lessens the water available for whole kernels (i.e., in fixed water-to-rice ratio conditions) which results in harder cooked rice. The increase in stickiness observed in rice containing larger proportions of broken kernels could be due to the fact that broken kernels leach out more starch than their intact counterparts.

Moisture Absorption During Cooking

Figure 1 shows plots of the moisture content of cooked rice samples containing various proportions of broken kernels. It is evident that during cooking, broken kernels uptake moisture at a faster rate than whole kernels. This is due to the increased surface area (i.e. broken kernels having a greater surface area compared with whole rice kernels) available for water absorption.

Pasting Properties

Table 2 presents the pasting properties of rice with various broken kernel proportions. Broken kernels had significantly ($P<0.05$) lower peak and breakdown and greater setback viscosities than whole kernels. The significantly ($P<0.05$) lower peak and breakdown viscosities of flour made from broken kernels is due to the greater amount of lipids present in these flours (Table 3). This is because kernels that break during milling do not get milled as hard as other kernels. Lipids are in fact known to lower paste viscosity. Saleh (2006) and Fitzgerald et al. (2003) reported an increase in peak viscosity after lipid removal from rice flour, pointing out the important effect of lipids on rice-flour pasting profiles. Furthermore, Wang et al., (2002) reported no differences in the pasting properties of starch (i.e., after removal of rice lipid and proteins) isolated from whole and broken rice kernels.

SIGNIFICANCE OF FINDINGS

Study results indicated that the proportions of broken rice kernels in a milled rice samples affects both cooked-rice texture and rice-flour pasting properties. The greater hardness and stickiness of rice containing higher proportions of broken kernels were ascribed to differences in rice water-uptake kinetics during cooking. Broken kernels had a tendency to also decrease peak viscosity due to the greater lipids in flours stemming from rice with a high percentage of broken kernels.

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Table 1. Instrumental hardness and stickiness of cooked rice samples of various rice grades (based on the proportions of broken kernels in the milled rice samples).^{z}

Texture properties	% Broken kernels	Rice cultivars			
		Bengal	161-CL	Medark	Wells
Hardness (N)	Head rice	91.1 a	93.0 b	84.7 b	106.5 b
	4%	92.9 ab	99.3 a	93.7 a	108.3 ab
	15%	99.2 a	103.0 a	89.5 ab	113.8 a
	35%	98.1 a	100.2 a	89.3 ab	110.9 ab
Stickiness (N.sec)	Head rice	11.2 b	5.8 b	9.4 b	8.5 a
	4%	13.3 ab	5.7 b	11.3 b	8.8 a
	15%	10.5 b	6.3 ab	11.5 b	7.7 a
	35%	16.6 a	7.7 a	15.7 a	9.1 a

^{z} For the same cultivar, means of hardness and stickiness of rice samples containing various proportions of broken kernels with different letter(s) are significantly (P<0.05) different according to LSD.

Table 2. Pasting properties of rice flour made from rice samples of various grades (based on the proportion of broken kernels in the milled rice).^{z}

Pasting properties	% Broken kernels	Rice cultivars			
		Bengal	161-CL	Medark	Wells
Peak viscosity (RVA U)	Head rice	191.5 cd	264.8 b	241.5 ab	208.3 a
	4%	206.8 a	275.1 a	243.8 a	212.6 a
	15%	198.0 b	249.0 d	237.4 bc	211.4 a
	35%	194.1 bc	260.9 bc	232.7 cd	211.0 a
	100%	185.8 d	255.8 cd	227.4 d	198.2 b
Breakdown (RVA U)	Head rice	73.2 b	135.5 ab	93.4 a	83.1 b
	4%	78.8 a	138.7 a	89.1 a	88.4 a
	15%	73.8 b	129.2 b	87.3 a	88.1 a
	35%	73.1 b	127.9 b	90.3 a	82.4 bc
	100%	68.5 c	128.5 b	86.9 a	78.3 c
Setback (RVA U)	Head rice	119.6 b	64.1 a	80.2 c	109.8 b
	4%	122.9 b	67.0 a	80.0 c	110.4 ab
	15%	123.0 b	64.2 a	82.1 c	110.6 ab
	35%	125.5 b	65.9 a	90.0 b	114.5 a
	100%	133.0 a	63.9 a	103.7 a	114.9 a

^{z} For the same cultivar, means of peak, breakdown, and setback viscosities of rice containing various proportions of broken kernels with different letter(s) are significantly (P<0.05) different according to LSD.

Table 3. Surface lipid content of rice samples made-up using various proportions of broken kernels.

% Broken	Rice cultivars			
kernels	Bengal	CL 161	Medark	Wells
Head rice	0.52 a	0.18 d	0.30 c	0.30 a
4%	0.53 a	0.19 d	0.31 c	0.29 a
15%	0.54 a	0.21 c	0.36 b	0.30 a
35%	0.56 a	0.24 b	0.36 b	0.33 ab
100%	0.56 a	0.29 a	0.42 a	0.36 b

[z] For the same cultivar, means of surface lipid content of rice samples containing various proportions of broken kernels having different letters are significantly ($P<0.05$) different according to LSD.

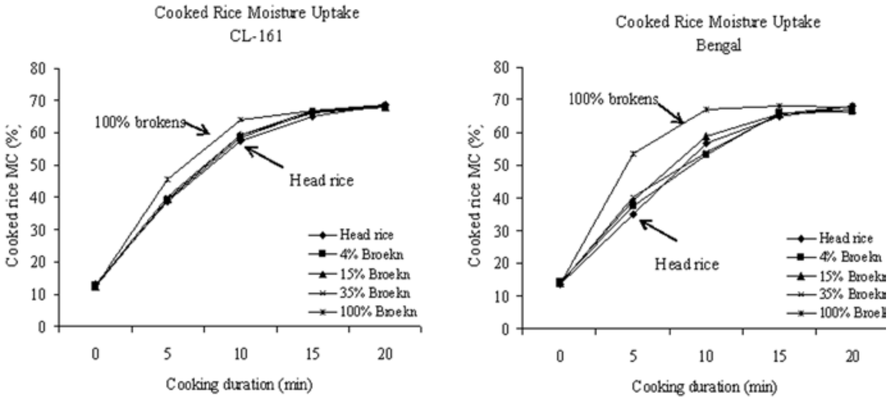

Fig. 1. Moisture content of cooked rice samples (CL 161 and Bengal) containing various proportions of broken kernels in the milled rice during cooking.

Optimal Harvest Moisture Contents for Maximizing Rice Milling Quality

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

ABSTRACT

The objective of this study was to determine the harvest moisture contents (HMCs) at which rice milling quality peaked. Samples of 'Bengal', 'Cypress', and 'Drew' were harvested over a range of MCs at northeast and southeast Arkansas locations in 1999 and 2000. Additional sample sets were collected in 2004 and 2005 in Arkansas, Mississippi, and Missouri. Head rice yields (HRYs) were described by a quadratic function of HMC. The general range of optimal HMCs, determined as the MC at which HRY peaked, varied from 19 to 22% for long-grain cultivars and 22 to 24% for medium-grain Bengal.

INTRODUCTION

Head rice yield (HRY) is defined as the mass percentage of rough rice that remains as head rice (kernels that are at least three-fourths of the original kernel length) after complete milling. Because of the premium for head rice relative to brokens, HRY is a direct determinant of economic return.

The bulk MC level and the individual kernel MC distribution at harvest influence milling quality (Siebenmorgen et al., 1998). Kocher et al. (1990) and Bautista and Siebenmorgen (2005) showed that at high HMCs, a significant percentage of kernels in a bulk had much higher MCs than the bulk average MC. These high MC kernels are typically thinner, weaker kernels than the bulk average and are likely to break during milling. Matthews et al. (1982) found that the thickest and thinnest kernel fractions had significantly higher percentages of fissured and broken kernels, respectively, than the intermediate thickness fractions. They postulated that thicker kernels, having lower

MCs, were more susceptible to fissuring due to re-wetting of kernels at MCs below a safe re-wetting threshold.

