B.R. Wells

Rice Research Studies 2004

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

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Cover photo: Professor Chuck Wilson, Extension Rice Specialist, evaluating one of his rice research tests

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Norman, Meullenet, and Moldenhauer

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

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

*(a unit of the University of Arkansas
System's statewide Division of Agriculture)*

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

John F. Robinson

Dr. John F. Robinson was born March 24, 1943 in Columbia, La., and raised in the small town of Grayson, La. His father was a vocational agriculture teacher, advisor to the Future Farmers of America, and instrumental in fostering John's interest in agriculture. John was very active in FFA and 4-H. His FFA project was a herd of Poll Hereford cattle and his 4H project was showing hogs and sheep at parish and state fairs.

In 1961, John enrolled at Northeast Louisiana University at Monroe, La., and in 1963 transferred to Louisiana State University, Baton Rouge, La. He graduated from LSU in 1965 with a B.S. degree in Pre-Med. In 1965, John began working in the USDA-ARS Rice Insects Research Project as a student worker and taking graduate courses in entomology. In 1966, he accepted a temporary position with USDA-ARS in Baton Rouge as a lab technician in the rice insects project. In 1967, John accepted a permanent laboratory technician position with USDA-ARS at the European Corn Borer Laboratory located at Ankeny, Iowa. This position offered the opportunity to work full-time and continue his education in entomology. He received his Ph.D. degree in entomology from Iowa State University, Ames Iowa, in 1974. In 1975, Dr. Robinson transferred to the USDA-ARS Vegetable Laboratory in Charleston, S.C., and conducted research on vegetable insects until the end of 1977.

In December of 1977, John was able to return to the familiar surroundings of Louisiana when he accepted the position of research scientist with USDA-ARS at the Rice Station in Crowley, La., conducting research on rice insects. He had a wonderful research career at the LSU Rice Station and was a major contributor in the control of the rice water weevil and stink bug in the southern United States. He was always very practical in his scientific approach to solving problems and was most interested in solving real-world problems. His research helped to set the economic thresholds for controlling the rice water weevil and stink bug in commercial fields not only in Louisiana, but also in the other southern states.

Although John enjoyed and was quite successful as a rice researcher, he also had interests in administration and thought he could help the rice industry in that capacity. Consequently, in the summer of 1989 he applied for, was offered, and accepted the position of Director of the University of Arkansas Rice Research and Extension Center located near Stuttgart, Ark. Dr. Robinson brought a fresh perspective to the Rice Research and Extension Center. His positive and people-oriented approach helped him to encourage rice research and extension personnel to work closely together to solve rice producer's problems. He was a committed, unselfish leader who always took great pride in the accomplishments of the scientists and staff at the Rice Research and Extension

Center and supported them well. His number one priority as the resident director was how the Rice Research and Extension Center could help improve the rice industry. He retired as Director of the University of Arkansas Rice Research and Extension Center in the fall of 2001.

Dr. John Robinson had many accomplishments while directing the Rice Research and Extension Center. He encouraged the expansion of the rice nursery in Puerto Rico to include Mississippi and the USDA-ARS group at the Dale Bumpers National Rice Research Center; this nursery has been very beneficial to the southern United State rice industry. John was instrumental in helping to make the Dale Bumpers National Rice Research Center more than a dream: a reality. Through this center the tools of biotechnology can now be integrated into the rice breeding program. John was active in several organizations on the local and national scale. He was a member of the Rotary and Ruritan clubs in Stuttgart, he served as Secretary, Vice President, and President of the Research Centers Administrators Society, and he was very active in the Rice Technical Working Group where he served on numerous committees and held the offices of Secretary/Program Chair and Chairman. During his career Dr. Robinson received Riceland Food's prestigious Friend of the Farmer Award and Distinguished Service Awards from the Rice Technical Working Group and the Research Centers Administrators Society.

Upon retirement John and his wife, Sarah, moved back to the small town of Grayson, La. Both are actively involved in the Grayson United Methodist Church. Sarah serves as treasurer and John is serving as lay leader and president of the Grayson United Methodist Men. They also do a monthly church newsletter. He is a member of the Caldwell Parish Industrial Board and is presently serving as its president, and is a board member of the Northeast Louisiana Economic Alliance. Always with an eye to the future, John is presently serving as president of the Welcome Home Cemetery Association. He recently volunteered to lead "insect safaris" for 3rd to 6th graders to help raise money to support the Martin Home Place which is listed on the National Historic Register.

John and Sarah's two children live in the same community. They spend a lot of time with their family and especially with Dillon, their eight year-old grandson. Dillon is presently trying to teach his grandparents how to get past the first level in "Lord of the Rings" on the Play Station and a few basic Taekwondo moves. They have a couple of houses built in the mid-to-late 1920s that they are renovating. John likes to fish and still makes the annual sailing of the "Perch Fleet" to fish with his Iowa State friends in Minnesota. John said when he retired that he was looking forward to a lot of fishing and reading. Oh well, maybe next year.

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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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Trends in Arkansas Rice Production

C.E. Wilson, Jr. and J.W. Branson

ABSTRACT

Arkansas is the leading rice-producing state in the U.S., representing 46.5% of the total U.S. production and 46.8% 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 produces 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 just over 46.5% of the total U.S. production and 46.8% 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.

PROCEDURES

A survey was conducted in August of the past three years (2002-2004) by polling county extension agents in each of the counties in Arkansas that produces rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage and yield information were obtained from the USDA National Agricultural Statistics Service. Rice variety distribution was obtained from summaries generated from the University of Arkansas Rice DD50 program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with acreage distribution of the most widely produced varieties. Wells was the most widely planted variety in 2004 at 39.9% of the acreage, followed by Cocodrie (15.4%), CL 161 (13.2%), Francis (11.4%), Bengal (9.9%), and CL XL8 (2.5%). The acreage planted to Wells in 2004 decreased slightly from over 45% in 2003 while the acreage planted to Cocodrie declined from almost 22% in 2003 to just over 15% in 2004. The biggest increase was by CL 161, which increased from 4.7% in 2003 to 13.2% in 2004. Francis acreage also increased in 2004 with almost twice the acreage planted in 2003. The adoption of the Clearfield rice system represents a significant factor that may eventually play a significant role in management of red rice. It provides an opportunity for red rice control that has never been available to rice farmers. Clearfield rice (e.g., CL 121, CL 161, and CL XL8) accounted for 16% of the total rice acreage in 2004.

Arkansas rice acreage represented 46.5% of the total US rice crop (Table 2). The state-average yield of 6,910 lb/acre (154 bu/acre) was the second highest average in the U.S. behind California. It represents a record high for Arkansas, surpassing the previous record established in 2003 of 6,610 lb/acre. This also represents the fourth consecutive year that Arkansas rice farmers have produced record state-average yields. The total rice produced in Arkansas was 107.4 million hundredweight (cwt). This represents 46.5% of the 230.8 million cwt produced in the U.S. during 2004. The total production for the state surpassed the previous record production of 102.9 million cwt achieved in 2001. Over the past three years, Arkansas has produced 46.8% of all rice produced in the U.S. The five largest rice-producing counties in 2004 were Poinsett, Arkansas, Cross, Jackson, and Lawrence, representing 36% of the state's total rice acreage (Table 1).

Based on the survey conducted with the cooperation of our county extension agents, approximately 60% of the rice produced in Arkansas was planted using conventional tillage methods in 2004 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. This was down slightly from 2003 and was offset by a slight increase in stale seedbed planting. The most common conservation tillage system utilized by Arkansas rice farmers is stale seedbed planting following fall tillage, representing approximately 30% of the state's rice acreage. True no-till rice production is not common but is done in a few select regions of the state. According to the survey, no-till accounts for approximately 10% 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 (21% and 14% 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 in 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 in 1984 to about 42,000 in 2004 (Arkansas Agricultural Statistics, 1984). Other areas where clay soils planted to rice 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 78% of the rice acreage (Table 3). Approximately 15% of the acreage in 2003 was planted following rice, with the remaining 7% made up of rotation with other crops including corn, grain sorghum, cotton, wheat, oats, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system with only approximately 6% 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. No-till water-seeded rice appears to be increasing from about 0.9% to 1.5% of the acreage. Most of this is done on zero-graded fields. Positive feedback from farmers who have incorporated this system suggests reduced labor, particularly irrigation labor, reduced input costs, and the ability to grow continuous rice as major advantages to this 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 all available water. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Approximately 82% of the rice acreage in Arkansas is irrigated with groundwater, with the remaining 18% irrigated with surface water 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 poly-pipe as a means of irrigating rice to conserve water and labor. As of 2004, rice farmers have adopted this practice for more than 27% of the rice acreage. This is an increase from 17% in 2002 and 25% in 2003, which constitutes an increase of approximately 166,000 acres irrigated using this technique since 2002. Approximately 72% of the rice is still irrigated with conventional levee and gate systems. Less than 1% of the rice is grown in 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. They have found it to be particularly efficient in fields that have steep slopes which would often contain more area in levees than in paddies. This has increased from less than 1,000 acres in 2002 to almost 5,000 acres in 2004.

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 40% of the 2004 rice acreage in Arkansas has been precision leveled, with 5% utilizing zero-graded fields (Table 3). Approximately 60% of the rice acreage still utilizes contour levees. Approximately 30,000 additional acres of rice were produced on zero-graded fields in 2004 compared to 2003. Zero-grading has advantages that allow producers to operate more efficiently and has generated high interest among farmers in some regions of Arkansas.

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 tilling, burning, rolling, and winter flooding. Approximately 17% of the acreage was burned, 26% was tilled, 41% was rolled, and 22% was winter flooded. Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather. 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.

Use of precision agriculture technology in their farming operations is slowly being adopted by the rice farmers of Arkansas. This is excluding the use of global positioning system (GPS) tracking used by nearly all aerial applicators. While there are certainly advantages to be gained from using this technology, the financial investment required often limits the use by many farmers. Practical applications that justify the expense are still under development. However, approximately 12% have yield monitors on their combines, while only about 6% use grid soil sampling and/or variable rate fertilizer applications. As new uses for precision ag technology are developed, the use will likely increase in the future. Remote sensing utilizing infared photography is used by a few consultants and producers to aid in crop scouting. However, additional research is needed to refine this technology so that better information can be obtained from the images developed.

Planting began in 2004 ahead of the 5-year average due to favorable weather during the end of March and beginning of April. Almost 50% of the crop was planted by 19 April in 2004, compared to a 5-year average of only 28% (Fig. 1). Although favorable planting conditions existed for much of the state early, cooler than normal temperatures during the season slowed crop development. Subsequently, the earlier planting did not result in earlier harvest, as illustrated in Fig. 2. Compared to the 5-year average, harvest proceeded very near the normal time-frame for Arkansas conditions.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state average yields in Arkansas have increased approximately 2300 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.

LITERATURE CITED

Arkansas Crop and Livestock Reporting Service. 1985. 1984 Agricultural Statistics for Arkansas, Rice Supplement 84. University of Arkansas Agricultural Experiment Station Report Series 293. Fayetteville, Ark.

Table 1. 2004 Arkansas planted rice acreage summary by county.

	Harvested acreage[z]		Medium		Long-grain							
County	2003	2004	Bengal	Others[y]	CL 161	CL XL8	Cocodrie	Cypress	Francis	XL 8	Wells	Others[y]
Arkansas	111,514	117,675	5,450	176	9,490	798	16,926	89	21,461	697	54,567	8,020
Ashley	15,513	14,846	0	0	2,917	0	5,818	1,020	3,604	0	1,330	156
Chicot	32,946	32,615	100	0	6,632	203	13,452	368	155	203	8,085	3,417
Clay	77,709	84,034	2,594	85	8,361	2,613	6,933	0	17,350	2,136	26,670	17,292
Craighead	78,110	83,923	12,444	149	10,594	2,554	15,251	0	8,257	320	31,599	2,755
Crittenden	36,818	41,839	356	0	5,302	80	6,045	0	1,111	0	28,458	487
Cross	105,919	106,254	6,794	185	16,646	2,894	4,516	1,440	9,611	1,283	56,389	6,486
Desha	42,992	45,784	48	0	9,495	1,668	13,742	230	1,225	234	17,868	970
Drew	15,906	17,030	422	0	9,209	0	3,188	0	1,000	423	2,290	498
Faulkner	3,190	2,844	0	0	307	0	374	0	1,568	0	596	0
Greene	61,662	69,044	5,649	0	7,293	7,911	8,674	829	15,170	3,473	19,253	792
Independence	8,634	10,896	92	0	0	0	0	0	0	0	10,804	0
Jackson	82,292	101,762	17,402	253	4,766	6,229	5,132	5	8,442	1,829	56,381	1,323
Jefferson	58,872	62,416	564	0	15,251	0	6,730	1,305	2,944	0	31,853	3,769
Lafayette	3,169	3,959	0	0	705	0	1,228	0	327	0	1,320	379
Lawrence	94,864	99,480	13,622	135	14,825	3,091	22,820	1,759	10,551	628	27,346	4,703
Lee	23,415	30,988	863	0	1,614	301	2,466	0	3,213	0	22,531	0
Lincoln	32,355	36,518	641	0	11,975	1,306	11,210	0	7,469	779	3,138	0
Lonoke	77,046	81,890	7,996	85	15,323	152	12,368	703	5,748	785	37,243	1,042
Miller	5,819	7,018	0	0	3,235	0	1,095	0	0	0	1,927	761
Mississippi	39,287	42,230	0	1	5,406	1,632	1,738	10,631	8,699	0	10,039	4,086
Monroe	51,398	54,869	2,647	0	3,003	117	17,761	0	7,558	345	21,190	2,248
Phillips	25,574	25,720	0	0	770	0	9,639	0	7,617	0	6,080	1,613
Poinsett	126,683	134,944	43,830	796	15,258	2,442	4,117	0	7,539	1,217	56,597	3,129
Prairie	57,031	68,122	10,009	9	7,564	120	14,493	0	7,015	2,494	21,336	5,082
Pulaski	4,792	6,505	1,671	0	3,352	0	154	0	0	0	1,328	0
Randolph	28,848	33,257	6,455	59	6,992	3,402	4,955	0	2,315	2,152	6,541	386
St. Francis	47,353	48,483	6,238	57	1,169	3	7,317	0	5,455	465	27,737	43
White	16,060	15,843	890	0	1,093	0	6,999	0	1,328	0	5,412	121
Woodruff	62,323	65,792	7,612	0	6,582	1,719	12,467	1,087	9,078	855	23,562	2,830

continued

Table 1. Continued.

County	Harvested acreage[z] 2003	Harvested acreage[z] 2004	Medium Bengal	Medium Others[y]	Long-grain CL 161	Long-grain CL XL8	Long-grain Cocodrie	Long-grain Cypress	Long-grain Francis	Long-grain XL 8	Long-grain Wells	Long-grain Others[y]
Others[x]	6,861	6,861	0	0	169	0	1,332	0	881	1,268	728	2,592
Unaccounted[w]	20,048	6,449	--	--	--	--	--	--	--	--	--	--
2004 Total		1,555,000	154,389	1,990	205,300	39,235	238,942	19,466	176,691	21,586	620,198	74,980
2004 Percent		100.00%	9.93%	0.13%	13.20%	2.52%	15.37%	1.25%	11.36%	1.39%	39.88%	4.82%
2003 Total	1,455,000		162,163	1,721	68,636	--	317,251	22,695	91,561	15,325	658,150	151,955
2003 Percent	100.00%		11.15%	0.12%	4.72%	--	21.80%	1.58%	6.29%	1.05%	45.23%	10.44%

[z] Source: Arkansas Agricultural Statistics and FSA.
[y] Other varieties: AB647, Adair, Alan, Banks, Bond, Cheniere, Clearfield 121, Clearfield 141, Delmatti, Dellrose, Drew, Earl, Gulfmont, Jackson, Jefferson, Koshikari, Lacassine, LaGrue, Lemont, Maybelle, Nortai, Pirogue, Rice Tec XL7, Rice Tec XP 710, Rice Tec 7015, Saber, Skybonnet, and Texmont.
[x] Other counties: Clark, Conway, Crawford, Hot Spring, Little River, Perry, Pope, and Yell.
[w] Unaccounted-for acres represent the total difference between USDA-NASS harvested acreage estimate and preliminary estimates obtained from each county FSA.

Table 2. Acreage, yield, and production of rice in the United States, 2002-2004.

State	Area planted 2002	Area planted 2003	Area planted 2004	Area harvested 2002	Area harvested 2003	Area harvested 2004	Yield 2002	Yield 2003	Yield 2004	Production 2002	Production 2003	Production 2004
	(1,000 acres)						(lb/acre)			(1,000 cwt)		
AR	1,516	1,466	1,561	1,503	1,455	1,555	6,440	6,610	6,910	96,752	96,188	107,440
CA	533	509	595	528	507	590	8,140	7,700	8,600	42,989	39,036	50,759
LA	540	455	538	535	450	533	5,500	5,870	5,350	29,400	26,397	28,522
MS	255	235	235	253	234	234	6,400	6,800	6,900	16,192	15,912	16,146
MO	190	176	196	182	171	195	6,050	6,130	6,800	11,011	10,484	13,261
TX	206	181	222	206	180	218	7,100	6,600	6,740	14,616	11,880	14,690
US	3,240	3,022	3,347	3,207	2,997	3,325	6,578	6,670	6,942	210,960	199,897	230,818

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

	2002		2003		2004	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,455,000	100.0	1,455,000	100.0	1,555,000	100.0
Soil texture						
Clay	-	-	345,245	23.7	332,278	21.4
Clay loam	-	-	247,559	17.0	222,728	14.3
Silt loam	-	-	737,101	50.7	860,836	55.4
Sandy loam	-	-	76,001	5.2	114,970	7.4
Sand	-	-	49,094	3.4	47,386	3.1
Tillage practices						
Conventional	964,316	64.0	904,050	62.1	944,474	60.7
Stale seedbed	399,605	26.5	402,731	27.7	488,394	31.4
No-till	142,079	9.4	148,219	10.2	150,819	9.7
Crop rotations						
Soybean	1,197,010	79.5	1,166,542	80.2	1,207,692	77.7
Rice	221,274	14.7	189,433	13.0	228,381	14.7
Cotton	23,753	1.6	20,228	1.4	23,891	1.5
Corn	27,564	1.8	29,082	2.0	44,619	2.9
Grain sorghum	4,373	0.3	15,584	1.1	17,130	1.1
Wheat	6,602	0.4	18,042	1.2	19,301	1.2
Fallow	25,424	1.7	15,902	1.1	13,246	0.9
Oats	-	-	185	<0.1	165	<0.1
Seeding methods						
Drill-seeded	1,138,424	80.1	1,054,868	72.5	1,175,367	75.6
Broadcast-seeded	173,466	11.5	327,681	22.5	308,156	19.8
Water-seeded	126,453	8.4	72,513	5.0	87,394	5.6
Irrigation water sources						
Groundwater	1,209,318	80.1	1,200,164	82.5	1,273,186	81.9
Stream, rivers, etc.	171,684	11.5	140,472	9.7	133,772	8.6
Reservoirs	124,998	8.4	114,364	7.9	147,867	9.5

continued

Table 3. Continued.