Chau and Kunze (1982) reported that for cultivar 'Brazos' in Texas, the highest HRYs were obtained at 24 to 26% MC. They also reported that the longer rice is left in the field, the greater the probability that the lower MC kernels will fissure. Jodari and Linscombe (1996) reported that HMC, rainfall, and humidity affected milling yields. They also indicated that the number of fissured kernels increased with a decrease in HMC and were primarily caused by rapid moisture adsorption due to rainfall. Siebenmorgen et al. (1992) showed that significant losses in HRY can be incurred when long-grain rice is harvested at MCs lower than 15% or higher than 22% MC in Arkansas. Geng et al. (1984) cited that the amount of head rice decreased when rice was harvested at low HMCs in California, particularly in very-early-maturing varieties. Further, Geng et al. (1984) stated that no single curve could adequately represent HRY vs. HMC relationships because of cultivar differences and environmental variations.

This research quantified the HRY vs. HMC relationships for cultivars harvested from the Mid-South rice-production region as a means to estimate the HMC at which HRYs peaked.

MATERIALS AND METHODS

Panicles of Bengal (medium-grain), Cypress and Drew (both long-grain) rice were harvested at the University of Arkansas Northeast Research and Extension Center near Keiser, Ark., and the Rice Research and Extension Center near Stuttgart, Ark., at HMCs from 12 to 24% during 1999 and 2000. Additional panicles of several cultivars were collected in 2004 and 2005 from Arkansas, Mississippi, and Missouri farm trials at HMCs from 12 to 26%. Figures 1 through 4 indicate the number of HMCs at which samples from each cultivar were collected at each location and year.

Each lot comprised at least 200 hand-harvested panicles (approximately 2 kg of grain). Immediately after harvest, five panicles were randomly selected from each 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 individual kernel MCs was taken to be the lot HMC.

Fissured Kernel Enumeration

Fissured kernels were enumerated in 1999 and 2000 by randomly selecting a second set of five panicles immediately after harvest, manually stripping the kernels from the panicles, and manually dehulling 200 randomly selected kernels. Each of the 200 brown-rice kernels was inspected for fissures by placing kernels on the glass top of a fissure inspection box (30 x 20 x 20 cm) and observing with a magnifying glass. The fissured kernel percentage was calculated as the percentage of the 200 inspected kernels having at least one fissure. The approximately 190 remaining panicles were stripped by hand and dried to 12.5% in a chamber in which air conditions were maintained at 21°C and 56% relative humidity.

In 2004 and 2005, panicles remaining from those selected for individual kernel MC measurement were introduced to a thresher (SBT, Almaco, Nevada, Iowa) to remove kernels. The rough rice was subsequently dried to 12.5% in the same chamber as used in 1999 and 2000. Two-hundred rough rice kernels were then randomly selected and fissures enumerated using the above procedure.

Milling Analyses

The remaining dried rough rice in each lot was cleaned and used for milling analyses. Two 150 g samples from each lot were dehulled using a laboratory huller (Rice Machine, Satake Engineering Co., Hiroshima, Japan). The resulting brown rice was milled for 30 s in a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas). Head rice was separated from brokens using a sizing machine (Grainman Model 61-115-60, Grain Machinery Manufacturing Corp., Miami, Fla.) with screen sizes #10 (4.0 mm, 10/64 in.) for medium-grain and #12 (4.8 mm, 12/64 in.) for long-grain cultivars.

RESULTS AND DISCUSSION

Fissured Kernel Percentages

Figures 1, 2, 3, and 4 show the percentage of fissured kernels from lots harvested in 1999, 2000, 2004, and 2005, respectively. Fissured kernel percentages increased exponentially as HMC decreased below 18 to 20%; however, the rate of increase varied among cultivars. For example, the rate of increase in fissured kernel percentage for 1999 Cypress from Stuttgart and Keiser was less than that of Bengal and Drew from those locations (Fig. 1). Cypress is regarded as a fissure-resistant cultivar (Jodari and Linscombe, 1996) and exemplified this characteristic in 1999 and to a lesser extent in 2000 (Fig. 2). As HMC decreased to 15%, approximately 35% of Bengal and Drew kernels had fissured in 1999 (Fig. 1). In 2000, when HMC had decreased to 15%, approximately 15 to 20% of the Bengal and Drew kernels had fissured (Fig. 2). Variation in weather during the harvest season could have been responsible for this year-to-year fissuring level variation. Additionally, year-to-year variation in production practices and environments could have produced different individual kernel MC distributions that could have caused different fissuring responses (Siebenmorgen et al., 1998).

The primary cause of fissure formation with decreasing HMC is reasoned to be moisture adsorption by low-MC kernels. Environmental conditions causing moisture adsorption could have been produced by rain or high ambient-air relative humidity, both of which have been shown to reduce HRYs (Kunze and Hall, 1967, Siebenmorgen and Jindal, 1986).

Some cultivars planted in different locations in the same year varied in fissured-kernel percentage trends. Such was the case for Bengal in 2004 (Fig. 3), which had greater fissured-kernel percentages at Brinkley, Ark., (20% at 16% HMC) than at Lodge Corner, Ark., (12% at 16% HMC). The variation is speculated to be due primarily to environmental differences.

Head Rice Yield Trends

Figures 1, 2, 3, and 4 also show HRY vs. HMC data. Analysis of variance showed a significant difference in HRY as a function of HMC ($P<0.0001$) for each cultivar except for 2004 Bengal harvested at Brinkley, Ark., and 2004 Cocodrie at Newport, Ark., (Fig. 3).

In 1999 and 2000, the overall HRY vs. HMC trends across cultivars showed that the magnitude of HRY reduction at either high or low HMCs was somewhat cultivar-dependent, with Cypress generally having the least HRY reduction, particularly in 2000.

Figures 1 through 4 show that as HMCs decreased from high levels (greater than 22%), HRYs increased; the increase in HRYs can be attributed to the decrease in the percentage of immature kernels. Siebenmorgen and Qin (2005) showed that the mechanical strength and milling quality of thin, immature kernels was drastically lower than that of thicker, fully mature kernels.

After reaching a peak, HRYs generally decreased as HMC decreased; the decrease in HRYs was highly correlated with the increase in fissured kernel percentages. There was no significant change in 2004 Bengal (Brinkley, Ark.) and Cocodrie (Newport, Ark.) HRYs with HMC. It is noted that the lowest HMC for the Bengal sample set was approximately 16% and for Cocodrie, 15%; as such, moisture adsorption effects in producing fissures were not evident. Additionally, the 2004 growing season in Arkansas was characterized as having lower than normal ambient temperatures. Counce et al. (2005) and Cooper et al. (2006) have shown that high nighttime air temperatures during kernel development can have deleterious effects on HRYs. Thus, the minimal HRY reductions in 2004 could possibly be due to favorable environmental conditions during kernel development and maturation.

Peak Head Rice Yields and Optimal Harvest Moisture Contents

The HRY vs. HMC relationships (Figs. 1 to 4) were described using a quadratic function:

$$HRY = a_i * HMC^2 + b_i * HMC + c_i \qquad (1)$$

HMC is expressed as percent wet basis and HRY as a percent; a_i, b_i, and c_i are regression coefficients; the subscript *i* refers to the year/location/cultivar lot sets depicted in Figs. 1 through 4. Eqation 1 regression analysis results are presented in Table 1. The quadratic equations generally described the HRY trends well with R^2 values being greater than 0.70, with most exceeding 0.90.

From these quadratic equations, the HMC at which HRY peaked for each lot set was determined by using the first derivative of Eq. 1:

$$\frac{\partial HRY}{\partial HMC} = 2 * a_i * HMC + b_i \tag{2}$$

By setting Eq. 2 to zero and solving for HMC, the "optimal" HMC at which HRYs peaked in each lot set was computed. Peak HRYs were calculated as the HRY of Eq. 1 at the optimal HMC. The peak HRYs and optimal HMCs are listed in Table 1. These peak HRYs and optimal HMCs are a manifestation of each cultivar's response to the environment in which it was produced.

Peak HRYs ranged from 63.8 to 70.6%. Because the hulls and bran comprise approximately 30% of the mass of rough rice, the theoretical maximum HRY that can be attained is approximately 70%; slight variations in this value can occur due to variations in the degree to which a rice sample is milled. In 1999, peak HRYs for Keiser were near the theoretical maximum, while for the other 1999 lot site peak HRYs were 1.0 to 3.7 percentage points (pp) below the 70% level, respectively. Similar observations held in 2000 in that the Keiser peak HRYs were near maximum, yet at Stuttgart, Cypress and Drew peak HRYs were 4.6 and 2.9 pp below maximum, respectively. The mean of peak HRYs in 2005, which was considered to have generally higher production temperatures, was 64.9% and was less than those in the other three years of the study.