	2002		2003		2004	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Irrigation methods						
Flood, levees	1,242,461	82.5	1,089,036	74.9	1,122,068	72.2
Flood, multiple inlet	262,025	17.4	361,178	24.8	428,183	27.5
Furrow	874	<0.1	4,437	0.3	4,904	0.3
Sprinkler	640	<0.1	349	<0.1	537	<0.1
Precision-leveled soils						
Contour levees	900,292	59.8	840,966	57.8	945,637	60.8
Precision-leveled	605,708	40.2	614,034	42.2	609,363	39.2
Zero grade	48,709	3.2	45,733	3.1	75,629	4.9
Stubble management						
Burned	248,035	16.5	324,902	22.3	256,371	16.5
Tilled	352,146	23.4	406,872	28.0	402,246	25.9
Rolled	633,560	42.1	545,608	37.5	641,800	41.3
Winter-flooded	344,765	22.9	384,348	26.4	339,622	21.8
Precision ag technology						
Yield monitors	151,706	10.1	177,440	12.2	185,305	11.9
Grid soil sampling	79,936	5.3	65,935	4.5	94,190	6.1
Variable rate fertilization	29,491	2.0	60,065	4.1	94,147	6.1
Other use of P.A. technology	-	-	1,225	0.1	7,442	0.5

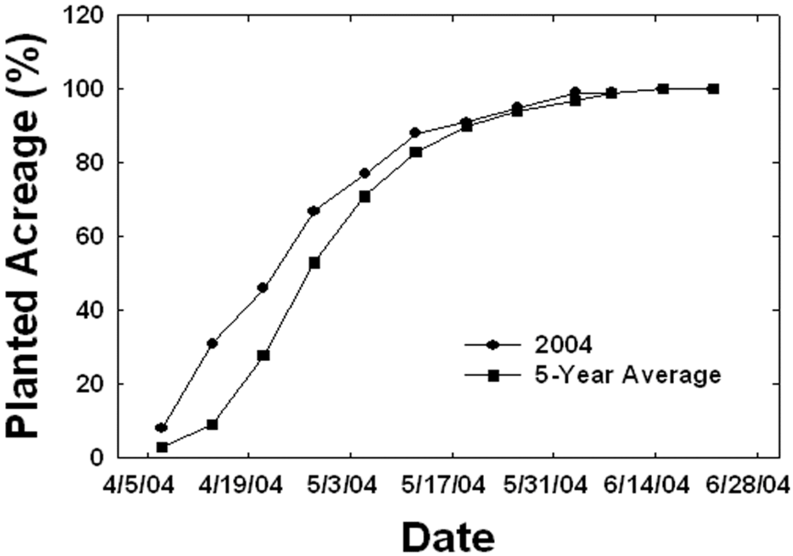

Fig. 1. Arkansas rice planting progress during 2004 compared to the five-year average. (Data obtained from NASS, 2004).

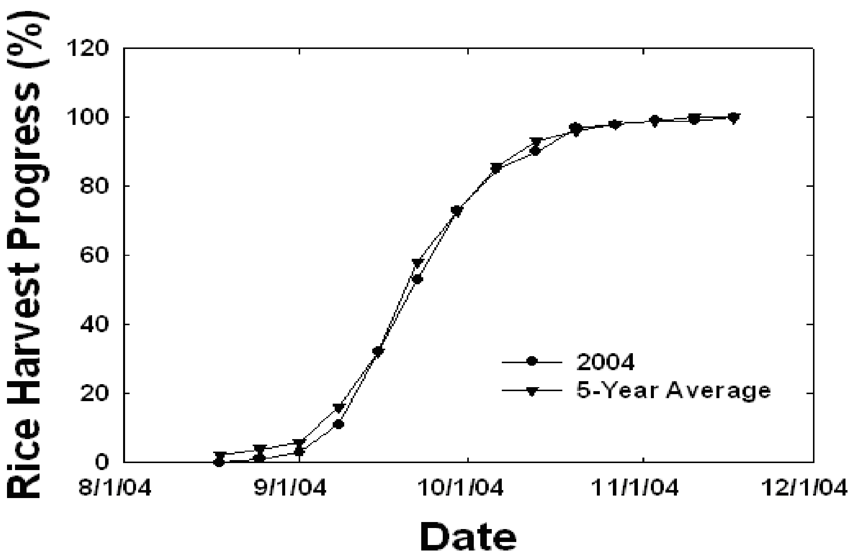

Fig. 2. Rice harvest progress during 2004 compared to the five-year average. (Data obtained from NASS, 2004).

Advancements in Marker-Assisted Selection Methods and Applications

V.A. Boyett, J.W. Gibbons, J. Jiang, and K.A.K. Moldenhauer

ABSTRACT

Molecular marker-assisted selection (MAS) is being used at the University of Arkansas Rice Research and Extension Center (UA RREC) in Stuttgart to accelerate the development of rice cultivars with improved cooking quality and disease resistance (the latter with emphasis on rice blast). Simple sequence repeat (SSR) markers are used to predict cooking quality of the milled grain and to screen populations for the blast resistance genes *Pi-b*, *Pi-k*, and *Pi-z*. A co-dominant gene fragment marker is used to analyze alleles of *Pi-ta*. Almost 7,000 individual genomic DNA samples were processed for MAS in 2004; the effort was greatly enhanced by the modification and incorporation of a high-throughput genomic DNA extraction method.

INTRODUCTION

MAS can be a useful tool to increase efficiency and accelerate the development process of improved germplasm by using molecular markers that are linked with important agronomic traits. Selection can be performed with seedling tissue, and can take place in the laboratory rather than the field, eliminating problematic environmental variables.

One of the most important aspects of cultivar development involves cooking quality. Amylose content influences cooking quality and rice cultivars can be grouped into market classes according to the size of the PCR product of the RM 190 marker, an SSR located within the 5' flanking region of the *Waxy* gene (Bergman et al., 2001). The *Waxy* gene is the structural gene for granule-bound starch synthase, thought to be the critical enzyme involved in the final polymerization stage of amylose biosynthesis in rice starch grains (Bligh et al., 1995; Sano et al., 1991). Most of the cultivars within a particular market class will have the amylose content and cooking characteristics predominant in that class, provided that the climatic conditions during developmental stage R6 are favorable for amylose synthesis (Counce et al., 2000; Resurreccion et al., 1977).

Blast resistance is another important breeding objective. Currently MAS is being used in screening selected populations to track introgression of resistance genes *Pi-b*, *Pi-k*, *Pi-z*, and *Pi-ta*. These are the major resistance genes to the predominant races of *Magnaporthe grisea* in the southern U.S. (Fjellstrom et al., 2000). *Pi-ta* was shown to confer resistance to two predominant *M. grisea* races, IC-17 and IB-49 (Jia et al., 2004). Putatively *Pi-ta* confers resistance to all the predominant races in the southern U.S. with the exception of IE-1k (Fjellstrom et al., 2000). Since both *Pi-b* and *Pi-z* confer resistance to IE-1k, it is desirable to pyramid *Pi-ta* and either of these other two major resistance genes to achieve broad-spectrum resistance in the improved germplasm.

Screening populations with the aforementioned DNA markers requires ample quantities of genomic DNA of acceptable purity for analysis. Performing DNA isolation and purification quickly, efficiently, and cheaply is of utmost importance in a successful MAS breeding program. The time involved for processing tissue is a major limiting step in the analysis, and the quality of the purified DNA determines the quality of the data downstream. Rapidly obtaining reliable PCR-quality DNA has been made possible by adapting a high-throughput DNA extraction method for use in rice (Xin et al., 2003). Population screening that previously encompassed several months can now be completed in a few weeks. The method yields enough DNA template suitable for fluorescent-tagged applications and allows for the analysis of 40 or more markers from a single isolation procedure, thus saving time and money. The procedure is performed in a 96-well format, takes about 12 minutes to complete, and works equally well with freshly harvested, frozen, or freeze-dried leaf tissue. It is now possible to go from fresh tissue to data in a day's time, which has eliminated DNA isolation as a time-consuming step in the MAS process.

The objective of this study is to develop, improve, and apply molecular marker technology to the projects of the breeding program at UA RREC, thus shortening the development time of new lines for commercial release. This has been made possible through the use of biotechnology equipment located in the Genomics Core Facility of the Dale Bumpers National Rice Research Center (DB NRRC) and the development of high-throughput DNA sampling and analysis techniques.

PROCEDURES

Seedling-leaf tissue was harvested into manila coin envelopes, 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; 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 for quantification on an FLx800 Microplate Fluorescence Reader (BIO-TEK Instruments, Winooski, Vt.). A 20 ng/µl DNA template of each sample was prepared and 2 µl of template were used for each PCR analysis. Alternatively, 2 µl of the 1:5 dilution were used as a template for PCR.

Adaptation of a high-throughput DNA extraction method for use with rice tissue greatly shortened the processing time and allowed data to be obtained more rapidly. 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. A sample consisted of one leaf disk per well in an inexpensive PCR plate. Buffer A (100mM sodium hydroxide, 2% Tween 20) was prepared immediately prior to use. Fifty µl of Buffer A were added to each well, and the plate was sealed with a re-usable silicone sealing mat and incubated at 95°C for 10 min in a PTC-200 DNA Engine thermalcycler (MJ Research, Waltham, Mass.). Immediately following incubation at 95°C, 50 µl of Buffer B were added (100mM Tris-HCl, 2 mM EDTA, prepared in advance) to each well, mixed, and then either stored at 4°C or immediately analyzed with PCR (Fig. 1).

PCR was performed by adding 2 µl template and final concentrations of 0.1% molecular grade bovine serum albumin and 1% polyvinylpyrrolidone 40 (Xin et al., 2003) and cycling the reactions in a PTC-225 DNA Engine Tetrad thermalcycler (MJ Research, Waltham, Mass.). Resulting PCR products were grouped according to allele sizes and dye colors and diluted together with a TECAN MiniPrep 75 liquid-handling robot (TECAN, Research Triangle Park, N.C.), separated on an ABI Prism 3700 DNA Analyzer (Applied Biosystems, Foster City, Calif.), and analyzed using GeneScan and Genotyper Software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

Molecular markers were used to analyze almost 7,000 individual DNA samples for the purposes of screening segregating populations, identifying those progeny possessing desirable alleles (Table 1), confirming hybrids, correlating with phenotypic assessments, tracing alleles through pedigree analysis, and genotyping parental lines.

Results are population specific. Marker data varied between crosses in a direct correlation with the different breeding parents. In a survey of 1,550 F_3 and TC_1 individuals representing 222 lines of 10 different crosses, on average 44% were homozygous-resistant at the *Pi-ta* locus, 42% were homozygous-susceptible, and 18% were heterozygous. RM 190 data collected on the same samples revealed that 67% were homozygous for long-grain amylose content, 14% were homozygous for medium-grain amylose content, and 19% were heterozygous. Overall, 44% of the individuals from this study were discarded in the early generation, thereby allowing for phenotypic selection of only those lines with desirable cooking quality and blast disease resistance (Table 1).

SIGNIFICANCE OF FINDINGS

Molecular marker data can be a useful tool for accelerating variety development and giving the breeders more confidence at each stage of the selection process. By revealing the pattern of recombination, identifying self-pollinated and off-types within a segregating population, and confirming phenotypic assessments, the breeders are able to discard undesirable material in early development stages, saving valuable time and resources.

ACKNOWLEDGMENTS

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Table 1. Survey of 222 lines of 10 different F_3 populations.

	Pi-ta			RM 190 (*Waxy*)			Discarded
Cross no.	Resistant	Susceptible	Heterozygous	Long-grain	Medium-grain	Heterozygous	overall
	(%)						
030379	79	18	3	31	40	29	40
030420	0	100	0	100	0	0	100
030434	23	76	0	70	0	3	76
030435	48	26	27	44	24	32	26
030483	45	10	45	100	0	0	10
030485	49	41	10	100	0	0	41
020231	38	60	39	34	39	26	60
020241	72	21	7	69	7	23	21
020242	34	36	30	44	28	28	36
020238	52	30	18	79	0	21	30
Average	44	42	18	67	14	19	44

Fig. 1. (A) Rice plants ready for tissue harvest. (B) Tools for tissue sampling. (C) 96-well plate loaded with tissue samples. (D) DNA extraction completed, ready for PCR.

Continued Evaluation of Blast Resistance Genes in Rice Wild Relatives (*Oryza* spp.) and Unique Rice (*O. sativa*) Accessions Utilizing DNA Markers

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

ABSTRACT

Blast, *Pyricularia grisea* Cav., is a major fungal disease of cultivated rice (*Oryza sativa* L.) that limits Arkansas rough rice yields and market potential. Resistance to Arkansas blast races was found in rice wild relatives (*Oryza* spp.). Resistance has also been found in 32 newly introduced *O. sativa* accessions which have been identified as potential sources of unique blast resistance (*Pi*-) genes that could be incorporated into U.S. rice varieties. Simple sequence repeat (SSR) markers can determine the genetic distance between the individual accessions, and associations of these SSR markers with blast resistance traits will aid in identifying new and novel *Pi*-genes. Objectives of this study were to 1) better define the resistance of *O. sativa* accessions to blast races found in Arkansas and potential new races that might arise in the future, 2) ascertain the relatedness between the *Oryza* spp. accessions using SSR markers, and 3) identify associations between blast resistance traits and SSR markers in the *Oryza* spp. and *O. sativa* accessions. Preliminary data indicate resistance to the new blast isolate IE-1k-Banks in 21 of the 35 *O. sativa* accessions screened. Associations between blast traits and SSR markers identified eleven markers not associated with known *Pi*-genes in the *O. sativa* accessions. Subsequently, analysis of associations between blast and SSR markers in the *Oryza* spp. accessions identified seven additional chromosomal regions that are potential locations of new *Pi*-genes. Genetic distance between the various accessions will assist in identifying accessions from a more diverse origin.

INTRODUCTION

Blast, *Pyricularia grisea* Cav., causes major rice (*Oryza sativa* L.) yield losses worldwide, including the U.S., and resistant varieties are a major method of controlling the rice blast disease (Lee, 1994). Rice wild relatives (*Oryza* spp.) are one possible source of novel, previously unknown blast resistance genes (*Pi*-genes) which could be incorporated into U.S. rice cultivars (Eizenga et al., 2002). Earlier, Eizenga et al. (2004) identified 32 blast resistant rice (*O. sativa*) accessions from the U.S. germplasm collection as potential sources of new *Pi*-genes because the accessions did not have the major *Pi*-genes, *Pi-b* and *Pi-ta*. In addition, the relatedness of these accessions was ascertained using SSR markers. Recently, software is available that will delineate associations between molecular markers and traits of agronomic importance (Liu, 2002).

During 2004, the newly released variety 'Banks' was severely damaged by rice blast. Isolates from Banks were identified as being either race IE-1k or closely related, thus these races are currently designated as IE-1k-Banks (Lee et al., 2005). The main objective of this research is to identify new and novel blast resistance genes in the aforementioned *Oryza* spp. and resistant *O. sativa* accessions by 1) better defining resistance of the *O. sativa* accessions to blast races commonly found in Arkansas and potential new races which might arise in the future, 2) ascertaining the relatedness of the *Oryza* spp. accessions using SSR markers, and 3) identifying associations between blast resistance traits and SSR markers to further characterize potential new and novel blast resistance genes.

PROCEDURES

Pathogenicity tests of *P. grisea* were done according to Eizenga et al. (2002). Genomic DNA was extracted from leaf tissue most recently according to Lu et al. (2005) or earlier using the CTAB method (Eizenga et al., 2004). Approximately 200 SSR markers (Lu et al., 2005) were visualized by fluorescent-labeled products and processed by an ABI Prism 3700 DNA Analyzer, and data were analyzed with GeneScan 3.6/Genotyper 2.6 software (Applied Biosystems, Foster City, Calif.). Data from 138 markers were used for the genetic distance and cluster analysis conducted using the *PowerMarker* program (Liu, 2002). Nei's genetic distance (Nei, 1973) was used to calculate pairwise genetic distance among all accessions. The neighbor joining method was used to conduct the cluster analysis. Associations between the SSR markers and blast resistance traits also were delineated using the *PowerMarker* program.

RESULTS AND DISCUSSION

Preliminary results from screening 35 of the previously identified blast resistant *O. sativa* accessions (Eizenga et al., 2004) indicated 21 accessions were resistant to the newly identified blast isolate, IE-1k-Banks (Lee, 2005), and 13 of the 21 were resistant to all races including laboratory race IB-33 (Table 1). Based on the previously reported genetic distance analysis (Eizenga et al., 2004) of the 21 accessions, twelve Chinese accessions from J. Tao were closely related and two, 460 and R-312, were not. The other resistant accessions (Table 1) were from a more diverse origin, providing further evidence that there are new and novel blast resistance genes in this germplasm.

Associations of blast resistance traits with 37 SSR markers were delineated by additional analysis of the blast resistance data and SSR marker data collected in previous studies (Eizenga et al., 2004; Table 1). Twenty-six of the 37 markers were located in chromosomal regions containing *Pi*-genes as summarized by Monosi et al. (2004). The remaining eleven markers will provide the basis for discovering new *Pi*-genes. Subsequent analysis of associations between these SSR markers and reaction to blast isolates IE-1k-Banks and IB-33 (Table 1) identified some SSR markers with a high probability of being associated with resistance to blast isolate IE-1k-Banks, and different SSR markers associated with IB-33. It should also be noted that two of the accessions, Wab450-1-B-P-62-hb and Wab450-24-3-2-P18-hb, which have resistance to all isolates, were derived from crosses with *O. glaberrima*. This indicates the importance of the *Oryza* spp. germplasm as a source for new and novel resistance genes.