The reasons for the lower peak HRYs in some lot sets versus others could be due to the deleterious effects of high nighttime air temperatures cited by Counce et al. (2005) and Cooper et al. (2006). The hypothesis of these works was that high nighttime air temperatures during the kernel filling stage could lead to disruptions in the enzymatic activities responsible for kernel formation, which would result in lower average kernel strengths, and thereby lower HRYs. Because the critical stage for this effect is at kernel filling, the negative effects of high nighttime-air temperatures would be manifested if the rice growth stage and high, ambient nighttime-air temperatures coincided. Thus, ambient environmental conditions, planting dates, and the rate of development for a given cultivar all determine whether deviations from the theoretical maximum occur.

The optimal HMC relative to maximizing HRY varied considerably across cultivar and year. In 1999 at Stuttgart, Bengal HRY peaked at 23.7% HMC, Cypress at 22.1%, and Drew at 23.5%. In 1999 at Keiser, Bengal HRY peaked at 23.8% HMC, Cypress at 19.3%, and Drew at 21.0%. In 2000 at Stuttgart, Bengal HRY peaked at 23.0% HMC, Cypress at 21.1%; and Drew at 21.6%. 2004 Bengal had different optimal HMCs, depending on location; HMC did not affect Bengal HRYs at Brinkley and the optimal HMC for Bengal at Lodge Corner was 22.4%. In 2004, Cocodrie harvested at Essex, Mo., peaked at 19.3% HMC. Wells harvested at Hunter in 2004, while not showing large HRY changes with HMC, had an optimal HMC at 21.3%. For 2005, dramatic changes in HRY were observed for samples collected at different HMCs and locations. Peak HRYs varied with HMC as follows: 'Cheniere' (Osceola) peaked at 18.8% HMC, 'Francis' (Stuttgart) at 18.7%, Wells (Qulin) at 19.9%, 'XP723' (Stuttgart) at 19.6%, and XP723 (Cleveland) at 19.5%.

SIGNIFICANCE OF FINDINGS

The HRY vs HMC relationships indicate that HRY can be substantially lower than attainable peak values for a given cultivar produced in a certain location in a particular year. These data provide basic information from which economic analyses can be made as to the ramifications of harvesting rice at various HMCs; these analyses must account for varying drying charge schedules. Additionally, the data indicate that maximum HRYs varied from 63.8 to 70.6%; based on recent research, the effects of nighttime air temperatures during kernel development could offer an explanation for this inexplicable HRY variation and merit further, specific investigation.

ACKNOWLEDGMENTS

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Table 1. Regression results of fitting Eq. 1 to each set of cultivar lots listed below. The optimal harvest moisture contents (HMCs) and peak head rice yields (HRYs) were calculated using Eqs. 1 and 2.

Year	Location	Cultivar	a_i	b_i	c_i	R^2	Opt. HMC	Peak HRY
							(%, w.b.)	(%)
1999	Stuttgart, Ark.	Bengal	-0.1207	5.7325	-1.7553	0.98	23.7	66.3
	Stuttgart, Ark.	Cypress	-0.1436	6.3436	-2.4039	0.98	22.1	66.7
	Stuttgart, Ark.	Drew	-0.2345	11.0100	-60.2390	0.93	23.5	69.0
	Keiser, Ark.	Bengal	-0.2730	12.9800	-87.5030	0.96	23.8	66.8
	Keiser, Ark.	Cypress	-0.2800	10.8060	-33.8400	0.82	19.3	70.4
	Keiser, Ark.	Drew	-0.3640	15.2540	-89.2060	0.86	21.0	70.6
2000	Stuttgart, Ark.	Bengal	-0.1063	5.5248	-1.8773	0.98	23.0[z]	69.9
	Stuttgart, Ark.	Cypress	-0.0732	3.0852	32.8430	0.71	21.1	65.4
	Stuttgart, Ark.	Drew	-0.3937	17.0080	-116.5800	0.77	21.6	67.1
	Keiser, Ark.	Bengal	-0.3068	13.1900	-73.0270	0.96	21.5	68.7
	Keiser, Ark.	Drew	-0.4690	19.0460	-123.9600	0.94	20.3	69.4
2004	Brinkley, Ark.	Bengal	.[y]	.	.	.	.	.
	Lodge Corner, Ark.	Bengal	-0.0668	2.9983	35.7500	0.93	22.4	69.4
	Hunter, Ark.	Wells	-0.1136	4.8420	15.8700	1.00	21.3	67.5
	Essex, Mo.	Cocodrie	-0.2151	8.2862	-12.2500	0.97	19.3	67.6
	Newport, Ark.	Cocodrie	.	.	.	.	.	.
2005	Osceola, Ark.	Cheniere	-0.3582	13.4440	61.3340	0.81	18.8	64.8
	Stuttgart, Ark.	Francis	-0.1735	6.4733	5.7470	0.74	18.7	66.1
	Qulin, Mo.	Wells	-0.1872	7.4632	-9.8707	0.94	19.9	64.5
	Stuttgart, Ark.	XP723	-0.1905	7.4658	-7.9433	0.93	19.6	65.2
	Cleveland, Miss.	XP723	-0.2228	8.6679	-20.5300	0.98	19.5	63.8

[z] This optimal harvest moisture content was determined by visual observation of HRY vs. HMC data of Figure 2.

[y] Head rice yields were not statistically related to harvest moisture content.

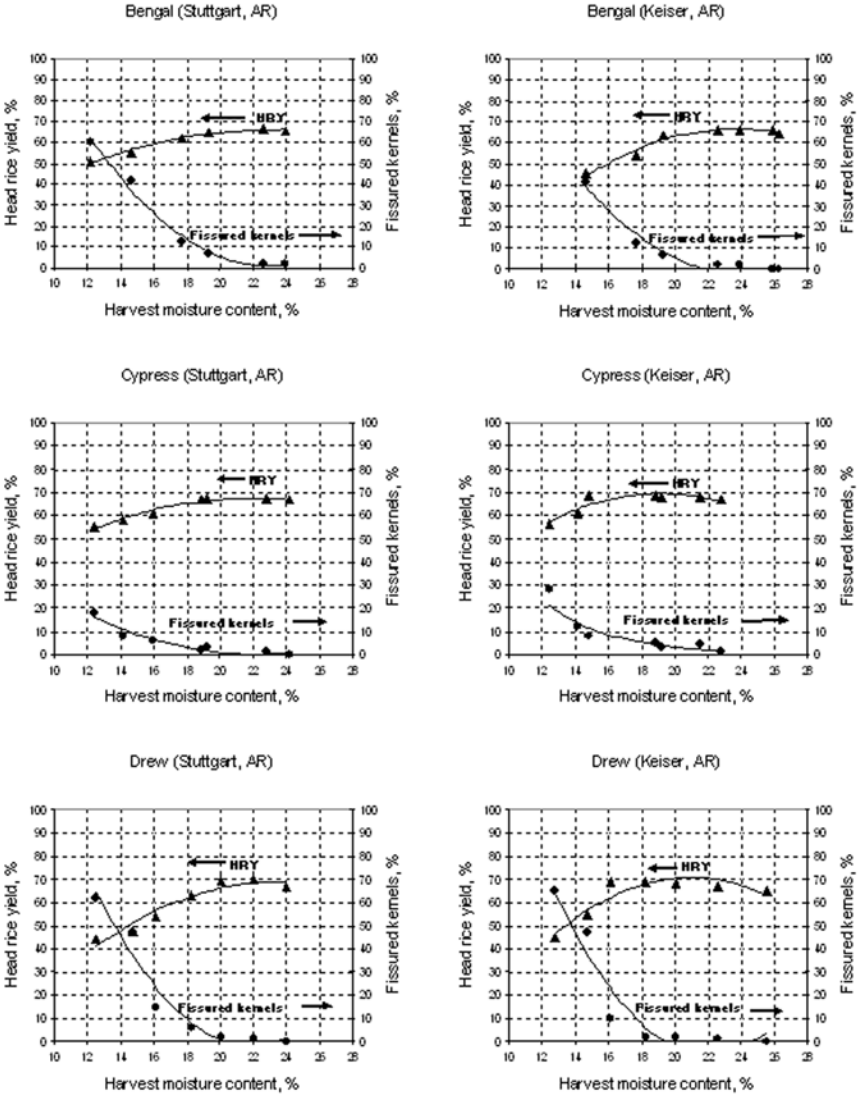

Fig. 1. Fissured kernel percentages and head rice yields (HRYs) vs. harvest moisture content for the indicated rice lots harvested in 1999. Each fissured kernel percentage data point represents the percentage of fissured kernels in 200 brown rice kernels. Each HRY data point represents the average of two milling repetitions.