Using SSR markers, the genetic distance between 48 *Oryza* spp. accessions representing *O. alta*, *O. australiensis*, *O. barthii*, *O. glumaepatula*, *O. latifolia*, *O. meridionalis*, *O. nivara*, *O. officinalis*, and *O. rufipogon* was determined (Fig. 1). The close relationship between many accessions of *O. barthii*, *O. nivara*, and *O. rufipogon* was readily apparent. One *O. nivara* accession clustered closely with the U.S. rice cultivars 'Bengal', 'Drew', 'Katy', 'Lagrue', and 'Saber' that were included for comparison. Clustering was more distant from the U.S. cultivars with accessions of *O. alta*, *O. australiensis*, *O. barthii*, *O. glumaepatula*, *O. latifolia*, *O. meridionalis*, and *O. officinalis* which are not progenitor species to the cultivated rice, *O. sativa*, grown worldwide (Jena and Khush, 2000).

Associations between the aforementioned SSR markers and the resistance/susceptibility of the *Oryza* spp. accessions to eight blast races (Eizenga et al., 2002 and unpublished) identified 34 markers associated with at least two blast races. Of these 34 markers, 18 were identified as also associated with blast traits in *O. sativa* accessions. The remaining seven markers were associated with chromosomal regions that had not previously been associated with *Pi*-genes (Monosi et al., 2004) and these regions will be investigated further to identify novel *Pi*-genes.

In conclusion, preliminary data suggest 13 of the *O. sativa* accessions are potential sources of new and novel *Pi*-genes with resistance to the new blast isolate, IE-1k-Banks and lab isolate IB-33. These *O. sativa* accessions were selected from the 32 accessions previously identified as potential sources of new and novel *Pi*-genes. Eleven SSR markers, not previously associated with blast resistance traits, have been identified in the blast resistant *O. sativa* accessions and an additional seven chromosomal regions were implicated as sources of blast resistance genes in the *Oryza* spp. accessions. This is evidence that both the *O. sativa* and *Oryza* spp. accessions will be excellent sources of new and novel blast resistance genes for U.S. rice breeding programs.

SIGNIFICANCE OF FINDINGS

These results represent a continued research effort to combine field, greenhouse, and molecular research data to identify novel blast resistance genes in the *Oryza* spp. and resistant rice (*O. sativa*) accessions that are not found in U.S. cultivated rice varieties. Thirty-two *O. sativa* accessions were identified that did not have either of the currently deployed resistance genes, *Pi-ta* found in 'Ahrent', Banks, Drew, and 'Kaybonnet' nor *Pi-b* found in 'Boliver' and Saber. Based on preliminary data, 13 of the 32 *O. sativa* accessions were resistant to the new blast isolate IE-1k-Banks, found in 2004, and laboratory isolate IB-33. These 13 *O. sativa* accessions are currently available to Arkansas and U.S. rice breeding programs, and will be invaluable in efforts to develop new cultivars with multiple major blast resistance genes. Also, seven chromosome regions were identified as possible locations of new and novel blast resistance genes in the *Oryza* spp. These regions differed from those found in the *O. sativa* accessions. Unique blast resistance genes obtained from the *Oryza* spp. are being incorporated into rice germplasm useful to rice breeding programs.

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Table 1: Preliminary data on the resistance of 35 *O. sativa* accessions to the new blast race IE-1k-Banks, laboratory race IB-33, and seven other blast races common in Arkansas. The 32 accessions identified earlier as possible sources of new *Pi*-genes are included (Eizenga et al., 2004).

			International blast races (Isolates)[y]								
No.	Entry name	Country of origin[z]	IB-1 (ZN-15)	IB-49 (ZN-52)	IC-17 (ZN-1)	IE-1 (ZN-6)	IG-1 (ZN-39)	IH-1 (74L2)	IE-1k (ZN-19)	IE-1k-Banks	IB-33
1	02428	China (CD)	R	R	R	R	R	R	R	S	S
2	Chunzhi No. 11	China (CD)	R	R	R	R	R	R	R	S	MS
3	Kechengnuo No4[x]	China (CD)	R	R	R	–[w]	R	R	R	R	R
4	Shufeng 117[x]	China (CD)	R	R	R	R	R	R	R	R	R
5	Shufeng 122	China (CD)	R	R	R	R	R	R	R	R	S
6	Tie 90-1	China (CD)	R	R	R	R	R	R	R	S	S
7	Tiejing No. 4	China (CD)	R	R	R	R	R	R	R	S	S
8	Xiangzaoxian No. 1	China (HN)	R	R	R	R	R	R	R	S	S
9	Aijiaonante	China (HZ)	MS	S	S	R	MS	S	R	S	S
10	Zanuo No. 1	China (HZ)	MR	S	S	—	R	--	R	S	S
11	Zhongyu No. 1	China (HZ)	R	R	R	R	R	R	R	S	S
12	Zhongzao No. 1	China (HZ)	R	S	R	R	R	MR	R	S	S
13	460	China (JT)	R	S	S	R	S	R	MR	R	S
14	4593	China (JT)	R	R	R	R	R	R	R	R	MS
15	4594	China (JT)	R	R	R	R	R	R	R	R	MS
16	4596	China (JT)	R	R	R	R	R	R	R	R	S
17	4597	China (JT)	R	R	R	R	R	R	R	MS	S
18	4607[x]	China (JT)	R	R	R	R	R	R	R	R	R
19	4611[x]	China (JT)	R	R	R	R	R	R	R	R	R
20	4612[x]	China (JT)	R	R	R	R	R	R	R	R	R
21	4632[x]	China (JT)	R	R	R	R	R	R	R	R	R
22	4633	China (JT)	R	R	R	R	R	R	R	R	MS
23	4642[x]	China (JT)	R	R	R	R	R	R	R	R	R
24	4641(1)[x]	China (JT)	R	R	R	R	R	R	R	R	R
25	R 147	China (JT)	R	R	S	R	R	R	R	S	S
26	R 312	China (JT)	R	R	R	R	R	R	R	R	S
27	ChiLAI #1	China	R	R	R	R	R	R	R	MS	MS

continued

Table 1. Continued.

No.	Entry name	Country of origin[z]	International blast races (Isolates)[y]								
			IB-1 (ZN-15)	IB-49 (ZN-52)	IC-17 (ZN-1)	IE-1 (ZN-6)	IG-1 (ZN-39)	IH-1 (74L2)	IE-1k (ZN-19)	IE-1k-Banks	IB-33
28	ChiLAI #2	China	R	--	R	R	R	R	R	R	S
29	Fkr 19 (Tox 728-8)	Ivory Coast	R	R	R	R	R	R	R	S	MS
30	Guang 6ai-4[x]	Ivory Coast	R	R	R	R	R	R	R	R	R
31	Tox3749-71-1-1-3-2-2[x]	Ivory Coast	R	R	R	R	R	R	R	R	R
32	Wab450-24-3-2-P18-hb[x,v]	Ivory Coast	R	R	R	R	R	R	R	R	R
33	Wab450-I-B-P-62-hb[x,v]	Ivory Coast	R	R	R	R	R	R	R	R	R
34	Pyongyang 23	North Korea	R	R	R	R	R	S	R	MS	MS
35	Nj70507 17578[x]	Philippines	R	R	R	R	R	R	R	R	R

[z] Source of Chinese germplasm: CD-Chengdu, HN-Hunan, HZ-Hongzhou, JT-J. Tao.
[y] Original ratings used the rating scale 0=no lesions to 9=dead.
[x] Accessions identified as potential source of resistance to all blast races.
[w] Indicates missing data.
[v] Accessions derived from crosses with *O. glaberrima*.

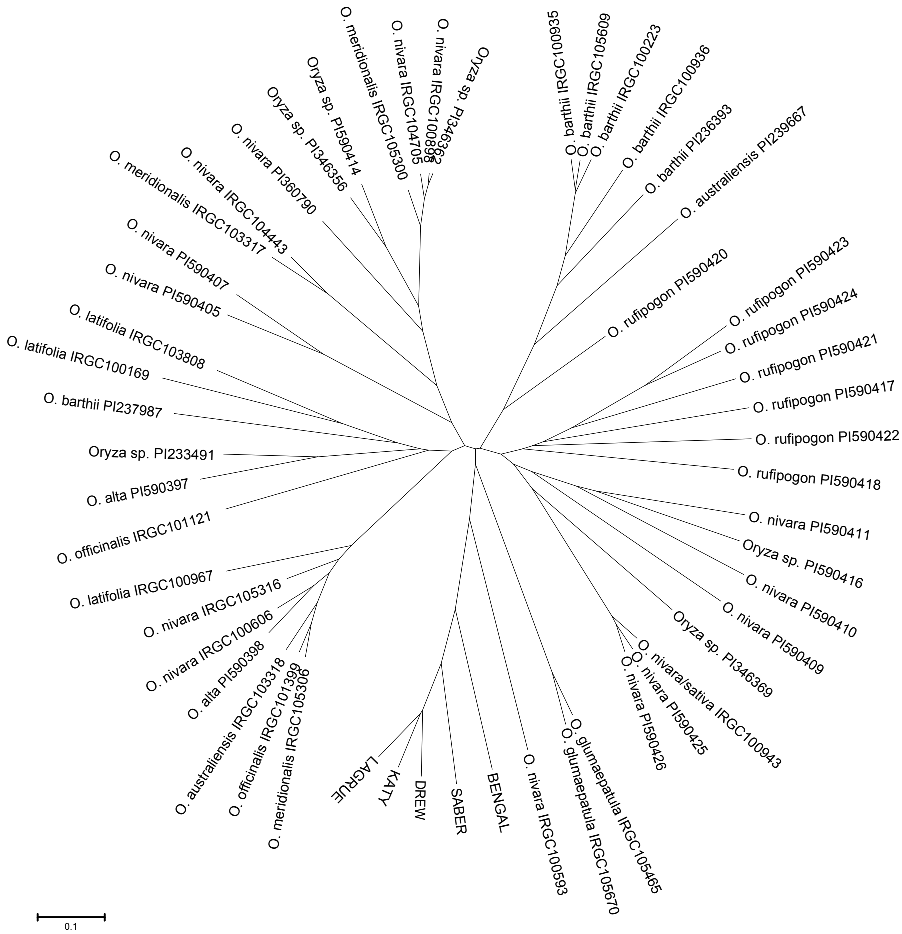

Fig. 1. The clustering of 48 *Oryza* species accessions and five U.S. cultivars (Bengal, Drew, Katy, Lagrue and Saber) was determined using 138 SSR markers. The separation was made using Nei (1973) and the neighbor joining method determined the clusters.

‘Cybonnet’, a Semi-Dwarf Long-Grain Rice Cultivar

J.W. Gibbons, K.A.K. Moldenhauer, K. Gravois, F.N. Lee, J.L. Bernhardt, J.-F. Meullenet, R. Bryant, R.J. Norman, R. Cartwright, M. Anders, K. Taylor, J. Bulloch, and M.M. Blocker

ABSTRACT

‘Cybonnet’ is a semi-dwarf long-grain rice cultivar originating from the cross ‘Cypress’//‘Newbonnet’/‘Katy’ made at the Rice Research and Extension Center in 1993. It has been tested in the Arkansas Rice Performance Trials and the Uniform Rice Regional Nursery for four years. It has grain yield, height, and lodging resistance similar to ‘Cocodrie’, grain quality similar to Cypress, and blast resistance similar to Katy. It is moderately susceptible to straighthead disorder. The major advantages of Cybonnet are its good grain yield, resistance to lodging, good blast disease resistance, and excellent milling quality. The major disadvantage of Cybonnet is susceptibility to sheath blight.

INTRODUCTION

Cybonnet was developed by the University of Arkansas Rice Breeding Project based at Stuttgart, Ark. It was released to qualified seed growers for the 2004 growing season. Cybonnet is the first semi-dwarf long-grain cultivar released by the station. It has high yields, high and stable milling yield, and blast resistance similar to ‘Drew’ and ‘Kaybonnet’. Cybonnet was developed with the use of rice grower check-off funds distributed by the Arkansas Rice research and Promotion Board.

PROCEDURES

Cybonnet originated from the cross Cypress//Newbonnet/Katy (cross no.930288), made at the Rice Research and Extension Center, Stuttgart, Ark., in 1993. Cypress (Linscombe et al.,1993) released from Louisiana in 1993, is a semi-dwarf long-grain rice cultivar with excellent grain quality. Newbonnet (Johnston et al., 1984) is a high yielding, blast susceptible long-grain cultivar released from Arkansas in 1984. Katy (Moldenhauer et al.,1989) is a blast resistant long-grain released from Arkansas in 1989. The experimental designation for early evaluation of Cybonnet was STG96F5-28-069, starting with a bulk of F_6 seed from the 1996 panicle row F5-28-069. Cybonnet was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2000-2003 as entry RU0001124 (RU number indicated Cooperative Uniform Regional Rice Nursery; 00 indicates year entered; 01 indicates Stuttgart, Ark.; and 124 its initial entry number).

The ARPT is planted every year at 6 or 7 locations in Arkansas and Missouri (Table 1). Plots are drill seeded and trimmed to approximately 60 sq ft with 3 replications per entry. Cultural practices depend upon location, but are based on recommended practices (CES, 2001). Data are collected on days to 50% heading, plant height, lodging, disease reaction, grain discoloration, grain yield, and grain and milling quality. The URRN is planted at Stuttgart Ark., and cooperators sites in 5 states (Table 2).

RESULTS AND DISCUSSION

Cybonnet is similar in maturity to Kaybonnet and ‘Wells’. It is a semi-dwarf cultivar like ‘Lemont’, Cypress, and Cocodrie and has good lodging resistance and nitrogen fertilizer response. Cybonnet averages 38 in. in plant height compared to 39 and 38 in. for Cocodrie and Cypress, respectively (Table 1).

Averaged over 26 Arkansas Rice Performance Trials (ARPT), rough rice grain yields of Cybonnet, ‘Ahrent’, Wells, ‘Francis’, Kaybonnet, Drew, Cocodrie, and Cypress were 168, 167, 189,192, 160, 170, 171, and 158 bu/acre (at 12% moisture), respectively. Data from the URRN conducted at Arkansas, Louisiana, Mississippi, and Texas during 2000 to 2004 showed Cybonnet average grain yield of 184 bu/acre compared with those of Ahrent, Wells, Francis, ‘Saber’, Drew, Cocodrie, and Cypress at 165, 195, 201, 166, 172, 186, and 168 bu/acre, respectively. Milling yields (percent whole kernel:percent total milled rice) at 12% moisture from the ARPT, 2000 averaged 68:72, 64:70, 64:73, 65:72, 66:72, 66:72, 67:72, and 68:72 for Cybonnet, Ahrent, Wells, Francis, Kaybonnet, Drew, Cocodrie, and Cypress, respectively. Milling yields for the URRN during 2000 to 2004, averaged 64:71, 58:68, 58:70, 60:70, 62:69, 60:70, 62:70, and 63:70 for Cybonnet, Francis, Ahrent, Wells, Saber, Drew, Cocodrie, and Cypress, respectively.

Cybonnet varies in greenhouse reaction to common rice blast [*Pyricularia grisea* (Cooke) Sacc.] races IB-1, IB-33, IB-49, IB-54, IC-17, IE-1K, IG-1 and IH-1 with summary ratings of 2.3, 6.5, 5.3, 0.0, 4.3, 8.0, 1.0, and 0.0, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R). Respective ratings for the resistant cultivar Drew are the following: 2.0, 7.3, 3.3, 0.0, 4.8, 8.0, 0.3, and 0.5. Cybonnet is rated resistant to blast in field tests conducted throughout Arkansas. Like Cypress, Cybonnet is rated VS to sheath blight (*Rhizoctonia solani* Kühn) which compares with Ahrent (MS), Wells (MS), Saber (MS), Cocodrie (S), and Drew (MS). Cybonnet is rated S for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] which compares to Ahrent (MS), Wells(MS), Saber (S), Cocodrie (VS), Cypress (S) and Drew (MS). Cybonnet is rated MS to straighthead (a physiological disorder) compared to VS for Cocodrie. Cybonnet is rated S to stem rot, R to brown spot [*Cochliobolus miyabeanus* (Ito & Kuribayashi in Ito) Drechs. ex Dastur], and S to false smut [*Ustilaginoidea virens* (Cooke) Takah]. Cybonnet, like Francis, is S for discolored kernels caused by the rice stink bug (*Oebalus pugnax*).

Plants of Cybonnet have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with brown-colored apiculi, awns are absent. Kernels are similar in size to those of Wells. Individual milled kernel weights of Cybonnet, Francis, Ahrent, Wells, Saber, Drew, Cypress, and Cocodrie, averaged 19.1, 17.4, 17.5, 20.1,15.6,16.9,18.6, and 19.2 mg, respectively, in the ARPT, 2003.

The endosperm of Cybonnet is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice quality parameters indicate that Cybonnet has typical southern U.S. long-grain rice cooking quality characteristics. Cybonnet has an average apparent starch amylose content of 21.7 % and an intermediate gelatinization temperature (70- 75°C), as indicated by an average alkali (17 g/kg KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

Cybonnet is the first semi-dwarf long-grain rice cultivar released in Arkansas. It has good yield potential and excellent and stable milling quality. Cybonnet has a good level of tolerance to the common blast isolates found in Arkansas with the exception of IE-1K races isolated in 2004, but is susceptible to sheath blight. Compared to Cocodrie, Cybonnet has the advantage of lower susceptibility to straighthead disorder.

ACKNOWLEDGMENTS

The release of this cultivar could not have been done without the assistance of many staff members either still working in the breeding project or who have left. Thanks also to the farm crew at RREC who helped with early multiplication and large-scale testing of Cybonnet. Thanks to rice researchers in cooperating states for conducting the URRN. The support of the Rice Research and Promotion Board and the farmers of Arkansas is highly appreciated.

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Table 1. Five-year average yield and four-year agronomic data from Arkansas Rice Performance Trials for Cybonnet and other cultivars.

	Grain yield						4-year average[y]			
Variety	2000	2001	2002	2003	2004	Avg.[z]	Height	Maturity	Kernel wt.	Milling HR:TOT[x]
	---------- (bu/acre) ----------						(in.)	(50% HD)	(mg)	
Cybonnet	159	158	178	183	163	168	38	88	17.2	68:72
Ahrent	155	176	180	163	160	167	42	86	16.4	64:70
Wells	181	190	197	201	174	189	42	88	19.0	64:73
Francis	188	190	203	201	177	192	40	87	16.6	65:72
Kaybonnet	149	168	164	164	157	160	44	89	14.9	66:72
Drew	144	166	186	186	167	170	46	91	16.1	66:72
Cocodrie	159	178	184	166	170	171	39	87	18.1	67:72
Cypress	142	160	169	169	150	158	38	90	17.6	68:72
C.V. (0.05)	18.4	15.6	17.6	14.8	19.4	17.2				

[z] 2000 ARPT harvested at Rice Research and Extension Center(RREC), Stuttgart; Pine Tree Branch Experiment Station (PTES), Colt; Jackson Co. Farmers Field (JCFF), Newport; Southeast Branch Experiment Station (SEBES), Rohwer; and Missouri Rice Research Farm (MO), Campbell, Mo. 2001 consisted of RREC, PTES, SEBES, Phipps Farm Cross County (PFCC), and Northeast Research and Extension Center (NEREC), Keiser. 2002 was harvested at RREC, PTES, SEBES, JCFF, and Clay County Farmers Field (CCFF), Corning. 2003 consisted of RREC, PTES, SEBES, JCFF, PFCC, MO, and NEREC. 2004 included RREC, PTES, SEBES, JCFF, PFCC, and NEREC.