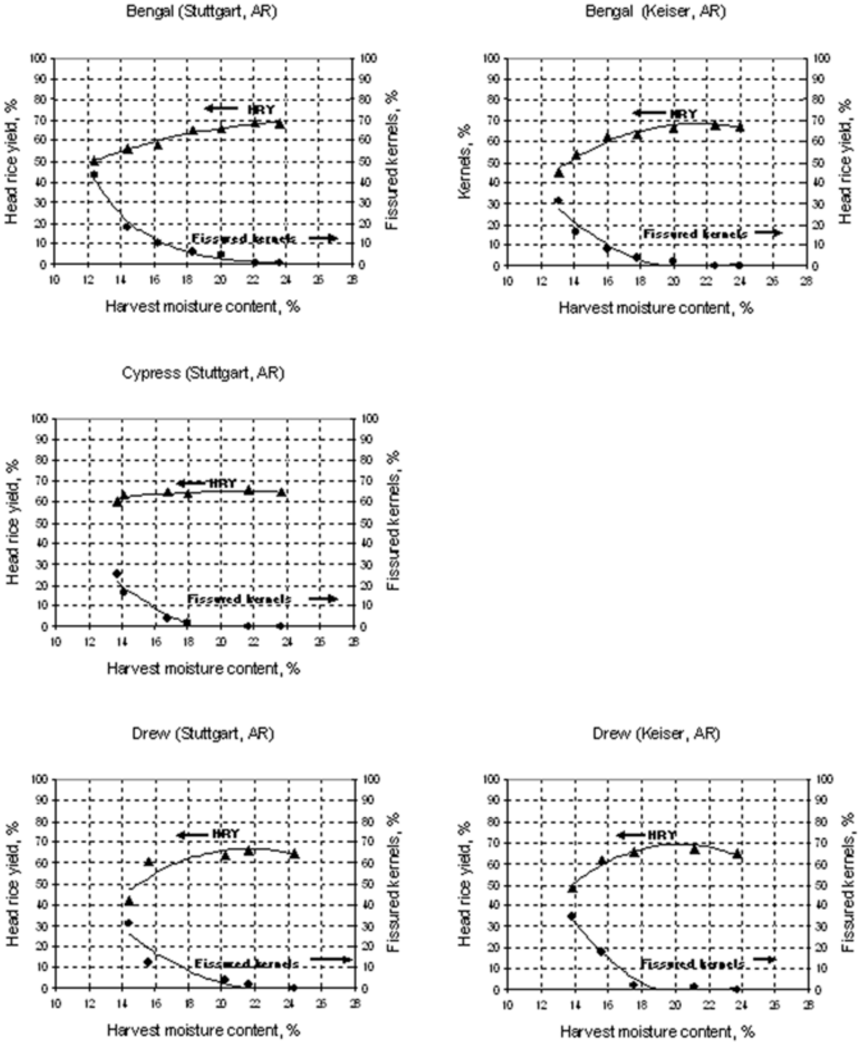

Fig. 2. Fissured kernel percentages and head rice yields (HRYs) vs. harvest moisture content for the indicated rice lots harvested in 2000. Each fissured kernel percentage data point represents the percentage of fissured kernels in 200 brown rice kernels. Each HRY data point represents the average of two milling repetitions.

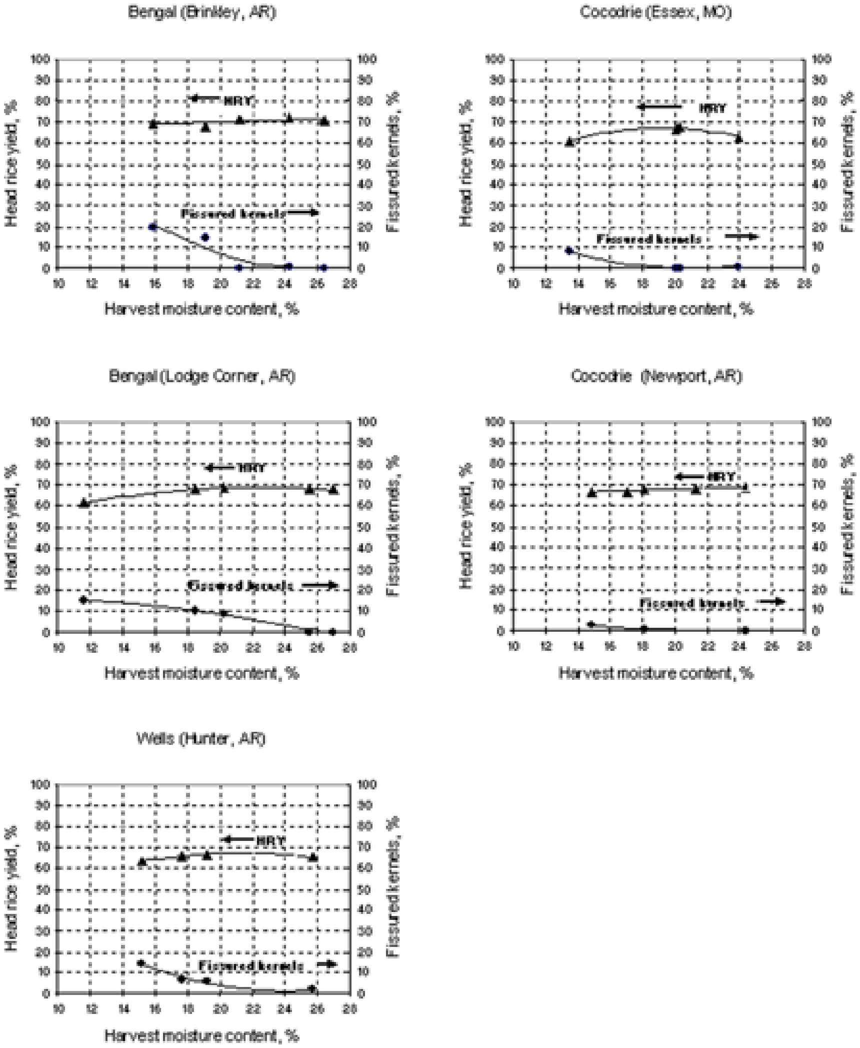

Fig. 3. Fissured kernel percentages and head rice yields (HRYs) vs. harvest moisture content for the indicated rice lots harvested in 2004. Each fissured kernel percentage data point represents the percentage of fissured kernels in 200 brown rice kernels. Each HRY data point represents the average of two milling repetitions.