[y] Four year average 2000 to 2003 over all locations.

[x] HR = Head rice % yield, TOT = Total rice % yield.

Table 2. Average grain yields for Cybonnet and check cultivars in 2000 to 2004 Uniform Rice Regional Nursery (URRN) from Arkansas (AR), Louisiana (LA), Mississippi (MS), and Texas (TX).

	Grain yield					Head rice (%):total rice (%)				
Variety	AR	LA	MS	TX	Avg.	AR	LA	MS	TX[z]	Avg.
	(bu/acre)									
Cybonnet	196	169	171	200	184	65:71	68:72	60:69	62:71	64:71
Ahrent[y]	140	163	164	192	165	61:70	66:70	48:62	59:69	58:68
Wells	200	175	188	216	195	64:72	62:70	50:69	56:71	58:70
Francis	194	182	207	222	201	65:72	64:70	53:66	56:71	60:70
Saber	161	143	166	192	166	62:70	68:70	57:67	62:69	62:69
Drew	167	172	168	181	172	66:72	61:69	55:68	60:70	60:70
Cocodrie	186	174	180	206	186	66:72	64:70	57:67	60:72	62:70
Cypress	161	170	164	176	168	68:72	64:72	58:66	63:71	63:70

[z] TX milling data for 2000, 2002 to 2004.
[y] 2000 to 2003.

'Medark', a Semi-Dwarf Medium-Grain Rice Cultivar

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ABSTRACT

'Medark' is a semi-dwarf medium-grain rice cultivar originating from the cross 'Bengal'/'Short Rico' made at the Rice Research and Extension Center in 1993. It has been tested in the Arkansas Rice Performance Trials and the Uniform Rice Regional Nursery for four years. It has grain yield, plant height, grain quality and lodging resistance similar to Bengal. The major advantages of Medark are its improved resistance to blast, brown spot and straighthead. The major disadvantage of Medark is susceptibility to panicle blight.

INTRODUCTION

Medark was developed by the University of Arkansas Rice Breeding Project based at Stuttgart, Ark. It was released to qualified seed growers for the 2004 growing season. Medark is the first semi-dwarf medium-grain cultivar released by the station. It has high yields, high and stable milling yield and improved blast-, straighthead- (a physiological disorder), and brown spot-resistance compared to Bengal. Medark was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

Medark rice (*Oryza sativa* L.) is a high-yielding, very short-season, semi-dwarf medium-grain cultivar developed by the Arkansas Agricultural Experiment Station. Medark originated from the cross Bengal//Short Rico (cross no.930254), made at the Rice Research and Extension Center, Stuttgart, Ark., in 1993. Bengal, released from Louisiana in 1993 (Linscombe,1993), is an early maturing, high-yielding semi-dwarf medium-grain rice cultivar. Short Rico, also a medium-grain rice, was designation RU9103069 in the 1991 Uniform Regional Rice Nursery. The experimental designation for early evaluation of Medark was STG97F5-05-084, starting with a bulk of F_6 seed from the 1997 panicle row F5-05-084. Medark was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2000 to 2003 as entry RU0001151 (RU number indicates Cooperative Uniform Regional Rice Nursery; 00 indicates year entered; 01 indicates Stuttgart, Ark.; and 151 indicates its initial entry number).

The ARPT is planted every year at 6 or 7 locations in Arkansas and Missouri (Table 1). Plots are drill seeded and trimmed to approximately 60 sq ft with 3 replications per entry. Cultural practices depend upon location, but are based on recommended practices (CES, 2001). Data are collected on days to 50% heading, plant height, lodging, disease reaction, grain discoloration, grain yield, and grain and milling quality. The URRN is planted at Stuttgart, Ark., and cooperators sites in 5 states (Table 2).

RESULTS AND DISCUSSION

Medark is similar in maturity to Bengal. It is a semi-dwarf cultivar like Bengal but has slightly less lodging resistance than Bengal. In Arkansas trials, Medark and Bengal measured 38 in. in plant height.

Rough rice grain yields of Medark, Bengal, ‘Wells’, ‘Francis’, ‘Kaybonnet’, ‘Drew’, ‘Cocodrie’, and ‘Cypress’, averaged over 26 ARPT, were 174, 177, 189, 192, 160,170, 171, and 158 bu/acre (at 12% moisture), respectively. Data from the URRN conducted at Arkansas, Louisiana, Mississippi, and Texas during 2000 to 2004 showed Medark had an average grain yield of 176 bu/acre compared with those of Bengal, Wells, Francis, ‘Saber’, Drew, Cocodrie, and Cypress at 186, 195, 201, 166, 172, 186, and 168 bu/acre, respectively. Milling yields (percent whole kernel:percent total milled rice) at 12% moisture from the ARPT, 2000 to 2003, averaged 66:71, 68:72, 64:73, 65:72, 66:72, 66:72, 67:72, and 68:72 for Medark, Bengal, Wells, Francis, Kaybonnet, Drew, Cocodrie, and Cypress, respectively. Milling yields for the URRN during 2000 to 2004, averaged 62:71, 61:69, 58:70, 60:70, 62:69, 60:70, 62:70, and 63:70 for Medark, Bengal, Ahrent, Wells, Saber, Drew, Cocodrie, and Cypress, respectively.

Medark varies in greenhouse reaction to common rice blast [*Pyricularia grisea* (Cooke) Sacc.] races IB-1, IB-33, IB-49, IB-54, IC-17, IE-1K, IG-1, and IH-1 with summary ratings of 6.0, 6.5, 8.0, 0.0, 4.0, 4.0, 4.8, and 3.0, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant

(MR), or resistant (R). Respective ratings for Bengal are the following: 6.0, 6.5, 8.0, 0.0, 4.5, 4.5, 4.0, and 1.3, indicating that greenhouse reactions are similar for these two cultivars. Field blast ratings, however, for Medark and Bengal are MS versus S, respectively. Like Bengal, Medark is rated MS to sheath blight (*Rhizoctonia solani* Kühn), MS for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.], and MS to false smut [*Ustilaginoidea virens* (Cooke) Takah]. Medark is rated S to sheath rot, R to brown spot [*Cochliobolus miyabeanus* (Ito & Kuribayashi in Ito) Drechs. ex Dastur], and S to the physiological disorder straighthead compared to VS, VS, and VS reactions of Bengal to these respective diseases. Medark, like Bengal, is VS to panicle blight and S to discolored kernels caused by the rice stink bug (*Oebalus pugnax*).

Plants of Medark have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are brown-colored at maturity with straw colored apiculi, awns are absent. Kernels are large and similar in size to those of Bengal. Individual milled kernel weights of Medark and Bengal averaged 20.2 and 20.4 mg, respectively, in the ARPT, 2000 to 2003.

The endosperm of Medark is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice-quality parameters indicate that Medark has typical southern U.S. medium-grain rice cooking-quality characteristics. Medark has an average apparent starch amylose content of 142 g/kg and a low gelatinization temperature (70 - 75°C), as indicated by an average alkali (17 g/kg KOH) spreading reaction of 6.

SIGNIFICANCE OF FINDINGS

Medark is the first semi-dwarf medium-grain rice cultivar released in Arkansas. It has good yield potential and grain quality. Medark has improved tolerance to the common blast isolates found in Arkansas, but like Bengal is susceptible to panicle blight. Compared to Bengal, Medark has the additional advantage of lower susceptibility to brown spot and straighthead disorder.

ACKNOWLEDGMENTS

The release of this cultivar could not have been done without the assistance of many staff members either still working in the breeding project or who have left. Thanks also to the farm crew at RREC who helped with early multiplication and large-scale testing of Medark. Thanks to rice researchers in cooperating states for conducting the URRN. The support of the Rice Research and Promotion Board and the farmers of Arkansas is highly appreciated.

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Table 1. Five-year average yield and four-year agronomic data from Arkansas Rice Performance Trials for Medark and other cultivars.

	Grain yield						4-year average[y]			
Variety	2000	2001	2002	2003	2004	Ave.[z]	Height	Maturity	Kernel wt.	Milling HR:TOT[x]
	(bu/acre)						(in.)	(50% HD)	(mg)	
Medark	170	188	171	170	171	174	38	88	20.2	66:71
Bengal	175	185	195	173	157	177	38	89	20.4	68:72
Wells	181	190	197	201	174	189	42	88	19.0	64:73
Francis	188	190	203	201	177	192	40	87	16.6	65:72
Kaybonnet	149	168	164	164	157	160	44	89	14.9	66:72
Drew	144	166	186	186	167	170	46	91	16.1	66:72
Cocodrie	159	178	184	166	170	171	39	87	18.1	67:72
Cypress	142	160	169	169	150	158	38	90	17.6	68:72
C.V. (0.05)	18.4	15.6	17.6	14.8	19.4	17.2				

[z] 2000 ARPT harvested at Rice Research and Extension Center(RREC), Stuttgart; Pine Tree Branch Experiment Station (PTES), Colt; Jackson Co. Farmers Field (JCFF), Newport; Southeast Branch Experiment Station(SEBES), Rohwer; and Missouri Rice Research Farm (MO), Campbell, MO. 2001 consisted of RREC, PTES, SEBES, Phipps Farm Cross County (PFCC), and Northeast Research and Extension Center (NEREC), Keiser. 2002 was harvested at RREC, PTES, SEBES, JCFF, and Clay County Farmers Field (CCFF), Corning. 2003 consisted of RREC, PTES, SEBES, JCFF, CCFF, MO, and NEREC. 2004 included RREC, PTES, SEBES, JCFF, CCFF, and NEREC.

[y] Four year average 2000 to 2003 over all locations.

[x] HR = head rice % yield, TOT = total rice % yield.

Table 2. Average grain yields for Medark and check cultivars in 2000 to 2004 Uniform Rice Regional Nursery (URRN) from Arkansas (AR), Louisiana (LA), Mississippi (MS), and Texas (TX).

	Grain yield					Head rice (%):total rice (%)				
Variety	AR	LA	MS	TX	Ave.	AR	LA	MS	TX[z]	Ave.
	(bu/acre)									
Medark	161	155	187	202	176	64:71	68:72	57:69	61:71	62:71
Bengal	174	167	195	208	186	68:71	66:70	53:65	58:71	61:69
Wells	200	175	188	216	195	64:72	62:70	50:69	56:71	58:70
Francis	194	182	207	222	201	65:72	64:70	53:66	56:71	60:70
Saber	161	143	166	192	166	62:70	68:70	57:67	62:69	62:69
Drew	167	172	168	181	172	66:72	61:69	55:68	60:70	60:70
Cocodrie	186	174	180	206	186	66:72	64:70	57:67	60:72	62:70
Cypress	161	170	164	176	168	68:72	64:72	58:66	63:71	63:70

[z] TX milling data for 2000, 2002 to 2004.

‘Spring’, a Very Early Long-Grain Rice Variety

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ABSTRACT

‘Spring’, a new very early, long-grain rice cultivar with good seedling vigor and cold tolerance was derived from the cross RU9101001//’Tebonnet’/’Katy’/3/’LaGrue’. Spring has been approved for release to qualified seed growers for the summer of 2005. The major advantage of the cultivar, released as Spring, is its earliness and cold tolerance which will allow for early planting and water savings over other cultivars. Spring has good milling yields and high yield potential when harvested in a timely manner. Spring, like LaGrue, is slightly better than other early cultivars for stink bug, moderately susceptible to kernel smut and sheath blight, and susceptible to straighthead.

INTRODUCTION

Spring was developed in the rice improvement program at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark., and has been released to qualified seed growers for the 2005 growing season. Spring is about ten days earlier than other RREC cultivars and has good seedling vigor and cold tolerance along with a good yield potential. Spring was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

Spring originated from the cross, RU9101001//Tebonnet/Katy/3/LaGrue (cross no. 19941023) made at the Rice Research and Extension Center, Stuttgart, Ark., in 1994. RU9101001 is an extremely early line from the cross ‘Bonnet73’/CI9837//PI265116/

4/'Vegold'/'Dawn'//'Starbonnet'/'Taducan'/3/L-201. This cultivar also has some cold tolerance which probably comes from the Hungarian parent PI265116. Tebonnet is an early high-yielding cultivar (Kuenzel et al., 1985) and Katy is a blast-resistant cultivar (Moldenhauer et al., 1990), respectively. LaGrue is a high-yielding long-grain rice described by Moldenhauer et al. (1994). The experimental designation for early evaluation of RU0101093 was STG97L10-118, starting with a bulk of F_6 seed from the 1997 panicle row L10-118. RU0101093 was tested in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) during 2001 to 2004 as entry RU0101093 (RU number indicated Cooperative Uniform Regional Rice Nursery; 01 indicates year entered was 2001; 01 indicates Stuttgart, Ark.; and 093 its entry number).

In 2001, the ARPT was conducted at five locations in Arkansas: RREC; Pine Tree Branch Experiment Station, (PTES), Colt, Ark.; Northeast Research and Extension Center, (NEREC), Keiser Ark.; Southeast Branch Experiment Station (SEBES), Rowher, Ark.; and a Cross County producer field (PFCC). In 2002, the ARPT was grown at the RREC, PTES, SEBES, PFCC, and a Jackson Co. Farmer Field, Newport, Ark. (JCFF). In 2003, the ARPT was grown at the RREC, PTES, NEREC, JCFF, Rice Research Farm in Campbell, Mo. (MORR), and a Clay Co. Farmer Field, Corning, Ark. (CCFF), and in 2004 at the RREC, PTES, NEREC, JCFF, MORR and CCFF. Each year the tests had three replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. Spring was also grown in URRN at RREC; Stoneville, Miss; Beaumont, Texas; and Crowley, La., from 2002 to 2004. Data collected from these tests included plant height, maturity, lodging, kernel weight, percent head rice, percent total rice and grain yield adjusted to 12% moisture, and disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas Cooperative Extension Service Rice Production Handbook MP192 (CES, 2001). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R). Straw strength is a relative estimate based on observations of lodging in field tests using the scale from 0 = very strong straw to 9 = very weak straw, totally lodged.

RESULTS AND DISCUSSION

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 Spring, in the ARPT, have consistently ranked higher than those of 'Maybelle' which is the only other cultivar with similar maturity. In 21 ARPT tests (2001 to 2004), Spring, Maybelle, 'Jefferson', 'Ahrent' and 'Cocodrie' averaged yields of 158, 134, 153, 168, and 175 bu/acre (12% moisture), respectively. Data from the URRN conducted at Arkansas, Louisiana, Mississippi, and Texas during 2002 to 2004 (Table 2) showed that Spring had an average grain yield of 171 bu/acre compared favorably with those of Jefferson, 'Francis', Ahrent, and Cocodrie at 160, 192, 165, and 186 bu/acre, respectively. Milling yields (percent whole kernel:percent total milled rice) at 12% moisture from the ARPT (2001 to 2004) averaged 64:71, 61:71, 63:71, 64:69, and 67:72 for Srping, Maybelle, Jefferson, Ahrent, and Cocodrie, respectively. Milling yields for the URRN (2002 to 2004) averaged 60:70, 61:70, 61:69, 61:68,and 62:71 for Spring, Jefferson, Francis, Ahrent, and Cocodrie, respectively.

Spring averages 8 to 10 days earlier in maturity than Francis, Ahrent, and Cocodrie, and 5 days earlier than Jefferson (Table 1 and 2). Spring has a straw strength similar to 'LaGrue'. On a relative straw strength scale (0 = very strong straw, 9 = very weak straw) Spring, Maybelle, Jefferson, Francis, Ahrent, Wells, LaGrue, 'Drew', and Cocodrie rated 4, 3, 2, 3, 3, 3, 4, 4,and 2, respectively. Spring is approximately 42 in. in plant height which is similar in height to Ahrent.

Spring is resistant to common rice blast (*Pyricularia grisea* (Cooke) Sacc.*)* races IC-17, IE-1, IG-1 and IH-1 under Arkansas greenhouse conditions, with average ratings of 3, 2, 2, and 1, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility (Table 3.). It is moderately resistant to IB-1 with an average rating of 4, and moderately resistant to susceptible to IB-49 with an average rating of 5. Like Katy, 'Kaybonnet', Drew, and Ahrent, Spring is susceptible to the blast races IB-33 and IE-1k, with an average rating of 7 and 8, respectively. Spring is rated MS - S for sheath blight (*Rhizoctonia solani* Kühn) which compares with Francis (MS), Ahrent (MS), Wells (MS), LaGrue (MS), Kaybonnet (MS), 'Cypress' (VS), and Drew (MS). Spring is rated MS for kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] which compares to Francis (VS), Ahrent (MS), Wells(MR), LaGrue (VS), Kaybonnet (MS), Cypress (VS), and Drew (MS).

Spring is rated S to stem rot, MR to leaf smut (*Entyloma oryzae* Syd. & P. Syd.), MR to brown spot [*Cochliobolus miyabeanus* (Ito & Kuribayashi in Ito) Drechs. ex Dastur], and MS to false smut [*Ustilaginoidea virens* (Cooke) Takah]. Spring, like LaGrue, is MS for discolored kernels caused by the rice stink bug (*Oebalus pugnax*).

Spring is a standard height long-grain rice cultivar and is S to crown (black) sheath rot. Spring was rated susceptible to bacterial panicle blight in 2002 to 2004 in Arkansas. Spring has a susceptible reaction to straighthead (a physiological disorder) like Cybonnet as compared to Cocodrie which is very susceptible. Spring should be drained on the most severe straighthead soils. This cultivar should be harvested on time and not be over-fertilized with nitrogen as lodging has been observed under these conditions.

Plants of Spring have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw-colored with straw to brown-colored apiculi, and some short tip awns on the lemma at maturity under high fertility. Kernels are similar in size to those of Maybelle and Ahrent. Individual milled kernel weights of Spring, Maybelle, Jefferson, Ahrent, and Cocodrie averaged 16.7, 16.6, 19.7, 16.2, and 17.9 mg, respectively, in the ARPT (2001 to 2004).