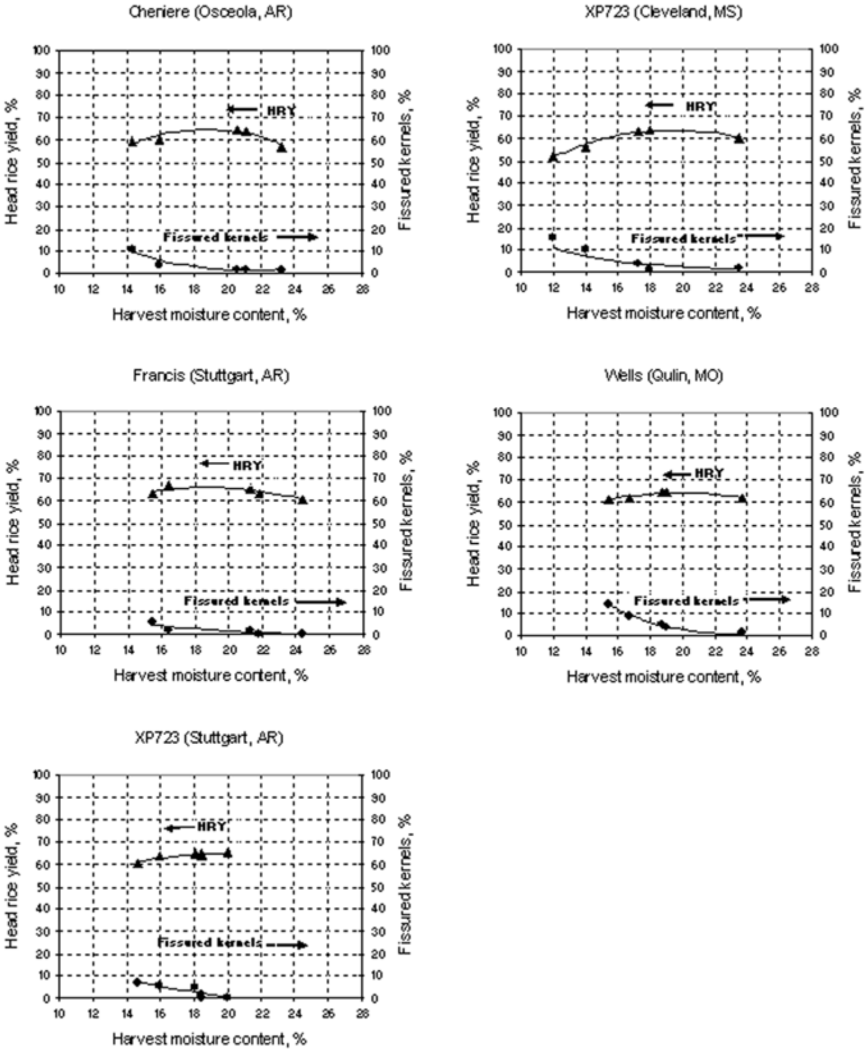

Fig. 4. Fissured kernel percentages and head rice yields (HRYs) vs. harvest moisture content for the indicated rice lots harvested in 2005. Each fissured kernel percentage data point represents the percentage of fissured kernels in 200 brown rice kernels. Each HRY data point represents the average of two milling repetitions.

Quality of Long-Grain Rice Dried by High-Temperature Fluidization

T.J. Siebenmorgen, E.E. Truitt, J.-F. Meullenet

ABSTRACT

An air-impingement oven was used to simulate fluidized bed drying (FBD) of rough rice in an evaluation of high, drying air temperature effects on milling characteristics and physicochemical properties. *Oryza sativa* L. 'Wells' at an initial moisture content (MC) of 21.9% was dried to 15 and 13% MC using drying air temperatures of 60, 90, 120, and 150°C and was immediately tempered at 60°C or above the grain temperature (GT) for 0 to 120 min before cooling. Head rice yields (HRYs) could be maintained or increased using drying air temperatures of 60 to 150°C when drying to 15% MC and tempering at the GT for at least 60 min. Significant changes in rice quality, including decreased peak and final viscosity, occurred when drying at 120 to 150°C and tempering at the GT, due to exposure of rice to high GTs (>82°C) for extended durations. All quality parameters were maintained when drying air temperatures did not exceed 90°C, MC after one drying pass was not less than 15%, and rice was tempered at the GT for at least 60 min. As rice was dried in a single layer, the reported results indicate the most severe effects of high-temperature drying on subsequent rice quality.

INTRODUCTION

With the increase in rice production and more rapid harvesting and transport capabilities, the rice industry must find quicker, quality-assured methods of drying the influx of rough rice. Fluidized bed drying enables rapid drying by utilizing high temperatures (90 to 200°C) and uniform drying across the drying bed by using high air velocities (2.3 to 4.4 m/s) (Soponronnarit et al., 1996; Soponronnarit and Prachayawarakorn, 1994). Fluidization techniques have been reported to produce increased HRYs compared to conventional drying methods (Inprasit and Noomhorm, 2001; Tirawanichakul et al., 2004; Prachayawarakorn et al., 2005).

Cnossen and Siebenmorgen (2000) and Schluterman and Siebenmorgen (2007) have investigated the role of the glass transition temperature (T_g) during rice drying. T_g is the temperature at which material properties change from a glassy to a rubbery state. They have proposed a hypothesis that incorporates material behavior in these states to explain fissure formation. It was shown that drying at 60°C (above T_g) could occur without reducing HRYs if rice was adequately tempered at the GT before cooling.

Fluidized bed drying studies have shown that with sufficient tempering, HRYs could be maintained or increased using temperatures of 90 to 150°C to dry 30.1% initial MC (IMC) rice to ~18% MC (Soponronnarit et al., 1999; Taweerattanapanish et al., 1999; Inprasit and Noomhorm, 2001; Wiset et al., 2001; Tirawanichakul et al., 2004; Prachayawarakorn et al., 2005). Other research has cited the effects of FBD on pasting properties (Wiset et al., 2001; Meeso et al., 2004) and starch gelatinization (Inprasit and Noomhorm, 2001), but changes in these functional properties warrant more study. Furthermore, little research has been done on the effects of high-temperature drying on rice with IMCs less than 20%.

MATERIALS AND METHODS

A pilot-scale air-impingement oven (Model 102 Lab Oven, Stein, Sandusky, Ohio) was used to simulate fluidized bed conditions. The oven was capable of maintaining temperatures up to 260°C. An air velocity of ~3-4 m/s was used, which fully fluidized rice within enclosed-screen drying trays.

Long-grain rice cultivar, Wells, was harvested from Keiser, Ark., in 2004 at 21.9% MC, cleaned, and stored in sealed plastic containers at 4°C for 12 weeks. Duplicate 200 g samples were dried in enclosed screens in the air-impingement oven to 15% and 13% MC using air at 60°C (9% relative humidity (RH)), 90°C (4.5% RH), 120°C (~1.3% RH), and 150°C (~0.5% RH). After drying to 15% or 13% MC, samples were tempered at either the GT or 60°C for durations ranging from 0 to 120 min. Duplicate control samples were dried to 12.5% MC in a chamber maintained at 21°C and 57% RH.

Dried samples were dehulled and milled to determine HRY. Head rice kernels were separated from brokens using a double-tray shaker table. Peak and final viscosities of rice flour from head rice were determined using a Rapid Visco Analyser (RVA) (Model 4, Newport Scientific, Warriewood, NSW, Australia) according to AACC method 61-20 (2000). A differential scanning calorimeter (Pyris 1, Perkin Elmer, Norwalk, Conn.) was used to determine the degree of starch modification (SM), similar to the method of Normand and Marshall (1989). Enzymatic hydrolysis of starch granules by fungal α-amylase according to AACC method 76-31 (2000) was also used to assess the SM.

RESULTS AND DISCUSSION

Head Rice Yields

HRY data from the 120°C, ~1.3% RH drying air condition are shown in Fig. 1. Tempering for 60 min was typically necessary to attain the maximum HRY for each drying treatment; HRY values for 60- and 120-min tempering durations were generally not significantly different. HRYs were greater when drying to 15% MC in one drying pass rather than removing more moisture by drying to 13% MC. Tempering at the GT also produced greater HRYs than tempering at 60°C. Final MC, tempering duration, tempering temperature, and drying air temperature had significant effects on HRY ($p < 0.0001$).

HRY results can be explained using a state diagram showing the glass transition temperature line (Cnossen and Siebenmorgen, 2000). Figure 2 is a plot of the rice MC and temperature attained after each drying trial. Additionaly, the HRY reduction (HRYR) from the control after tempering at the GT for 120 min for each drying trial is plotted. Figure 2 indicates that as more moisture was removed in drying to 13% MC compared to 15%, greater MC gradients were created, resulting in significantly reduced HRYs. Siebenmorgen and Schluterman (2007) have shown that extended drying creates intrakernel MC gradients, causing the kernel surface to dry to low MCs, thereby causing sufficient portions of the kernel periphery to transition into the glassy state while the center remains in the rubbery state. The dramatic differences in kernel properties between these states, particularly expansion rates, can lead to fissure formation and resultant HRY reductions. The glass transition line can also be employed to explain trends due to tempering. When samples were tempered at 60°C instead of the GT (GTs were higher than 60°C when drying at 90 to 150°C), HRYRs were greater (Fig. 3). Cooling kernels to 60°C before allowing MC gradients to subside through tempering caused greater portions of the kernel periphery to transition into the glassy region while the center core remained in the rubbery region; this scenario produces kernel fissures as explained above. Such a scenario may occur in an industrial setting if rice exiting driers is cooled before tempering.