The endosperm of Spring is nonglutinous, nonaromatic, and covered by a light brown pericarp. Rice-quality parameters indicate that Spring has typical southern U.S. long-grain rice cooking-quality characteristics as described by Webb et al. (1985). Spring has an average apparent starch amylose content of 216 g/kg and an intermediate gelatinization temperature (70-75 C), as indicated by an average alkali (17 g/kg KOH) spreading reaction of 3 to 5.

SIGNIFICANCE OF FINDINGS

The release of Spring offers producers a very short-season cultivar with good seedling vigor, cold tolerance, and milling. It provides the producers with an early variety that can be planted earlier to take advantage of the spring rains. Spring also maintains good quality characteristics and plant type.

ACKNOWLEDGMENTS

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Table 1. Four-year average agronomic data from the 2001 to 2004 Arkansas Rice Performance Trials for Spring and other cultivars.

Cultivar	Grain type[z]	Yield 2001	Yield 2002	Yield 2003	Yield 2004	Yield Mean[y]	Height	50% Heading	Kernel wt. mg	Milling HR:TOT[x]
		(bu/acre)					(in.)	(days)	(mg)	
Spring	L	154	171	159	146	158	42	79	16.7	64:71
Maybelle	L	125	141	128	143	134	40	79	16.6	61:71
Jefferson	L	150	159	153	149	153	38	84	19.7	63:71
Ahrent	L	176	172	163	160	168	42	87	16.2	64:69
Cocodrie	L	178	184	166	170	175	39	89	17.9	67:72

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

[y] 2001 consisted of five locations: Rice Research and Extension Center, (RREC), Stuttgart Ark.; Pine Tree Branch Experiment Station, (PTES),Colt, Ark.; Northeast Research and Extension Center, (NEREC), Keiser Ark.; Southeast Branch Experiment Station (SEBES), Rowher, Ark.; and Phipps Farm Cross County (PFCC); 2002 consisted of RREC, PTES, SEBES, PFCC, and Jackson Co. Farmer Field (JCFF), Newport, Ark.; 2003 consisted of RREC, PTES, SEBES, JCFF, NEREC, Missouri Rice Research Farm, (MORR) Campbell, MO; and Farmers Field in Clay County, (CCFF); and in 2004 at the RREC, PTES, NEREC, JCFF, MORR, and CCFF.

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

Table 2. Data from the 2002 to 2004 Uniform Regional Rice Nursery for Spring and other check cultivars.

Cultivar	Grain type[z]	Yield AR	Yield LA	Yield MS	Yield TX	Yield Mean[y]	Height	50% Heading	Kernel wt. mg	Milling HR:TOT[x]
		(bu/acre)					(in.)	(days)	(mg)	
Spring	L	171	146	175	191	171	42	78	17.0	60:70
Jefferson	L	163	147	159	173	160	36	82	20.3	61:70
Francis	L	183	179	195	219	192	39	87	17.8	61:69
Ahrent[w]	L	126	169	169	196	165	41	85	16.5	61:68
Cocodrie	L	179	175	190	199	186	37	85	18.7	62:71

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

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

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

[w] Data for Ahrent from 2002 to 2003.

Table 3. Preliminary greenhouse blast race rating[z] of Spring (based upon 2002 to 2004 data) and other comparative varieties.

	IB-1		IB-49		IC-17		IE-1		IG-1		IH-1		IE-1K		IB-33	
Banks	R	2.3[y]	MR-S	5	R	1.8	R	0.1	R	0.9	R	0.7	S	7.4	S	7.3
Spring	MR	4.0	MR-S	5.4	R	2.7	R	2.3	R	1.9	R	0.6	S	7.8	S	7.4
Ahrent	R	1.3	MR	3.9	R	0.9	R	0.1	R	0.4	R	0.4	S	7.1	S	6.1
Kaybonnet	R	1.6	MR	3.5	R	1.6	R	0.1	R	0.1	R	0.1	S	7.4	S	6.8
Drew	R	1.3	R	3	R	0.4	R	0.4	R	0.4	R	0.1	S	7.2	S	6.7
Jefferson	S	5.2	S	6.3	R	2.6	R	0.7	R	0.2	R	0.7	R	2.1	S	6.5
LaGrue	S	7.4	S	7.9	S	7.9	S	6.9	S	7.4	S	6.7	S	7.6	S	6.9
Wells	S	7.5	S	8	S	7.8	S	6.3	R	3	R	0.2	S	7.5	S	7.5
Francis	S	6.3	S	7.6	S	7.5	S	7.3	S	5.6	R	0.9	S	6.0	S	6.9
Saber	R	1.8	R	3	R	2.6	R	0.8	R	0.1	R	0	R	2	S	6.5
Mars	S	7.8	S	8	R	2.6	R	3	R	2.8	R	1.6	S	4.2	S	7.4

[z] *Pyricularia grisea* races as defined using the international set of blast differentials. Composite leaf blast ratings on the 0 (none) -9 (maximum) disease scale in multiple, comparative, inoculated greenhouse tests conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark. Ratings indicate relative susceptibility under conditions favorable for seedling blast.

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

Growth Stages of 12 Rice Cultivars (*Oryza sativa* L.) Expressed in DD50 Thermal Heat Units

N.T. Watson, P.A. Counce, and T.J. Siebenmorgen

ABSTRACT

From 1996 to 1999, a new developmental staging system was developed for rice (Counce et al, 2000). In order to make the staging system more meaningful and useful as a means of determining when to apply pesticides and fertilizers, it is necessary that the developmental stages of current rice varieties be expressed in terms of thermal time. Twelve rice cultivars (‘Starbonnet’, ‘Cypress’, ‘Wells’, ‘Bluebonnet’, ‘Lemont’, ‘Mars’, ‘Carolina Gold’, ‘Magnolia’, ‘Drew’, ‘Guichao’, C-GL-13, and ‘LaGrue’) were planted at the University of Arkansas Rice Research and Extension Center in Stuttgart, Ark., in 2001. The growth stage of each plant was determined on a daily basis and expressed in terms of thermal time using the DD50. In combination with the rice development timeline, the rice developmental stages of the 12 tested cultivars are expressed in terms of thermal time (DD50), which will ultimately aid producers in using the objective rice developmental staging system in rice crop management.

INTRODUCTION

Rice producers utilize rice growth stages to predict the timing of fertilizer and pesticide application, as well as when to harvest. Terms such as “booting” or “50% heading,” “flowering,” or “anthesis” are commonly used to describe rice developmental stages. However, there are many terms such as “turn-down” and “maturity” that can be vague and misinterpreted between interested parties. Moreover, the kernels on a rice plant do not mature concurrently since tillers are produced throughout the growth of the rice plant, which further confuses language associated with rice developmental staging.

During the time period from 1996 to 1999, a new, adaptive growth-staging system was developed for the rice industry (Counce et al., 2000) that can provide improved communication throughout the rice industry. The rice developmental staging system of Counce et al. (2000) provides a framework for objectively and uniformly expressing the developmental stages of a rice plant. The staging system uses the rice plant main stem as a point of reference for growth-stage classification and separates the vegetative and the reproductive stages of the rice plant with the denotations "V" and "R," respectively. Within the vegetative stages, a number is assigned to each true leaf that forms on the main stem, thus giving a description of the plant physiological state as well as its biological age. For example, stage V3 is the vegetative stage with three true leaves on the main stem. The reproductive stages start with panicle initiation, which is denoted R0. The R1 stage can only be seen if the plant is destroyed and cut open to see a tree-like formation inside the main stem. R2 occurs when the collar of the flag leaf becomes visible. During R2 the main stem starts to swell with a rice panicle also referred to as "booting." R3 occurs when the panicle exerts from the main stem ("heading"), and R4 occurs when the anthers of at least one floret on the main stem panicle emerges. When at least one rice kernel on the main stem begins to fill with starch, the plant has reached R5. The "grain-filling" stage is termed R6, which starts when at least one rice kernel on the main stem panicle has completely lengthened to the end of the hull. The grain fills with starch during R6. The appearance of one yellow hull and subsequently the appearance of one brown hull on the main stem panicle are termed R7 and R8, respectively. The end of maturation is R9, when all of the kernels that had reached R6 have a brown hull.

While this new staging system can improve communication among rice producers, extension workers, and researchers, the system could become even more meaningful as a precise predictive staging tool for nitrogen and pesticide application as well as other management decisions. In order to achieve this, research was necessary to quantify the developmental growth stages in terms of thermal time.

It was the goal of this research to determine the thermal heat units (DD50) required to reach each individual growth stage of the new, Counce et al. (2000) rice developmental staging system.

PROCEDURES

Plant Growth and Staging

Twelve rice cultivars (Starbonnet, Cypress, Wells, Bluebonnet, Lemont, Mars, Carolina Gold, Magnolia, Drew, Guichao, C-GL-13, and LaGrue) were planted in randomized complete block design experiment with 4 replications. Plots were planted in 19-cm rows in a DeWitt silt loam soil on 3 May 2001 at the Rice Research and Extension Center, Stuttgart, Ark. Plants had emerged by 16 May 2001. Plot sizes were approximately 4 ft wide by 15 ft long. Subsequently, nine plants in each plot were tagged for growth-stage determination on or before the V2 stage of development. The growth stage of each plant, using the system of Counce et al. (2000), was determined on a daily basis thereafter.

Weather Data and Degree-Day Determination

Weather data from 2002 were obtained from the USDA weather station at Stuttgart, Ark., which included average daily high and low temperatures in °F, the two data points necessary to calculate DD50. The DD50 uses equation 1 to calculate, with a base temperature of 50°F, a day's thermal growing quality based on air temperature (Kiesling et al., 1984).

EQUATION 1:

$$\text{DD50} = \left\{ \frac{(\text{Daily MaximumTemperature (°F)} + \text{Daily Minimum Temperature (°F)})}{2} - 50 \right\} \times 1 \text{ day}$$

Where: Daily Maximum Temperature = 94°F if maximum temperature is >94°F
Daily Minimum Temperature = 70°F if minimum temperature is >70°F

RESULTS AND DISCUSSION

When the thermal time intervals (Table 1) are plotted against the rice development time line (Fig. 1), a crop management map for a rice cultivar is obtained (Fig. 2), which provides a means of visualizing plant growth and the growth pattern differences between cultivars. For example, from Fig. 2 and Table 1, it can be seen that the Chinese cultivar, Guichau, required the fewest DD50 units to reach the individual vegetative stages. The other 11 cultivars did not differ in the number of days required to reach the individual vegetative growth stages. The cultivars Bluebonnet, Magnolia, Starbonnet, Carolina Gold, and Guichau had the most leaves on the main stem at 15 to 16 leaves. Figure 3 reveals that the cultivars CG-L-13 and Wells both reached the reproductive stage before the other tested cultivars, having reached R2 in approximately 1600 degree days (DD50). Bluebonnet required the most thermal time, 2350 degree days (DD50) to reach the reproductive stages.

SIGNIFICANCE OF FINDINGS

With this staging information, a producer may use the new rice-staging system for improving nitrogen and pesticide application timing and decisions related to water management. The DD50 program and the growth staging system are interchangeable. R2 and VF occur at the same time. R3 is equivalent to heading, R0 is equivalent to panicle initiation and R1 is very close to IE=0.5 in. Using the timing intervals, which can be derived from Table 1, the flexibility of the DD50 program can be greatly increased. If an emergence date is missed for a field, the date for starting DD50 accumulations could be reset at V1, V2, V3 instead. Therefore, instead of just guessing at an emergence date, a grower can find the actual growth stage and time from that date and stage of development.

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Table 1. Average degree days (DD50) required to reach each growth stage for 12 cultivars.

Stage	BBNT	C-GL-13	CGLD	CPRS	DREW	GCHW	LGRU	LMNT	Magnolia	Mars	STBN	Wells
V02	0	0	0	0	0	0	0	0	0	0	0	0
V03	3	0	8.58	3	3	10.35	11.58	25.57	10.5	26.15	18.23	0
V04	111.5	125	114.85	114.85	111.5	118.25	121.55	127.17	114.85	124.9	124.9	146.17
V05	237.75	223.6	255	241.7	221.95	174.25	254.18	286.93	232.75	246.05	246.28	210.98
V06	398.8	391.6	397.2	376.78	390.2	278.15	438.55	471.63	405.2	403.38	402.53	390.14
V07	626.18	633	606.58	626.18	620	443.9	635.18	658.76	622.05	613.2	618.9	590.33
V08	724.28	779	735.45	770.5	737	638.6	772.45	846.21	764.9	743.65	724.45	715.62
V09	902.6	967.9	909.28	1013.75	926.6	745	966.63	1042.43	951.18	915.45	914.43	905.91
V10	1139.73	1186	1125.03	1260.53	1148.28	903.6	1230.58	1278.94	1215.2	1162.15	1159.75	1134.78
V11	1492.65	1405.2	1403.2	1477.95	1438.4	1087.2	1464.42	1491.7	1541.68	1441.25	1497.48	1396.26
V12	1763.95	1701	1640.85	1646.95	1607.95	1368.55	1641.68	1666.34	1763.85	1604.5	1756.08	1554.96
V13	1998.63		1841.48	1728.64	1756.35	1610.5	1800.32	1729.33	2008.15	1781.03	1949.33	1674.25
V14	2244.33		2034.76		1814.5	1843.11		1888.13	2193.66	1867.5	2149.12	1783.5
V15	2408.29		2257			1960.63			2345		2223.8	
V16						2193.5						
R02	2352.15	1604.5	2031.78	1709.9	1746.55	1992.83	1744.79	1771.8	2187.13	1800.25	2185.28	1632.62
R03	2642.93	1993.4	2293.05	1981.28	2012.9	2274.22	2029.67	2113.9	2487.53	2023.73	2464.4	1929.64
R04	2709.03	2132.2	2346.88	2080.47	2100.3	2334.72	2128.47	2186.96	2532.63	2141.35	2516.2	2021.86
R05	2799.23	2199.7	2467.26	2164.45	2170.53	2416.06	2214.25	2251.73	2613.84	2214.43	2628.7	2136.71
R06	2974.05	2307.8	2563.67	2278.16	2291.88	2517.69	2349.67	2361.08	2776.11	2305.1	2804.35	2222.03
R07	3061.55	2410.8	2669	2422.74	2419.4	2661.94	2409	2505	2976.58	2436	2988.25	2373.08
R08	3175	2574.1	2831.89	2581.26	2567.5	2853.56	2584.89	2788.13	3079.37	2575	3143.45	2523.49
R09	3315.98	2859.2	3043.03	2971.03	2948.68	3016.44	2984.94	3024.38	3329.68	2909.33	3316.8	2879.36

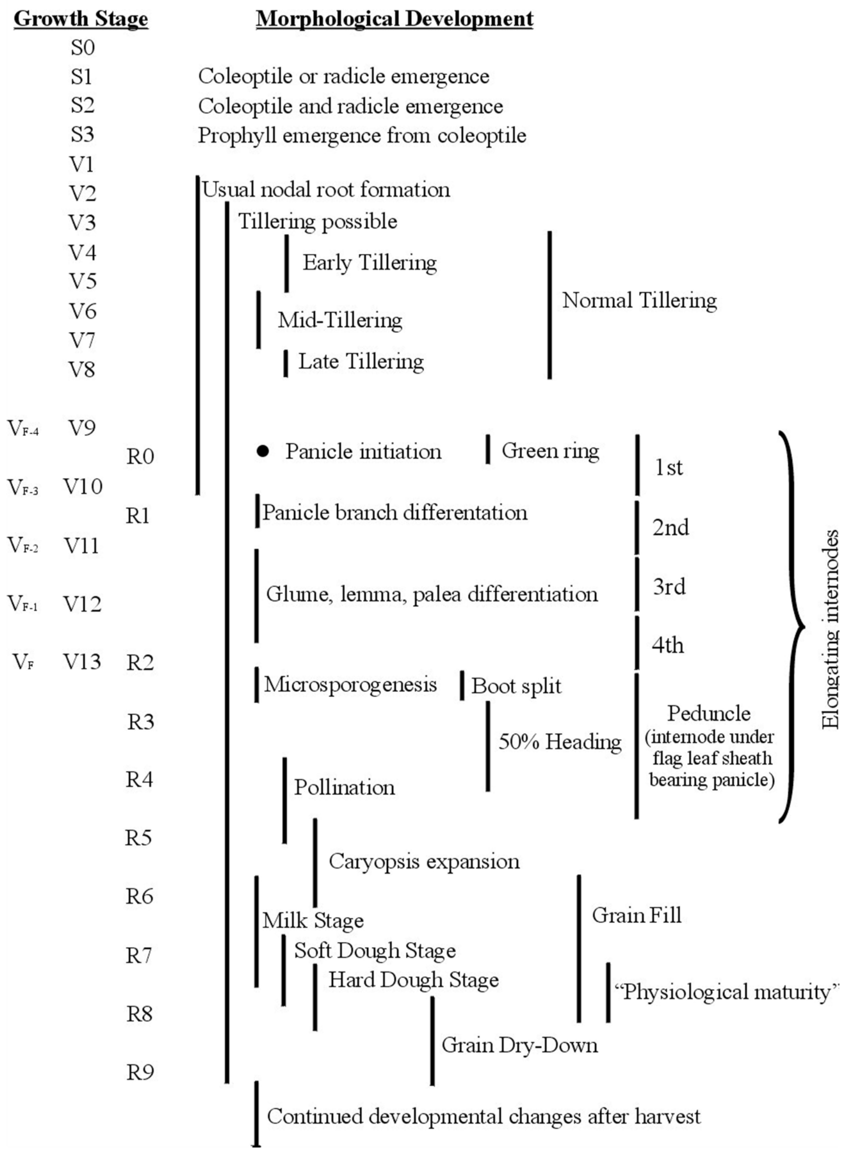

Fig. 1. Rice development timeline (Counce et al., 2000).

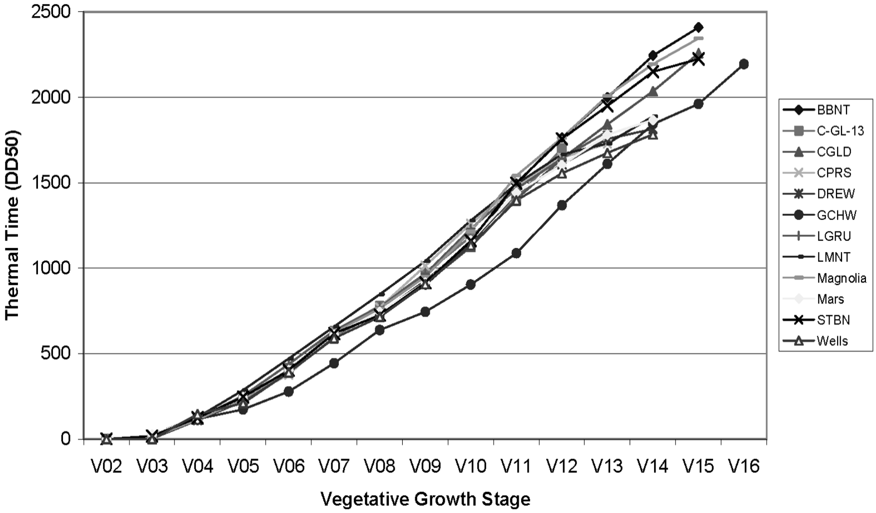

Fig. 2. Graphic representation of the thermal degree days (DD50) needed to reach the vegetative growth stages (Counce et al., 2000) of 12 rice cultivars.