The highest HRYs, with no functionality degradation, were achieved by drying to 15% MC using 120 to 150°C air and tempering at the GT; it was possible to dry to 13% MC in one drying pass using 150°C air with tempering at the GT for 120 min with no significant HRYR, but some starch modification occurred. When drying at 120 to 150°C, GTs were between 82 and102°C, which is below the melting temperature of starch (~160°C at ~21% MC, as reported by Sun et al., 2002). While changes in starch occurred, as will be discussed below, these changes could not explain the increases in HRY over the control seen in samples dried at 120 to 150°C to 15% MC. Although there was an apparent, non-significant 2.8 percentage point increase in HRY over the control when drying at 120°C to 15% MC with tempering at GT for 120 min, there was no significant increase in starch modification (Fig. 4). Starch gelatinization contributes to increases in HRY in high MC rice, such as during parboiling. However, at the low MCs used in this study, HRY increases could be due to interactions between starch and denatured proteins (Ju et al., 2001) when heated, case hardening (Wilhelm et al., 2004), or partial gelatinization.

Starch Modification

Fig. 4 shows that, in general, as drying treatment "severity" increased, the amount of starch modification increased, but the amount of modification depended on the measurement method. "Severity" increased by increasing drying air temperature, tempering temperature, amount of moisture removed in one pass, and tempering duration. The exact cause of the SM is not known, but could be due to the processes listed above or as cited by Jacobs and Delcour (1998), a heat moisture treatment cited as a hydrothermal modification of starch occurring at temperatures above T_g but below the gelatinization temperature, and at low MCs. The high GTs, low MCs, and long tempering durations that rice kernels were exposed to in this study might have induced changes in starch. Generally, a drying air temperature of 150°C, producing GTs of 92 to 102°C, was necessary to induce significant SM, up to ~8 to 30% depending on the measurement method.

Based on DSC, SM values were much higher than those measured using the enzymatic method. Tirawanichakul et al. (2004) reported 22.3% starch gelatinization using the DSC method in 22.4% IMC rice dried at 150°C. The DSC method may not be very accurate for lower temperature- (60 to 90°C) dried samples, however, because significantly negative SM values were obtained (Fig. 4). The enzymatic method of determining SM did not produce significantly negative SM values and, as it would incur no interference from proteins, was deemed more appropriate than the DSC method. The lower SM obtained using the enzymatic method indicated significant SM only in samples that experienced GTs above 100°C. Drying air temperature ($p \leq 0.0002$) and final MC ($p \leq 0.0081$) were significant factors in determining the degree of SM regardless of measurement method.

Viscosities

Fig. 5 shows that as drying treatment severity increased, peak and final viscosities increased within each drying temperature treatment set, but decreased sharply under the more severe drying conditions (150°C, 13% MC, GT). Only final MC ($p \leq 0.0021$) had a significant effect on viscosities. Tempering at 60°C had no effect on peak viscosity, but tempering at the GT for at least 60 min after drying to 15% MC using drying air temperatures of 90 to 150°C generally increased peak viscosity. This was possibly due to proteins being denatured by high temperatures, which could allow for greater starch swelling (Hamaker and Griffin, 1993; Yang and Chang, 1999). Severe drying conditions (120 to 150°C, 13% final MC, tempering at the GT for 30 to 120 min) resulted in a progressive decrease in peak viscosity from 161 RVA units before drying to 46 RVA units after drying under the most severe condition. Final viscosities followed similar trends as those of peak viscosity (Fig. 5). Those samples that displayed decreased peak and final viscosities also had significant starch modification (Fig. 4). Ban (1971), Dillahunty et al. (2001), Wiset et al. (2001), and Meeso et al. (2004) have shown similar decreased peak and final viscosities with high-temperature treatment of rough rice.

SIGNIFICANCE OF FINDINGS

The results show the need for optimization of high-temperature drying in order to maintain HRYs but minimize other quality degradation. As shown by the milling quality of rice dried at 120 to 150°C to 15% MC and tempered at the GT, high drying air temperatures can potentially be used to reduce MC quickly without incurring HRYR, but exposure of rice to high GTs (>82°C) for extended durations produced significant starch quality changes. Tempering at temperatures lower than GT, however, may risk HRY reduction, as explained previously by the glass transition hypothesis. It must be noted that this study was meant to serve as a "worst case scenario." Rice was dried in a single layer to assure complete fluidization, inducing higher GTs than may be seen in thicker bed depths of commercial fluidized bed dryers. Thus, some of the severe quality damage shown in this study may or may not be seen in commercial-scale fluidized bed dryers.

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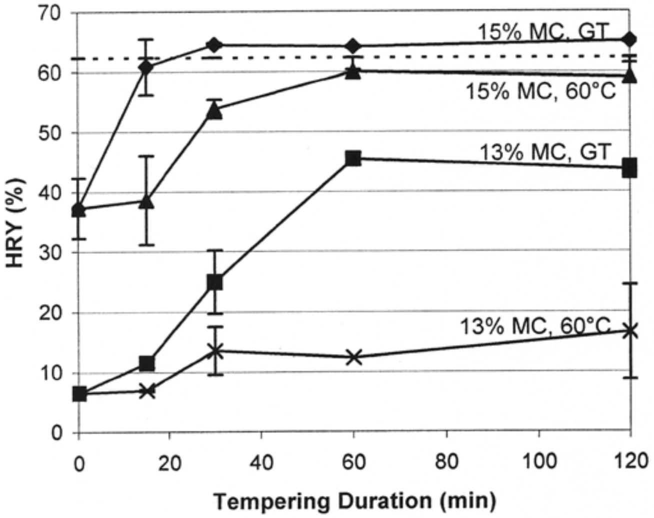

Fig. 1. Head rice yield (HRY) data of Wells [21.9% initial moisture content (MC)] dried at 120ºC, ~1.3% RH to 13% or 15% moisture content (MC) and tempered at the grain temperature (GT) or 60ºC for various durations. The dotted line represents the control HRY of 62.3%. Vertical bars display standard deviation from the mean of two replications.

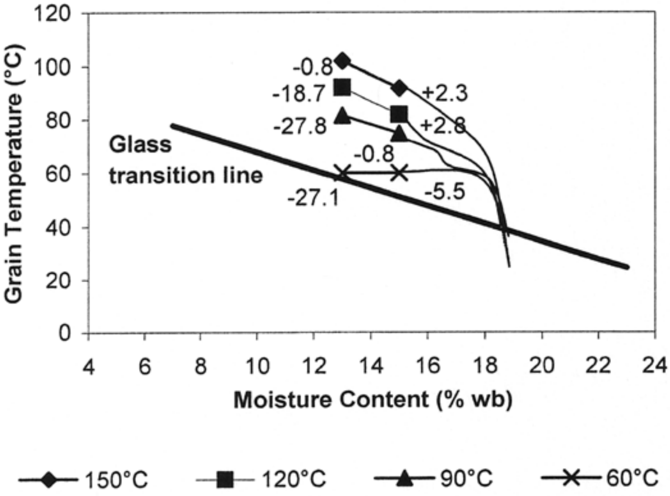

Fig. 2. State diagrams of head rice yield reduction (expressed as percentage points) of Wells (21.9% initial moisture content [MC]) dried at each drying air temperature to 15% and 13% MC and tempered at the grain temperature for 120 min before cooling to 21ºC.

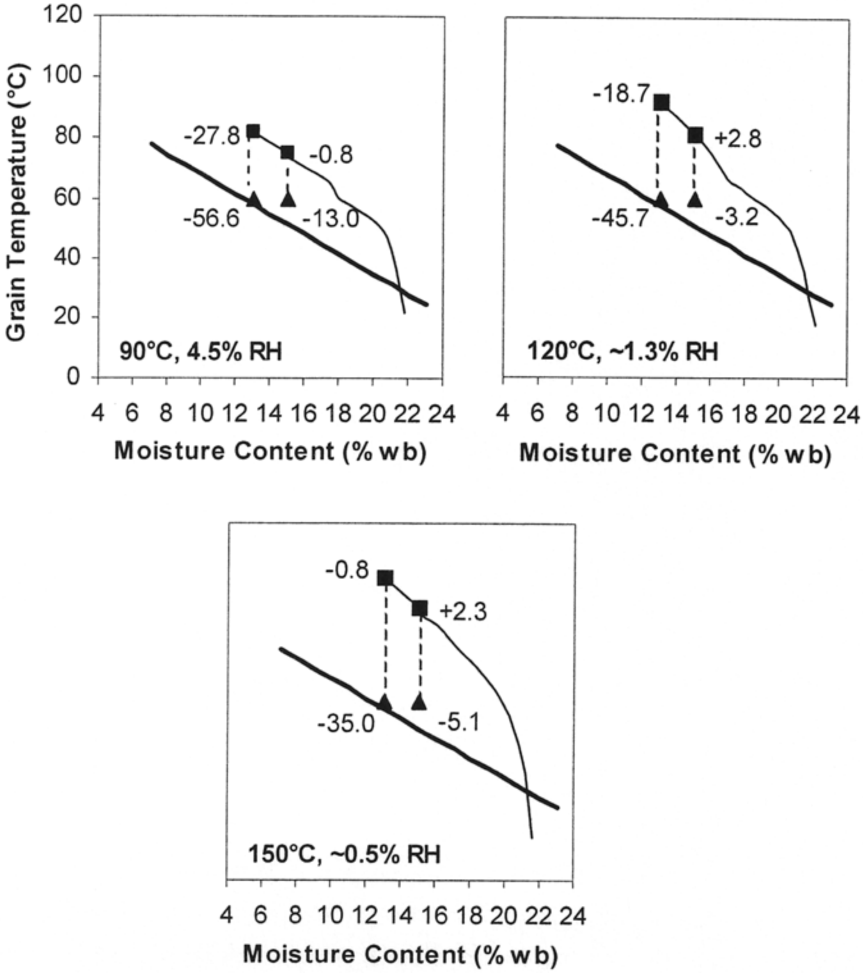

Fig. 3. State diagrams plotting average head rice yield reduction (expressed as percentage points) of Wells (21.9% initial moisture content [MC]) dried using the indicated air conditions to 15% and 13% MC and tempered at the grain temperature (■) or 60ºC (▲) for 120 min.

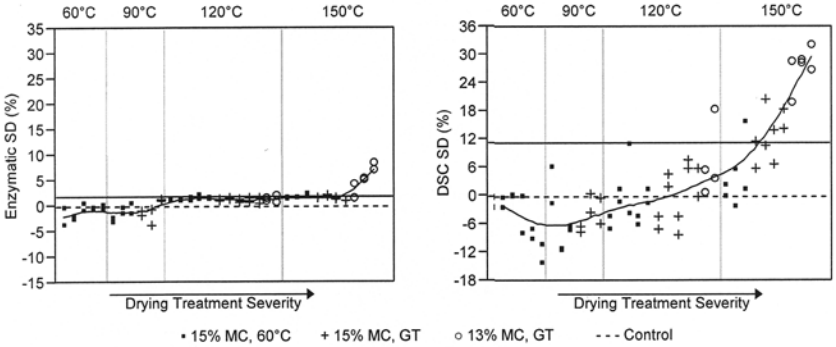

Fig. 4. Starch modification (SM) trends, measured by enzymatic hydrolosis and differential scanning calorimetry (DSC), with increasing drying treatment severity–defined by increasing drying air temperature (60 to 150ºC), tempering temperature (60ºC or the grain temperature [GT]), amount of moisture removed in one drying pass (15% to 13% final moisture content [MC]), and tempering duration (0 to 120 min)–for Wells (21.9% initial MC). Average values above the solid black lines were significantly different from the control.

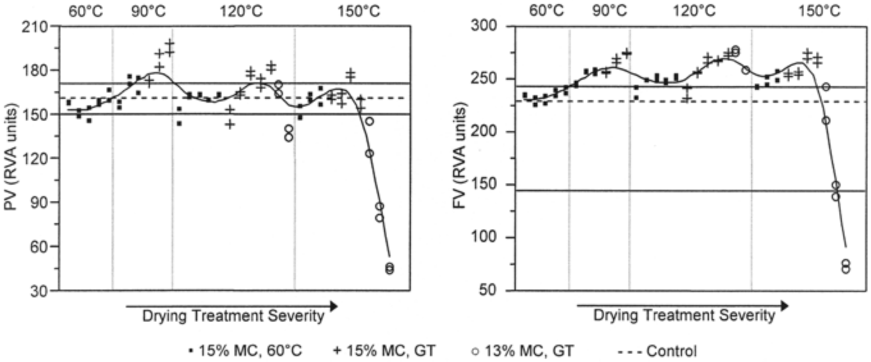

Fig. 5. Peak viscosity (PV) and final viscosity (FV) trends with increasing drying treatment severity for Wells (21.9% initial MC). Average values above the top and below the bottom solid black lines were significantly different from the control.

ECONOMICS

Evaluating the Costs of Precision-Leveling Rice Fields

K.B. Watkins, J.L. Hill, and M.M. Anders

ABSTRACT

Precision-leveled rice fields require significantly less applied water than contour-levee fields. However, precision leveling is a land improvement and involves a capital cost to be paid upfront. The landowner must determine whether the work should be custom-hired or performed using owned dirt-moving equipment and on-farm labor. This study evaluates the costs of precision leveling using either custom-hire or owned equipment at varying volumes of soil moved per acre. The results demonstrate how the amount of soil moved per acre might impact the choice of leveling option used. Custom charges for precision leveling in Arkansas range from \$1.15 to \$1.25/yard^3. Single-pan owned equipment is more attractive than custom hire at volumes of soil moved exceeding 142 yard^3/acre. At these volumes, the cost per cubic yard for single-pan equipment is less than that for custom hire assuming the lower custom charge of \$1.15/yard^3. Dual-pan equipment is more cost efficient than single-pan equipment at volumes of soil moved exceeding 215 yard^3/acre.

INTRODUCTION

Most rice acres in Arkansas are flood irrigated using contour-levee systems. Contour-levee systems are extremely water intensive and can apply as much as 39 acre-inches of total water to maintain a flood during an average growing season (Epting, 2004). Precision-leveled rice fields require significantly less applied water. Precision leveling removes depressions in the field that hinder water movement and results in a reduction in the minimum depth of water required to cover the entire field (Salassi, 2001, 2003). Water savings associated with precision leveling can range from 12% for straight levee fields without multiple-inlet irrigation tubing to 60% for fields graded to a zero slope (Epting, 2004).

Precision leveling is a land improvement and requires a capital cost to be paid upfront. The landowner must determine whether the work should be hired on a custom basis or performed using owned dirt-moving equipment and on-farm labor. Custom hire may be more appropriate if only a few acres need to be leveled or the volume of soil moved per acre is small. However, owned equipment and on-farm labor may be more economical if a large number of acres will be precision-leveled or if the volume of soil moved per acre is large. The objective of this study was to compare the costs of precision leveling using custom hire to costs of precision leveling using owned equipment at varying volumes of soil moved per acre.

PROCEDURES

Custom precision-leveling charges were obtained by contacting professional dirt-moving businesses in eastern Arkansas by phone. Purchase prices and cost data for owned equipment were obtained based on phone conversations with equipment dealers and farmers with owned dirt-moving equipment. All phone conversations occurred during the summer of 2006. Cost estimates for owned equipment were calculated for single-pan and dual-pan equipment and included fuel, labor, repair and maintenance, depreciation, and interest charges. Owned-equipment costs were calculated for varying volumes of soil moved per acre assuming 200 acres of land are precision-leveled per year. Owned-equipment costs were converted to a cubic-yard basis for direct comparison with custom-hire charges obtained for eastern Arkansas. Precision-leveling costs were also calculated on a per-acre basis to compare the cost-per-acre of moving specific volumes of soil using either custom-hire or owned equipment.