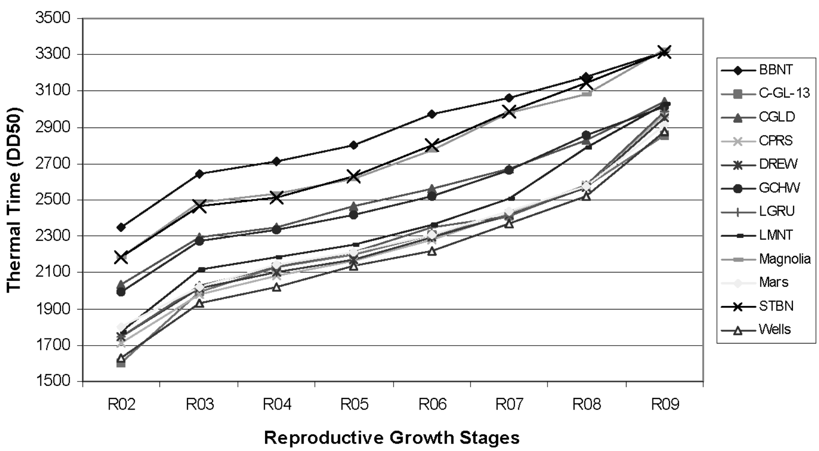

Fig. 3. Graphic representation of the thermal degree days (DD50) needed to reach the reproductive growth stages (Counce et al., 2000) of 12 rice cultivars.

Agronomic Evaluation and Seed Stock Establishment of the USDA Rice Core Collection[1]

W.G. Yan, J. Neil Rutger, H.E. Bockelman, and T.H. Tai

ABSTRACT

A total of 1,687 out of 1,801 accessions in the USDA rice core collection was planted in 2002 for agronomic evaluation and seed stock establishment. The remaining 114 accessions were undergoing an additional cycle of initial seed increases and were not included in these evaluations. Seed amounts ranging from 11 to 1633 g were harvested from 1,645 accessions, in which days from emergence to 50% heading varied from 42 to 180 days and averaged 97 ± 19. Plant height ranged from 61 to 212 cm and averaged 126 ± 25 cm. Twelve hundred seventeen or 75% of accessions had no lodging with ratings of 2 or less, and 187 or 11% lodged badly with ratings of 7 or more. The remaining 241 accessions were rated between 2 and 7 for lodging. Plant types included 41% erect, 35% intermediate, 21% open, 3% spreading, and zero procumbent. Panicle type of the core collection was 1% compact, 97% intermediate, and 2% open. The core had 81% awnless, 5% short and partly awned with a few short and fullly awned, 5% long and partly awned, and 9% long and fullly awned. Late heading plants tended to be taller (r=0.22). Tall plants lodged more (r=0.40) and had less awning (r=-0.14). Open plant types had more lodging (r=0.13) and yielded more (r=0.16). Plants with open panicles were taller (r=0.15) and more awned (r=0.85). All these correlations were significant at the 0.01 probability level.

[1] This is a completed study.

INTRODUCTION

The USDA rice core collection, containing 1,801 accessions and representing about 10% of the entire rice germplasm collection in the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) National Small Grains Collection (NSGC), was established by a stratified random sampling method (Yan et al., 2004a). Evaluation of germplasm collections using the core strategy has several advantages. First, it improves evaluation efficiency because a representative core collection greatly reduces the number of accessions, so that comprehensive evaluations for both phenotypic and genotypic properties are feasible. Secondly, it leads to a better understanding of the entire collection because the comprehensive evaluations reveal genetic diversity, gene composition, and genetic relationships of accessions in the entire collection. Thirdly, it improves management efficiency because the resulting knowledge facilitates identifying of genetic gaps in the entire collection for further expansion, monitoring genetic drift or change when accessions are regenerated, and removing duplicates from regeneration and new introductions. Finally it improves the use efficiency of the collection because the resulting knowledge makes it easier for breeders to locate the genes or traits of interest. Furthermore, the background information of phenotyping and genotyping for those accessions containing the desirable traits may assist researchers in designing effective strategies for transferring the traits.

Comprehensive evaluations, including phenotyping and genotyping the core collection, attract great interest from state, federal, and international agencies (Yan et al., 2004b). Establishing seed stocks for the core collection is a necessary prerequisite to conducting evaluations. The objectives of this study were to evaluate the core collection for agronomic characteristics and establish seed stocks for further evaluations.

PROCEDURES

A total of 1,687 accessions from the USDA rice core collection was included in this study. The remaining 114 accessions were undergoing an additional cycle of initial seed increases and were not included in these evaluations. Seeds of each accession were visually purified by seed-shape (long, medium, and short) and hull-color (white, straw, golden, and black) descriptors as described in the database of Germplasm Resources Information Network (GRIN) (USDA-ARS, NGRP, 2004). Each accession was grown in a plot consisting of two rows, 1 ft apart and 4.5 ft long, and 3 g of seeds were planted in each row by Hege 500 planter at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark., on 16 April 2002. Plots were separated 3 ft to avoid biological and mechanical contamination. Seedlings emerged on 28 April 2002, and weeds were controlled with Propanil at 1 gal/acre mixed with Bolero at 2 gal/acre. A permanent flood was established after 60 lb/acre of nitrogen as urea were applied at about 5-leaf stage.

Agronomic descriptors were scored with standard criteria described in the Germplasm Resources Information Network (USDA-ARS, NGRP, 2004) as: Days to flower - days from seedling emergence to 50% of the flowering panicles in an accession; Plant type - five codes classified by the culm angle of plants grown in the entire plot from the perpendicular at maturity as 1-erect, the angle is less than 30°; 3-intermediate, the angle is about 45°; 5-open, the angle is about 60°; 7-spreading, the angle is greater than 60°; and 9-procumbent, the culm or its lower parts rest on ground surface; Panicle type - three codes classified by panicle mode of branching, angle of primary branches, and spikelet density at maturity as 1-compact, 5-intermediate, and 9-open; Plant height - length from ground level to the tip of panicles at maturity; Lodging - nine codes classified by percentage of lodging plants at maturity as 1, 0 to 10% lodged; 2, 11 to 20% lodged; 3, 21 to 30% lodged; 4, 31 to 40% lodged; 5, 41 to 50% lodged; 6, 51 to 60% lodged; 7, 61 to 70% lodged; 8, 71 to 80% lodged; and 9, 81 to 100% lodged; Awn type - five codes classified by awn presence at maturity as 0-no awn, 1-short and partly awned, 5-short and fully awned, 7-long and partly awned, and 9-long and fully awned; and Seed yield - grams of seed harvested from the entire plot.

RESULTS AND DISCUSSION

Heading and Seed Yield

Nineteen accessions did not head before the first frost at the end of October. Days from emergence to heading ranged from 42 to 180 and averaged 97 with a standard deviation of 19 among the 1,668 headed accessions. 'Amaura' (PI 439617) from the Russian Federation was the earliest, and RPP 31-3 (PI 312760) from the Philippines the latest in heading.

However, 1,645 out of the headed accessions produced seeds ranging in weight from 11 to 1633 g. R 312 (PI 614959) from China headed 96 days from emergence and yielded the most. 'Juma 58' (PI 420241) from the Dominican Republic headed 161 days from emergence and yielded the least. Variation of seed yield among the core accessions is displayed in Fig.1. Those that yielded less than 250 g and failed to head were planted in Puerto Rico in the winter of 2002 for further seed stock increase.

Plant Height and Lodging

Plant height ranged from 61 to 212 cm and averaged 126 cm with a standard deviation of 25 cm. The shortest was a Japanese cultivar 'Johiku No. 314' (PI 341933) and the tallest was 'Colombian 16776' (PI 503073). Twelve hundred seventeen or 75% of accessions showed no sign of lodging with ratings of 2 or less, and 187 or 11% lodged badly with ratings of 7 or more.

Plant Type, Panicle Type, and Awn Type

Forty-one percent of the accessions had plant types that were erect, 35% were intermediate, 21% were open, 3% were spreading, and none were procumbent (Fig. 2). Panicle type was compact in 1% of the accessions, intermediate in 97%, and open in 2% (Fig. 3). The core accessions evaluated were 81% awnless, 5% short and partly awned with a few short and fullly awned, 5% long and partly awned, and 9% long and fully awned (Fig. 4).

Late-heading accessions tended to be taller (r=0.22). Taller accessions lodged more (r=0.40), and were less awned (r=-0.14). Accessions with open plant type had a greater chance of lodging (r=0.13) and yielded more (r=0.16). Accessions with open panicles were taller (r=0.15) and more awned (r=0.85). All these correlations were significant at the 0.01 probability level.

SIGNIFICANCE OF FINDINGS

The wide range of variations in the agronomic traits in the core collection indicates that rich genetic diversity is available for the needs of the U.S. rice industry. Seed stock establishment and increase of the USDA rice core collection provides researchers with a subset of the world collection entries for comprehensive evaluations.

ACKNOWLEDGMENTS

The authors appreciate the outstanding help and support of Tony Beaty, Patricia Calvert, William Richter, Rachel Joslin, Edith Baugh, Emily Hendrix, and Curtis Kerns.

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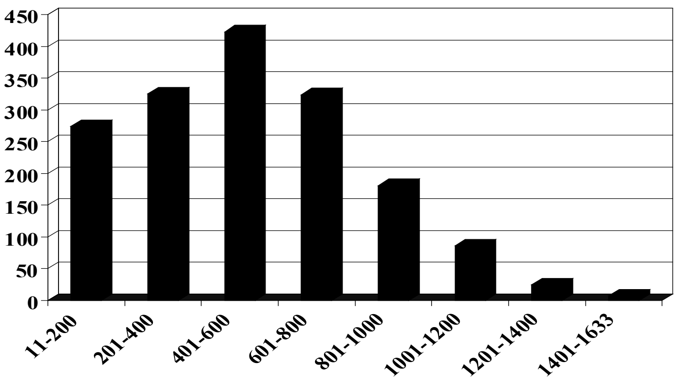

Fig. 1. Distribution of grain yield (g/plot) produced by individual accessions in the USDA rice core collection.

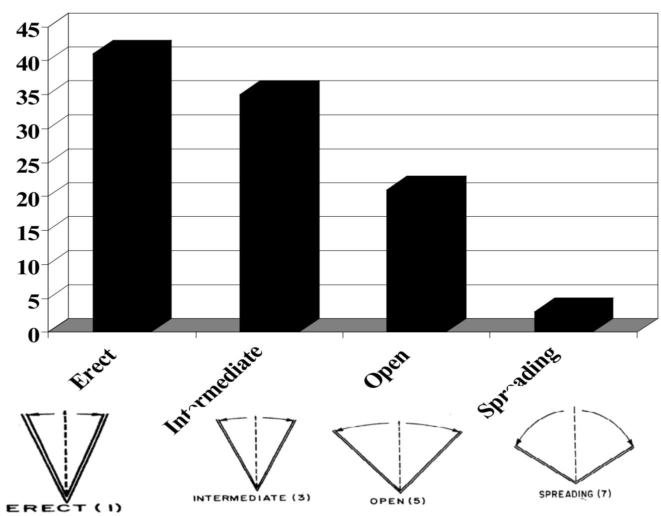

Fig. 2. Distribution of plant type in the USDA rice core collection.

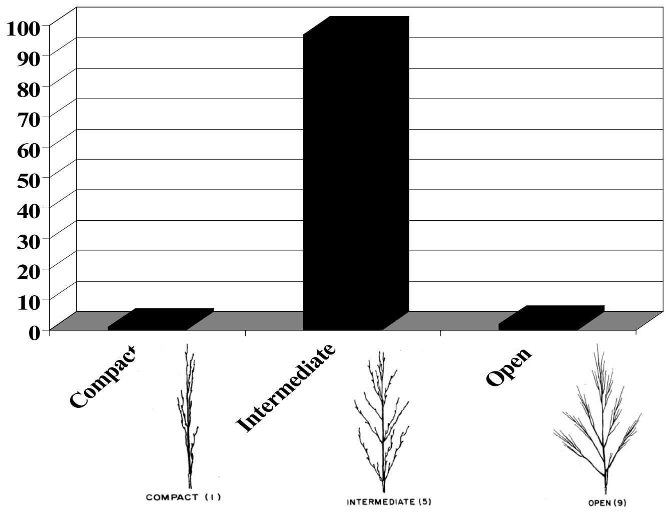

Fig. 3. Distribution of panicle type in the USDA rice core collection.

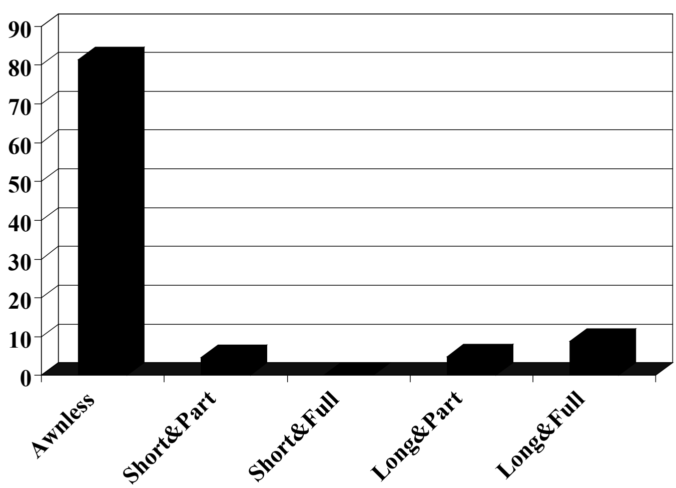

Fig. 4. Distribution of awn type in the USDA rice core collection.

Evaluation of Kernel Characteristics of the USDA Rice Core Collection[1]

W.G. Yan, J. Neil Rutger, H.E. Bockelman, and T.H. Tai

ABSTRACT

Grain type in rice usually is associated with specific milling, cooking, and processing characteristics. Kernel dimensions, weight, and color of 1,615 accessions in the USDA rice core collection were evaluated using the GrainCheck 2312 (Foss Tecator, Hoganas, Sweden). Sample size of rough rice varied from 100 to 732 grains. Hull colors of 67 (4.1%) accessions were white, 814 (50.4%) straw, 123 (7.6%) gold, 57 (3.5%) russet, 85 (5.2%) furrowed, 449 (27.8 %) spotted or piebald, 16 (1%) purple, and 4 (< 1%) black. Rough rice grain length ranged from 5.9 to 13.0 mm with an average of 8.7±0.9 mm, and width from 2.2 to 4.4 mm with an average of 3.1±0.4 mm. Ratio of length to width ranged from 1.7 to 4.4 with an average of 2.8± 0.5, and 1000 grain weight from 12.5 to 42.7 g with an average of 26.2± 4.4 g. Brown rice sample sizes ranged from 78 to 862 kernels. Seed bran colors of 54 accessions (3.3%) were white, 1357 (84.0%) light brown or speckled brown, 58 (3.6%) brown, 144 (8.9%) red, and 2 (< 1%) purple. Length ranged from 4.2 to 10.0 mm with an average of 6.5± 0.8 mm, and width from 1.5 to 3.5 mm with an average of 2.6± 0.3 mm. Ratio of length to width ranged from 1.5 to 4.5 with an average of 2.7± 0.5, and 1000 kernel weight from 9.5 to 37.4 g with an average of 21.4± 3.7 g. There were 282 (17.5%) accessions with short-, 1036 (64.1%) medium-, and 297 (18.4%) long-grain types in the accessions evaluated.

INTRODUCTION

In the U.S., rice grain type is usually associated with specific milling, cooking, and processing characteristics (Webb, 1994). Grains of typical long-grain cultivars cook

[1] This is a completed study.

dry, fluffy, and separate when boiled or steamed and also are preferred for use in such prepared products as parboiled rice, quick-cooking rice, canned rice, canned soups, dry soup mixes, frozen dishes, and other convenience-type rice-containing foods. Typical short- and medium-grain types cook moist, chewy, and clingy and are preferred for such products as dry breakfast cereals, steamed rice, baby foods, and for brewing uses. The association of grain type with specific cooking and processing behavior occurs primarily in the U.S. and is a result of planned breeding (Adair et al., 1973). Most consumers in the U.S. prefer the dry, fluffy, and separate texture of the long-grain type, but many Asian immigrants like the more moist and clingy or sticky texture of the short- and medium-grain types. The typical U.S. long-grain types are characterized by relatively high amylose content, slight-to-moderate alkali-spreading reaction, moderate water uptake, and intermediate gelatinization temperature. Typical U.S. short- and medium-grain types are characterized by comparatively low amylose content, high alkali-spreading reaction, high water uptake, and low gelatinization temperature. The objective of this study was to characterize the USDA rice core collection for grain or kernel descriptors in order to better serve the U.S. rice breeding community and enrich the database of the Germplasm Resources Information Network (GRIN) (USDA-ARS, NGRP, 2004).

PROCEDURES

Grain samples of 1,615 accessions in the USDA rice core collection were developed from seed stocks established in the 2002 agronomic evaluation. Rough or paddy rice is the mature rice grain as harvested, which becomes brown rice when the hulls are removed. A rough rice sample of each accession was prepared only for fully filled mature grains, and brown rice samples for de-hulled whole kernels. Rough and brown rice samples were analyzed on an automated grain-image analyzer (GrainCheck 2312; Foss Tecator AB, Hoganas, Sweden) to determine rice kernel dimensions (length, width, and length/width ratio), hull and seed pericarp colorations, and 1000 seed weights. A complete color set of rough and brown rice samples was supplied to the programmer in Foss Tecator company in Hoganas, Sweden. The programmer set the GrainCheck 2312 analyzer for measuring kernel color and assigning a color code accordingly based on the standard color samples. The coloration and coding of rough and brown rices are described in the GRIN (USDA-ARS, NGRP, 2004).