RESULTS AND DISCUSSION

The unit of payment for custom hire can vary by hour or by cubic yard depending on the amount of soil moved per acre. If the per-acre amount of soil moved is small (100 cubic yards or less), the custom work is usually charged on an hourly basis and ranges from \$125 to \$150/hour. If large amounts of soil are moved per acre (greater than 100 cubic yards), the custom work is usually charged by cubic yard and ranges from \$1.15 to \$1.25/yard^3. Other circumstances such as total volume of soil moved and distance soil is moved will influence the payment method selected by the land-leveling business.

The charge per cubic yard of precision leveling may be reduced if owned equipment and on-farm labor are used in place of custom hire. Table 1 presents a description of the equipment needed for on-farm precision leveling and the cost per hour and per cubic yard associated with each piece of equipment assuming 300 cubic yards of soil per acre are moved on 200 acres of land per year. Fuel costs were calculated using a farm diesel price of \$2.20/gal, and labor costs were calculated assuming a labor wage of \$10/hour. For this particular example, the total cost per unit of soil moved using owned equipment and on-farm labor ranges from \$0.83/yard^3 if two dirt pans are used to \$0.90/yard^3 if one dirt pan is used. Both cost estimates are lower than the custom charges of \$1.15 to \$1.25/yard^3 reported above.

Estimated costs of precision leveling using on-farm equipment are presented for selected volumes of soil moved in Table 2. These data demonstrate how the amount of soil moved might impact the choice of leveling option used (custom hire versus owned equipment). Custom hire is more attractive than single-pan equipment when the volume of soil moved is less than 142 yard^3/acre and is more attractive than dual-pan equipment when the volume of soil moved is less than 165 yard^3/acre. At these volumes, the cost per cubic yard of soil moved for custom hire is lower than single-pan or dual-pan equipment assuming a custom charge of \$1.15/yard^3. The choice of single- or dual-pan setup also is impacted by the amount of soil moved. The single-pan setup produces the lowest cost per volume of soil moved at volumes less than 215 yard^3/acre. Beyond 215 yard^3/acre, the dual-pan setup results in the lowest cost per cubic yard of soil moved.

Table 3 presents the estimated per-acre costs of precision leveling for selected volumes of soil moved using either owned equipment or custom hire. The charges reported in Table 3 include a \$10/acre charge for obtaining a cut sheet of the field prior to land leveling. A cut sheet provides a topographic layout of the “cut” and “fill” areas of the field and provides an estimate of the total cubic yards of soil to be moved to achieve the desired grade. A charge of \$46.45/acre is also included to account for the cost of applying one ton of loose raw broiler litter as a soil amendment (Young et al., 2006). Excluded from the total-cost figures reported in Table 3 are charges for ripping (subsoiling). Ripping might be necessary for some fields if soil compaction or hardness prevents efficient scraper operations. Such conditions might prevail if land leveling is conducted during a dry period prior to a rain. An additional charge of \$12/acre would be added to the total cost figures in Table 3 to account for ripping.

The per-acre cost of precision leveling increases as the number of cubic yards of soil moved per acre increases. Custom hire is less costly than single-pan equipment at volumes less than 142 yard^3/acre and is less costly than dual-pan equipent at volumes less than 165 yard^3/acre. Greater efficiencies may also be achieved for large volumes of soil moved per acre using two dirt pans as opposed to one. The cost per acre for dual-pan equipment is less than that for single-pan equipment at volumes of soil moved exceeding 215 yard^3/acre.

SIGNIFICANCE OF FINDINGS

This study demonstrates how the amount of soil moved per acre can impact the decision to use either custom hire or owned equipment and on-farm labor for precision-leveling a field. Custom hire is more economically attractive at volumes of soil moved less than 142 yard^3/acre, assuming a custom charge of \$1.15/yard^3. Single-pan equipment is more efficient than either custom hire or dual-pan equipment at volumes of soil moved between 142 and 215 yard^3/acre. Dual-pan equipment is more cost-efficient than single-pan equipment at volumes of soil moved exceeding 215 yard^3/acre.

The results of this study should help landowners make better-informed decisions about precision leveling for their particular farm operations.

ACKNOWLEDGMENTS

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Table 1. Description of on-farm precision leveling setup.

Item	Purchase price	Useful life	Annual use	Cost per hour	Cost per cubic yard[z]
			(hours)	($)	
Single pan					
4wd 400 Hp tractor	183,000	10	1,000	97.25	0.68
Scraper – 18yd	60,000	15	417[y]	22.36	0.16
Laser equipment	25,600	10	417	9.85	0.07
Total, single scraper	268,600			129.47	0.90
Dual pans					
4wd 400 Hp tractor	183,000	10	1,000	97.25	0.45
Scraper – 18yd	60,000	15	278[y]	33.54	0.16
Scraper – 18yd	60,000	15	278	33.54	0.16
Laser equipment	27,600	10	278	15.93	0.07
Total, dual scrapers	330,600			180.28	0.83

[z] Estimated volume of soil moved per hour for single-pan setup is based on 8 cycles per hour with an 18-yard pan (144 cubic-yards per hour with 1 pan). Estimated volume of soil moved per hour for dual-pan setup is based on 6 cycles per hour with two 18-yard pans (216 cubic-yards per hour with 2 pans).

[y] Number of annual hours required to move 300 yard^3 soil/acre on 200 acres using either single-pan equipment or dual-pan equipment.

Table 2. Estimated costs of precision leveling using on-farm equipment for given volumes of soil moved.

	Single pan, owned		Dual pans, owned	
Volume of soil moved	Cost per hour[z]	Cost per cubic yard[y]	Cost per hour[y]	Cost per cubic yard[y]
(yard^3/acre)	($)			
75	226.12	1.570	429.34	1.988
100	193.90	1.347	346.32	1.603
142[x]	165.31	1.148	272.65	1.262
165[w]	155.83	1.082	248.20	1.149
200	145.58	1.011	221.79	1.027
215[v]	142.21	0.988	213.10	0.987
300	129.47	0.899	180.28	0.835
400	121.41	0.843	159.52	0.739
500	126.58	0.810	147.07	0.681
600	123.36	0.787	148.76	0.642
700	121.06	0.771	142.83	0.615
800	109.33	0.759	128.39	0.594
900	107.99	0.750	124.93	0.578
1000	106.92	0.742	122.16	0.566

[z] Costs per hour calculated based on 200 leveled acres/year.

[y] Estimated volume of soil moved per hour for single-pan setup is based on 8 cycles/hour with an 18-yard pan (144 cubic-yards/hour with 1 pan). Estimated volume of soil moved per hour for dual-pan setup is based on 6 cycles/hour with two 18-yard pans (216 yard^3/hour with 2 pans).

[x] Volumes ≥142 yard^3/acre - the cost per cubic yard for single-pan equipment is less than custom hire at a custom charge of $1.15 yard^3.

[w] Volumes ≥165 yard^3/acre - the cost per cubic yard for dual-pan equipment is less than custom hire at a custom charge of $1.15 yard^3.

[v] Volumes ≥215 yard^3/acre - the cost per cubic yard for dual-pan equipment is less than that for single-pan equipment.

Table 3. Estimated costs of precision leveling per acre at selected volumes of soil moved with on-farm equipment and custom hiring.

Volume of soil moved	Leveling options[z] Single pan, owned	 Dual pans, owned	 Custom hired
(yard^3/acre)			
75	174.22	205.53	142.70
100	191.10	216.78	171.45
142[y]	219.47	235.69	219.75
165[x]	235.00	246.05	246.20
200	258.64	261.81	286.45
215[w]	268.77	268.56	303.70
300	326.18	306.83	401.45
400	393.71	351.86	516.45
500	461.25	396.88	631.45
600	528.79	441.91	746.45
700	596.32	486.93	861.45
800	663.86	531.96	976.45
900	731.40	576.98	1,091.45
1000	798.93	622.00	1,206.45

[z] Custom-hired precision leveling charge = \$1.15/yard^3. Additional charges of \$10/acre for obtaining a cut sheet of the field and \$46.45/acre for applying one ton of loose, raw broiler litter as a soil amendment are included in the total costs.

[y] Volumes ≥142 yard^3/acre - the cost per acre for single-pan equipment is less than than for custom hire.

[x] Volumes ≥165 yard^3/acre - the cost per acre for dual-pan equipment is less than that for custom hire.

[w] Volumes ≥215 yard^3/acre - the cost per acre for dual-pan equipment is less than that for single-pan equipment.