RESULTS AND DISCUSSION

Hull and Bran Color

Rough rice samples of the 1,615 accessions varied from 100 to 732 filled mature kernels. Hull colors of 67 accessions (4.1%) of the evaluated core collection were white, 814 (50.4%) straw, 123 (7.6%) gold, 57 (3.5%) russet, 85 (5.2%) furrowed, 449 (27.8%) spotted or piebald, 16 (1.0%) purple, and 4 (< 1%) black. Brown rice samples ranging from 78 to 862 whole de-hulled kernels were measured. Seed pericarp or bran colors of

54 accessions (3.3%) of the evaluated core collection were white, 1357 (84.0%) light brown or speckled brown, 58 (3.6%) brown, 144 (8.9%) red, and 2 (< 1%) purple.

Kernel Length

Variations in rough and brown rice lengths among 1,615 accessions of the rice core collection are presented in Fig. 1. On average, rough rice was 2.2 mm longer than brown rice. 'Kaukkyi Ani' (PI 584567) from Myanmar had both the shortest rough rice of 5.9 mm, and brown rice of 4.2 mm. Madagascar cultivar 923 (PI 402638) had the longest rough rice of 13.0 mm, and cultivar 45-5-18 (PI 315652) from El Salvador had the longest brown rice of 10.0 mm.

Kernel Width

Variations in rough and brown rice widths among 1,615 accessions of the rice core collection are presented in Fig. 2. Rough rice was 0.5 mm wider than brown rice in average. Width of rough rice ranged from 2.2 mm for 'Basmati' (PI 431251) introduced from Pakistan to 4.4 mm for 'Ardito' (PI 215478) from Italy. For brown rice, 'La Plata Gena F.A.' (PI 431172) from Argentina was the thinnest at 1.5 mm, and Ardito was the widest at 3.5 mm.

Kernel Length-to-Width Ratio

Variations in the ratios for rough and brown rice among 1,615 accessions of the rice core collection are presented in Fig. 3. Mean ratios, and minimum and maximum ratios between rough and brown rices were about the same. Bolivian cultivar 'Mojito Colorado' (PI 242804) had the lowest ratio for both rough (1.7) and brown rice (1.5). Cultivar Sadri Type (CIor 12425) from Iraq had the greatest ratio of 4.4 for rough rice, and the thinnest La Plata Gena F.A. had the greatest ratio of 4.5 for brown rice. Length-to-width ratio (L/W) is used to determine rice grain type; long ($L/W>3.0$), medium ($2.1<L/W\leq3.0$) and short ($L/W\leq2$) (USDA, 1982). There were 282 (17.5%) accessions with short-, 1036 (64.1%) medium-, and 297 (18.4%) long-grain types in the core collection.

Kernel Weight

Variations in 1000 kernel weights for rough and brown rice are presented in Fig. 4. On average, rough rice weighed 4.87 g more than brown rice. Indian cultivar 'Purple Puttu' (PI 377620) had the smallest kernels with 1000 rough grains weighing 12.47 g and brown kernels weighing 9.52 g. The Italian cultivar Ardito was the largest with 1000 rough rice grains weighing 42.72 g (due to its having the widest kernels among the accessions evaluated). For brown rice, cultivar 'Khao Luang' (PI 373249) from Laos was the largest with 1000 kernels weighing 37.39 g.

SIGNIFICANCE OF FINDINGS

The wide range in the kernel characteristics of the USDA core collection indicates rich genetic diversity available for U.S. rice breeding.

ACKNOWLEDGMENTS

The authors appreciate the outstanding help and support of Tony Beaty, Patricia Calvert, William Richter, Rachel Joslin, Edith Baugh, Emily Hendrix, and Curtis Kerns.

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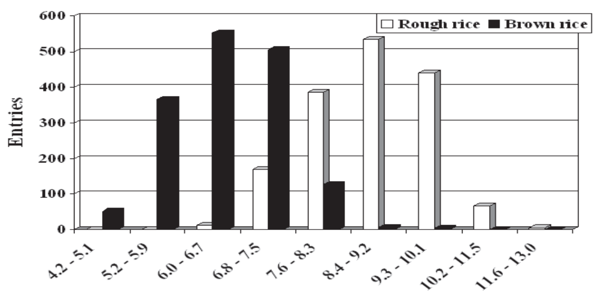
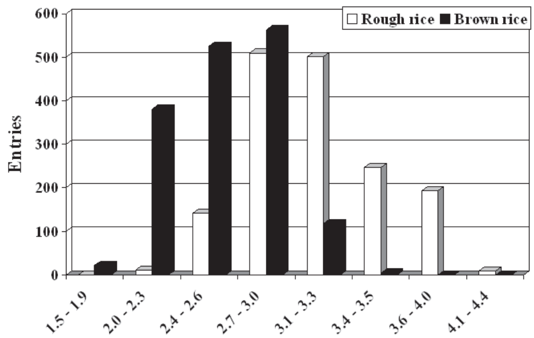


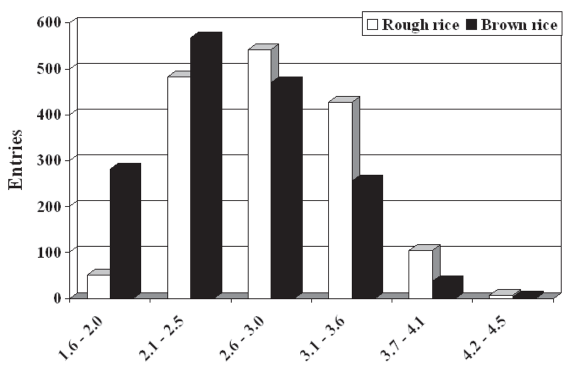
	Brown rice	Rough rice
Mean	6.5±0.8	8.7±0.9
Minimum	4.2 - PI 584567	5.9 - PI 584567
Maximum	10.0 - PI 315652	13.0 - PI 402638

Fig. 1. Analysis of kernel length (mm) in the USDA rice core collection.



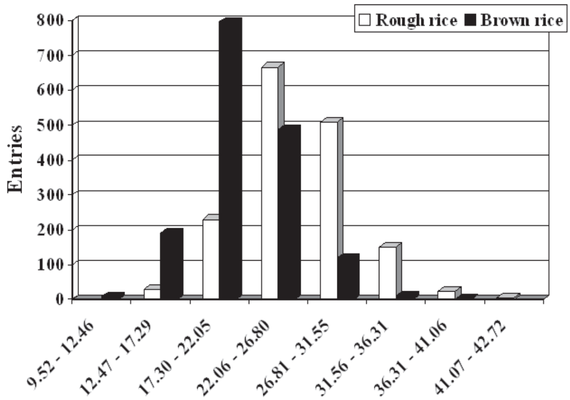
	Brown rice	Rough rice
Mean	2.6±0.3	3.1±0.4
Minimum	1.5 - PI 431172	2.2 - PI 431251
Maximum	3.5 - PI 215478	4.4 - PI 215478

Fig. 2. Analysis of kernel width (mm) in the USDA rice core collection.



	Brown rice	Rough rice
Mean	2.6±0.5	2.8±0.5
Minimum	1.5 - PI 242804	1.7 - PI 242804
Maximum	4.5 - PI 431172	4.4 – Clor 12425

Fig. 3. Analysis of kernel length/width ratio in the USDA rice core collection.



	Brown rice	Rough rice
Mean	2.58±0.32	3.13±0.36
Minimum	9.52 - PI 377620	12.47 - PI 377620
Maximum	37.39 - PI 373249	42.72 – PI 215478

Fig. 4. Analysis of 1000 kernel weight (g) in the USDA rice core collection.

Effect of Preventative Fungicide Application on Rice Yield, Milling Quality, and Return

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ABSTRACT

Rice cultivars 'Francis', 'Bengal', 'CL-161', and 'RiceTec XL-8' were planted in replicated plots in two counties in 2003 and four counties in 2004. Fungicide treatments in 2003 included an untreated control and a maximum fungicide treatment consisting of Stratego® at 16 fl oz p/acre applied at pre-booting and again at late boot (Craighead site) or Quadris® at 12.3 fl oz/acre applied at pre-booting followed by Quadris at 12.3 fl oz/acre + Tilt® at 6 fl oz/acre at late booting (Prairie site). In 2004, an untreated control, a standard fungicide treatment consisting of 16 fl oz of Stratego during late boot, and a high fungicide treatment of 34 fl oz Quilt® fungicide during late boot were compared on each of the four cultivars. Results in 2003 showed higher yield, milling quality, and profit from fungicide use only for CL-161 at the Craighead County site, where sheath blight was severe. None of the cultivars benefitted from fungicide treatment at the Prairie County location in 2003 and Bengal and Ricetec XL-8 did not benefit at either location. In 2004, both the standard and high fungicide treatments resulted in higher yield for Francis and Cl-161 at only the Lonoke County site, where sheath blight was present. Milling quality was not affected at this location by fungicide treatment. Milling quality was higher for fungicide-treated Francis and CL-161 at the Poinsett County location but yields were not affected at this site nor at the Prairie and Chicot locations. Based on these results, disease at yield-limiting levels needs to be present to justify fungicide use on rice in Arkansas and scouting pays off more than preventative sprays.

INTRODUCTION

Rice diseases continue to be important in limiting profitable rice production in Arkansas and the southern U.S. However, major rice diseases do not cause measurable loss in every field. Sheath blight, blast, and kernel smut are important diseases in Arkansas and fungicides are routinely used to control them. In 2004, fungicides were used on more than 600,000 acres of rice, approximately 39% of the crop. While scouting and decision thresholds are encouraged before any fungicide application, some growers routinely treat their entire acreage, assuming a benefit or at least “break-even” will result. Typically, a single application costing $23 - $25/acre will be made in these preventative situations, although certain growers may use even more. While the value of fungicides in inoculated test plots has been researched for years, their impact in natural-disease or low-disease environments has not been objectively assessed in recent years. The effect of fungicides on current cultivars that vary in disease resistance has not been recently evaluated.

The objectives of this study were to determine the effect of fungicides on yield, milling quality, and return for four rice cultivars that differ in disease resistance.

PROCEDURES

The rice cultivars were the same in study years 2003 and 2004, and included Francis, Bengal, CL-161, and Ricetec XL-8. Francis is a very high-yield potential, long-grain rice with good milling quality but susceptible to blast and kernel smut and moderately susceptible to sheath blight. Bengal is a high-yield potential, medium-grain rice with good milling quality and moderate susceptibility to most fungal rice diseases but is susceptible to bacterial panicle blight. CL-161 is a moderate-yield potential, long-grain rice resistant to Newpath® herbicide, which permits chemical control of red rice within the growing season, but this cultivar is very susceptible to sheath blight and susceptible to blast and kernel smut. Ricetec XL-8 is a very high-yield potential, long-grain hybrid rice with moderate resistance to most rice diseases in Arkansas.

Cultivars were planted during April in both years at 100 lb seed/acre, except for Ricetec XL-8 at 35 lb seed/acre, using a plot grain drill in either 7 or 8 row (7 in. spacing) x 25 ft long plots. Locations were cooperating grower fields in Craighead and Prairie counties in 2003 and Chicot, Lonoke, Prairie, and Poinsett counties in 2004. Plots were fertilized and irrigated with the balance of the field managed by the grower, but all locations were considered high-yield potential environments. Weed and insect control were provided by cooperating growers as necessary.

Treatments in 2003 at the Craighead site included an untreated control and an application of Stratego fungicide at 16 fl oz/acre applied 10 days after panicle differentiation (pre-booting) and again 2 to 3 weeks later during late booting (total of two applications). Treatments in 2003 at the Prairie County location included an untreated control and an application of 12.3 fl oz/acre Quadris 10 days after panicle differentiation (pre-booting) followed by 12.3 fl oz/acre Quadris + 6 fl oz /acre Tilt fungicide 2 to

3 weeks later during late booting. Fungicides in 2003 were applied using a calibrated CO_2-powered backpack sprayer delivering 10 gpa at 20 psi using 11015 tips.

Since the two applications made in 2003 appeared to be "over-kill," treatments in 2004 were modified to a single application of Stratego fungicide at 16 fl oz/acre during booting (standard fungicide treatment) and Quilt (premix of Quadris + Tilt) at 34 fl oz/acre during booting (high fungicide treatment); an untreated control was also included for each cultivar. Fungicides were applied by CO_2-powered backpack sprayer delivering 10 gpa at 20 psi using 11015 tips at the Chicot and Prairie county sites while a Mudmaster 4WD multi-purpose sprayer using compressed air-charged containers delivering 10 gpa at 20 psi and a spray boom fitted with 110015 flat fan spray tips was used at the Lonoke and Poinsett county sites.

Plots were inspected periodically but disease ratings were not collected. Plots were harvested when grain moisture was estimated to be 16 to 22% for each cultivar. A Yanmar rice-plot combine was used that had been modified to provide separate grain samples to preserve plot milling data integrity. However, a Hege rice-plot combine was used at the Chicot County site in 2004. Plot yield was adjusted to 12% grain moisture and milling quality determined using standard rice milling equipment and procedures. Loan rate values were used for all milling value and gross return calculations because this is standardized and not subject to local market fluctuations. Data were analyzed using ANOVA by cultivar and location within year and mean separation was by Tukey's HSD test at P=0.05.

RESULTS AND DISCUSSION

Sheath blight pressure at the Craighead County location was severe in 2003, but appeared to visually affect CL-161 the most. Yield and milling quality were significantly higher for the fungicide treatment on CL-161 (Table 1). While yield was numerically higher for the treated plots of Francis, the difference was not significant (Table 1). Yields for the treated and untreated plots for Bengal and RiceTec XL-8 were not different (Table 1). Milling quality was not affected by fungicide treatment for Francis, Bengal, or RiceTec XL-8 at this site (Table 1).

We calculated milling value and gross return/acre based on numerical values, regardless of whether they differed significantly (Table 1). This approach follows the assumption of farmers that all values differ, regardless of statistical tests. Using this assumption and the total cost of fungicides used at the Craighead site, a profit from treating ($ 45.66/acre) was realized only for CL-161 (Table 1). If the yield and milling quality values could have been obtained with a single Stratego application, then a profit of $ 19.77/acre for Francis would also have resulted, again assuming all numerical differences were real. At best, fungicides applied to Bengal or RiceTec XL-8 would have resulted in "break-even" or a slight loss, even for one Stratego application.

These results clearly demonstrate that 1) significant disease must be present to justify fungicide investment, and 2) variety makes a tremendous difference in whether fungicides are justified, regardless of disease pressure. On the other hand, the results clearly show the value of fungicides when used to protect a highly susceptible variety like CL-161 under Arkansas conditions.

Diseases were not noticeable at the Prairie County site in 2003. Yield and milling quality were not affected by fungicide treatment for any variety (Table 2). Given the high-cost fungicide application ($74.20/acre) used at this site, all fungicide treatments resulted in substantial losses across varieties (-$ 40.47 to -$ 46.20/acre) (Table 2). If the assumption was made that all values were real and could have resulted from a single Stratego application at $23.54/acre, then profit/loss would have been near "break-even."

There was a slight trend for numerically higher yield and milling averages for the treated plots at this location (Table 2). This "bump," real or not, is what convinces growers of the preventative value of fungicides on high yield-potential fields. On the other hand, the "bump" certainly cannot be used to justify more than a single, lower cost fungicide application – at best.

Results in 2004 were more erratic than in 2003. Since the two fungicide applications used in 2003 were unrealistic, we compared a single application of Stratego at 16 fl oz/acre (standard) to a more expensive high-fungicide treatment of Quilt at 34 fl oz/acre, both during booting.

Yield and milling quality were not affected by either fungicide treatment at the Chicot (Table 3) or Prairie sites (Table 5). Milling quality values for CL-161 – untreated, and Francis – high treatment, were very low for unknown reasons at Chicot (Table 3). These locations had little noticeable disease. Assuming all numerical values were real, the standard treatment resulted in a slight profit ($3.29/acre) to minor losses (-$ 8.48/acre) for Francis and Bengal, respectively (Table 3). Large losses occurred from both standard and high fungicide treatments for CL-161 and RiceTec XL-8 (Table 3). If the unexplained low milling quality for CL-161 under the standard fungicide treatment were discarded, this treatment would have resulted in a slight loss of -$ 13.82/acre.

Limited losses were observed at the Prairie County site for Francis, Bengal, and the high-fungicide treatment on CL-161 (Table 5). A slight profit would have resulted for the standard fungicide treatment on CL-161 at this site (Table 5), assuming all values were real. Huge losses resulted in both fungicide treatments on RiceTec XL-8, because the average yield for the untreated control was numerically higher than either fungicide treatment (Table 5).

Yield was increased by fungicide treatment at the Lonoke site in 2004 on Francis and CL-161 (Table 4). This location was an extremely high-yield environment with moderate sheath blight. There was no difference between fungicide treatments (standard and high) though (Table 4). Milling quality was high and unaffected by treatment for any variety at this location (Table 4). Assuming all values to be real, a $24.81/acre profit resulted from standard fungicide use on Francis and a $1.02/acre profit from the more expensive high treatment (Table 4). Profits from the standard and high treatments for CL-161 were very close, $23.49 and $22.72/acre, respectively (Table 4). A slight loss was noted for fungicide treatments on RiceTec XL-8 at this site, probably a reflection of the overall disease resistance in this hybrid (Table 4).

Yield was not affected by fungicide treatment at the Poinsett County location (Table 6). Milling quality was improved by both fungicide treatments for Francis, Bengal, and CL-161 (Table 6). Yield and milling quality were not affected by the fungicides on RiceTec XL-8 (Table 6). Assuming all values to be real, both fungicide treatments resulted in a small profit on Francis; a small loss for the standard treatment, and a small profit for the high treatment on Bengal; a substantial profit of $31.80/acre for the standard treatment and a very small profit for the high treatment on CL-161; and small losses for both treatments on RiceTec XL-8 (Table 6). Diseases at the Poinsett site were limited, with stem rot being the most commonly noted one.

Results from the 2004 trials illustrate again the importance of variety with respect to disease and potential fungicide benefit. Francis and CL-161 tended to benefit more than Bengal and RiceTec XL-8, and this is a strong reflection of the susceptibility to multiple diseases of the former and the resistance to various diseases of the latter. Results from both years do not support "automatic" benefits from preventative fungicide applications, not even with respect to milling quality. Based on loan rate pricing, the value from a gain of 1 percentage point in head or total milled rice averaged $2 ½ cents per bushel – somewhat lower than claims from other sources. On 200 bu/acre rice, this would mean $5/acre in added value for every milling point, if increased milling quality could be consistently achieved with fungicides. Yet this does not always happen, as evidenced by these results.

These trials will be continued for a number of years to more clearly define the benefits of fungicides on rice grown in Arkansas under natural conditions.

CONCLUSIONS

It is clear that disease needs to be present in order to justify any fungicide application in Arkansas. This is not the case in every field and the variety grown greatly influences disease impact, even when present. Thus scouting and sound decision-making are worthwhile, compared to "blanket" preventative fungicide applications.

SIGNIFICANCE OF RESULTS

Based on these results, Arkansas growers could save up to $23.54/acre by utilizing "scout and treat" programs conducted by themselves, county extension agents, rice consultants, or other trained advisors.

ACKNOWLEDGMENTS

We appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the rice check-off administered by the Arkansas Rice Research and Promotion Board. We also thank Carl Hayden, Hank Chaney, Brent Griffin, Keith Perkins, Jeff Welch, and Branon Thiesse for their help.

Table 1. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a heavy sheath blight environment, Craighead Co., 2003.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	---------------- ($/acre)	--------------
Francis	Untreated	183 a[x]	66/73 a	$3.33	$609.56	
Francis	Treated	196 a	65/74 a	$3.33	$652.87	-$3.77
Bengal	Untreated	195 a	69/75 a	$3.14	$612.35	
Bengal	Treated	201 a	68/76 a	$3.14	$632.10	-$27.33
CL 161	Untreated	146 a	67/73 a	$3.35	$489.81	
CL 161	Treated	170 b	69/74 b	$3.43	$582.55	$45.66
RiceTec XL-8	Untreated	195 a	61/72 a	$3.19	$621.52	
RiceTec XL-8	Treated	200 a	62/73 a	$3.19	$638.00	-$21.56

[z] Milling value was calculated at 2003 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1065/lb for long-grain; $0.0965/lb for medium-grain), and BP = Broken Kernel Price ($0.0533/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were from "2003 Crop Rice Loan Rates and Grade Discounts" (USDA, Farm Service Agency, Notice LP-1919, December 1, 2003).

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield averages) less the per-acre cost of fungicide applied. Treated meant Stratego @ 16 fl oz/acre applied pre-booting [$18.54/acre] plus $5/acre aerial application charge followed by Stratego @ 16 fl oz/acre applied late-booting [$18.54/acre] plus $5/acre aerial application charge = $47.08/acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Table 2. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a limited disease environment, Prairie Co., 2003.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	----------------- ($/acre)	--------------
Francis	Untreated	198 a[x]	68/74 a	$3.40	$673.76	
Francis	Treated	205 a	69/74 a	$3.43	$702.48	-$45.47
Bengal	Untreated	181 a	68/77 a	$3.17	$573.55	
Bengal	Treated	185 a	69/77 a	$3.19	$589.82	-$40.47
CL 161	Untreated	164 a	69/74 a	$3.43	$551.71	
CL 161	Treated	166 a	69/75 a	$3.45	$572.82	-$45.31
RiceTec XL8	Untreated	183 a	67/74 a	$3.38	$618.33	
RiceTec XL8	Treated	190 a	68/74 a	$3.40	$646.53	-$46.20

[z] Milling value was calculated at 2003 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1065/lb for long-grain; $0.0965/lb for medium-grain), and BP = Broken Kernel Price ($0.0533/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were from "2003 Crop Rice Loan Rates and Grade Discounts" (USDA, Farm Service Agency, Notice LP-1919, December 1, 2003).

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield and milling averages) less the per-acre cost of fungicide applied. Treated meant Quadris @ 12.3 fl oz/acre applied pre-booting [$24.60/acre] plus $5/acre aerial application charge followed by Quadris @ 12.3 fl oz/acre [$24.60/acre] plus Tilt @ 6 fl oz/acre [$15/acre] applied late-booting plus $5/acre aerial application charge = $74.20/acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Table 3. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a limited disease environment, Chicot Co., 2004.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	---------------- ($/acre)	--------------
Francis	Standard	154 a[x]	62/69 a	$3.13	$481.63	$3.29
Francis	Untreated	150 a	60/67 a	$3.03	$454.79	
Francis	High	153 a	52/61 b	$2.70	$412.76	-$74.91
Bengal	Standard	149 a	68/71 a	$3.01	$448.84	-$8.48
Bengal	Untreated	144 a	68/71 a	$3.01	$433.78	
Bengal	High	151 a	68/72 a	$3.04	$458.47	-$8.19
CL161	Standard	139 a	57/64 a	$2.89	$401.53	-$66.81
CL161	Untreated	136 a	66/71 b	$3.27	$444.81	
CL161	High	135 a	66/71 b	$3.27	$441.54	-$36.15
XL-8	Standard	172 a	55/70 a	$2.98	$513.32	-$62.74
XL-8	Untreated	174 a	59/74 a	$3.18	$552.52	
XL-8	High	172 a	55/69 a	$2.96	$509.21	-$76.19

[z] Milling value was calculated at 2004 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1061/lb for long-grain; $0.0961/lb for medium-grain), and BP = Broken Kernel Price ($0.0531/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were obtained from http://www.fsa.usda.gov/pas/FullStory.asp?StoryID=1592 - USDA, Farm Service Agency, March 5, 2004.

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield averages) less the per-acre cost of fungicide applied. Standard treatment = Stratego @ 16 fl oz/acre applied during booting [$18.54/acre] plus $5/acre aerial application charge = $23.54/acre total . High treatment = Quilt @ 34 fl oz/acre applied during booting [$27.88 per acre] plus $5/acre aerial application charge = $32.88 per acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Table 4. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a limited disease environment, Lonoke Co., 2004.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	---------------- ($/acre)	--------------
Francis	Standard	236 a	62/73 a	$3.22	$760.64	$24.81
Francis	Untreated	221 b	62/73 a	$3.22	$712.29	
Francis	High	235 a	61/72 a	$3.18	$746.19	$1.02
Bengal	Standard	217 a	66/74 a	$3.05	$660.84	-$14.39
Bengal	Untreated	211 a	67/75 a	$3.09	$651.69	
Bengal	High	208 a	66/74 a	$3.05	$633.43	-$51.14
CL161	Standard	189 a	66/72 a	$3.29	$622.67	$23.49
CL161	Untreated	176 b	65/72 a	$3.27	$575.64	
CL161	High	193 a	65/72 a	$3.27	$631.24	$22.72
XL-8	Standard	246 a	60/73 a	$3.18	$781.13	-$8.67
XL-8	Untreated	245 a	59/72 a	$3.13	$766.26	
XL-8	High	247 a	60/72 a	$3.15	$778.41	-$20.73

[z] Milling value was calculated at 2004 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1061/lb for long-grain; $0.0961/lb for medium-grain), and BP = Broken Kernel Price ($0.0531/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were obtained from http://www.fsa.usda.gov/pas/FullStory.asp?StoryID=1592 - USDA, Farm Service Agency, March 5, 2004.

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield averages) less the per-acre cost of fungicide applied. Standard treatment = Stratego @ 16 fl oz/acre applied during booting [$18.54/acre] plus $5/acre aerial application charge = $23.54/acre total. High treatment = Quilt @ 34 fl oz/acre applied during booting [$27.88/acre] plus $5/acre aerial application charge = $32.88/acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Table 5. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a limited disease environment, Prairie Co., 2004.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	----------------- ($/acre)	--------------
Francis	Standard	175 a	63/68 a	$3.13	$547.30	-$14.07
Francis	Untreated	176 a	60/68 b	$3.06	$537.83	
Francis	High	179 a	60/68 b	$3.06	$547.00	-$23.71
Bengal	Standard	160 a	69/72 a	$3.06	$488.89	-$11.32
Bengal	Untreated	156 a	69/72 a	$3.06	$476.67	
Bengal	High	166 a	69/72 a	$3.06	$507.23	-$2.32
CL161	Standard	166 a	66/72 a	$3.29	$546.89	$5.68
CL161	Untreated	156 a	67/72 a	$3.32	$517.67	
CL161	High	160 a	67/72 a	$3.32	$530.94	-$19.61
XL-8	Standard	187 a	56/69 a	$2.98	$558.07	-$87.17
XL-8	Untreated	210 a	55/69 a	$2.96	$621.71	
XL-8	High	200 a	55/68 a	$2.94	$587.32	-$67.26

[z] Milling value was calculated at 2004 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1061/lb for long-grain; $0.0961/lb for medium-grain), and BP = Broken Kernel Price ($0.0531/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were obtained from http://www.fsa.usda.gov/pas/FullStory.asp?StoryID=1592 USDA, Farm Service Agency, March 5, 2004.

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield averages) less the per-acre cost of fungicide applied. Standard treatment = Stratego @ 16 fl oz/acre applied during booting [$18.54/acre] plus $5/acre aerial application charge = $23.54/acre total. High treatment = Quilt @ 34 fl oz/acre applied during booting [$27.88/acre] plus $5/acre aerial application charge = $32.88/acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Table 6. Effect of preventative fungicide treatment on rice yield, milling quality, and return/acre in a limited disease environment, Poinsett Co., 2004.

Variety	Treatment	Yield	Milling %HR/%TR	Milling value[z]	Gross return	Profit/loss[y]
		(bu/acre)		($/bu)	---------------- ($/acre)	--------------
Francis	Standard	175 a	64/70 a	$3.20	$559.83	$5.58
Francis	Untreated	171 a	61/69 b	$3.10	$530.72	
Francis	High	182 a	63/68 a	$3.13	$569.19	$5.59
Bengal	Standard	131 a	68/71 a	$3.01	$394.62	-$9.28
Bengal	Untreated	130 a	66/69 b	$2.93	$380.36	
Bengal	High	140 a	68/71 a	$3.01	$421.73	$8.49
CL161	Standard	138 a	67/72 a	$3.32	$457.94	$31.80
CL161	Untreated	124 a	65/71 b	$3.25	$402.60	
CL161	High	133 a	66/72 a	$3.29	$438.17	$2.69
XL-8	Standard	195 a	62/72 a	$3.20	$623.83	-$11.08
XL-8	Untreated	194 a	61/71 a	$3.15	$611.37	
XL-8	High	201 a	62/72 a	$3.20	$643.03	-$1.22

[z] Milling value was calculated at 2004 loan value using the following formula: 0.45*(HP*%HR + BP*[%TR-%HR]) where HP = Whole Kernels Price ($0.1061/lb for long-grain; $0.0961/lb for medium-grain), and BP = Broken Kernel Price ($0.0531/lb for both long- and medium-grain). Loan values for whole kernels and broken kernels were obtained from http://www.fsa.usda.gov/pas/FullStory.asp?StoryID=1592 - USDA, Farm Service Agency, March 5, 2004.

[y] Profit/loss equals the difference in per-acre gross returns (based on numerical yield averages) less the per-acre cost of fungicide applied. Standard treatment = Stratego @ 16 fl oz/acre applied during booting [$18.54/acre] plus $5/acre aerial application charge = $23.54/acre total. High treatment = Quilt @ 34 fl oz/acre applied during booting [$27.88/acre] plus $5/acre aerial application charge = $32.88/acre total.

[x] Means within cultivar were not significantly different if followed by the same letter (P = 0.05, Tukey's HSD test).

Opportunities for Variable-Rate Fungicide Application in Rice

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ABSTRACT

Fungicide treatments for sheath blight and other diseases typically cost more than $20/acre per application. These treatments represent a significant cost of production in rice. The objectives of this study were: 1) to determine if multi-spectral images correlate with rice stress areas caused by disease, lack of water, or early flooding; and, 2) to assess the use of biomass zones to make a prescription for variable fungicide application. Imagery taken late in the season did not visually indicate where sheath blight was in the field. Imagery will be taken earlier in the 2005 season just prior to the boot stage. In this case, a 35% chemical savings would have occurred if an aerial applicator capable of variable-rate applicants had been available.

INTRODUCTION

In Arkansas, most of the 1.5 million acres of rice planted are susceptible to sheath blight and other fungal diseases (University of Arkansas, 2004; Cartwright and Lee, 2004). Under the current system, the entire field is treated when conditions call for a fungicide application. Many times, the occurrence of sheath blight varies with factors such as field elevation and soybean stubble. An opportunity may exist to apply fungicide only where it is needed based on field scouting and rice biomass maps from imagery. The objectives of this study were to determine: 1) if multi-spectral images could correlate with rice stress areas due to disease, lack of water, or early flooding, and 2) whether biomass zones were consistent enough to be used to make a prescription for variable-rate application.

PROCEDURES

A rice-production field in Lawrence County was observed in this study. Aerial images were acquired of the rice crop throughout the growing season with an aircraft-mounted multispectral camera capable of an image resolution of approximately one to two meters depending on altitude. The camera used three filters set for various wavelengths, which allowed the camera to sense wavelengths of 550nm, 600nm, and 800nm.

Color infrared digital orthoquarterquads (DOQQ) photographs obtained from the United States Geological Survey (USGS), used for surveying, were acquired from the University of Arkansas Center for Advanced Spatial Technologies (CAST) website. The DOQQs provided geographical correction of the multispectral aerial images in a GIS.

The images were enhanced with a classified NDVI calculation, normalized difference vegetative index, so that the best view of the rice variability could be viewed. Images were classified into seven biomass groups, then exported into an iPAQ to be used as a scouting tool.

During the growing season, the rice field was scouted weekly for signs of stress. The iPAQ was equipped with a DGPS with an accuracy of approximately 2 meters for field scouting. Each biomass class was evaluated with regard to plant vigor (biomass). A prescription was created in SMS Advanced based on the image. This prescription was developed for an aerial applicator with grid cells size of 200 ft by 60 ft.

RESULTS AND DISCUSSION

Sheath blight was found by scouting in the lower elevation of the field, which is typical for the disease (Cartwright and Lee, 2003). An elevation map was created by digitizing images of the levees to show this relationship (Fig. 1). This particular field had a large area covered by soybean stubble from early-season flooding (Fig. 2). Sheath blight was also found in areas of the higher elevation of this field, likely related to deposits of sclerotia or infested crop debris from the previous season. The same pathogenic fungus that causes aerial blight in soybeans causes sheath blight in rice and it survives well in a rice/soybean rotation (Coker et al., 2000). As a result of early flooding of the lower end of the field, the rice was delayed in development compared to a non-flooded field. In aerial imagery taken later in the growing season, this portion of the field was classified differently with regards to biomass. The image did not visually match up with the scout observation. Sheath blight was evident in this lower portion of the field (Fig. 3). The field was treated with a full rate of Quadris, 12.3 oz/acre (Syngenta, 2004). Based on a variable-rate prescription map shown in Figure 4, it was predicted that the producer could have achieved a chemical savings of 35% compared to this full- rate blanket application.

SIGNIFICANCE OF FINDINGS

Timing of the image is an important part of the analysis to be used as an effective scouting tool. Past studies have indicated that the best time to acquire imagery on rice is just prior to boot. Another way to gauge flight timing is to use the DD50 program that the University of Arkansas Cooperative Extension Service provides. The week that the DD50 recommends scouting for diseases would be an appropriate time to acquire an image. Weather also plays an important role with clouds being the greatest concern, due to shadows they cast even if the actual clouds don't obscure. The model used predicted that a producer would save chemical costs by using a variable-rate application based on routine remote scouting.

ACKNOWLEDGMENTS

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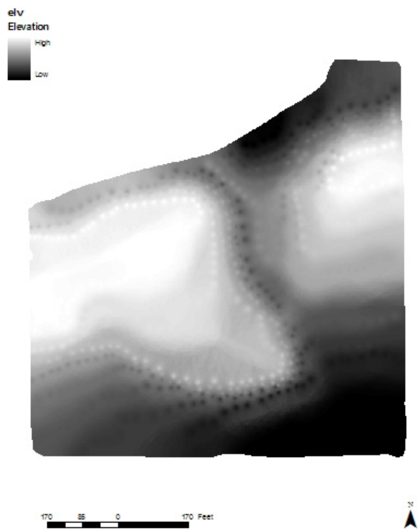

Fig. 1. Elevation surface created by digitizing the levee images.

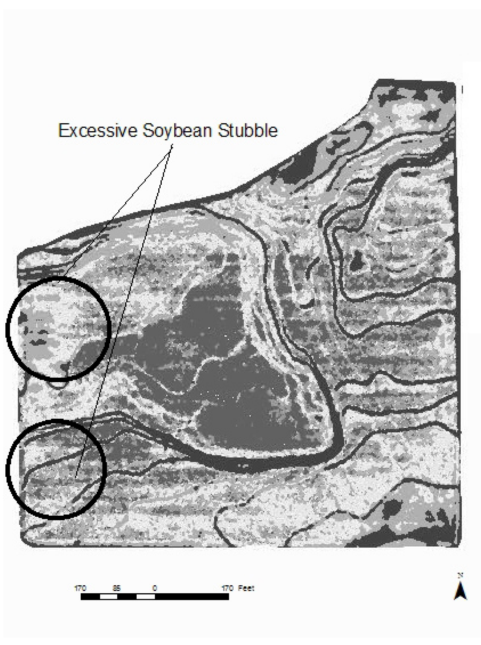

Fig 2. Classified image from 5 July 2004 showing large areas of soybean stubble that were field-scouted.

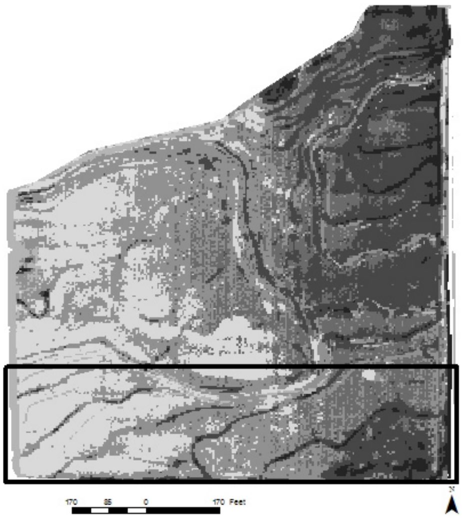

Fig. 3. Classified image from 21 July 2004 showing the lower portion where sheath blight was found by ground-truthing.

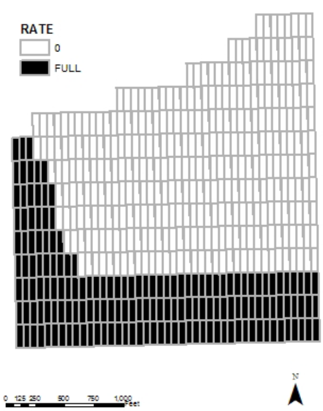

Fig. 4. Variable-rate prescription developed on the basis of scouting.

Two Major Resistance Genes Confer Resistance to Race Shift Isolates Overcoming Blast Resistance Gene *Pi-ta*

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ABSTRACT

One of the major challenges for blast disease management is that major resistance genes are often defeated by new virulent isolates. The goal of this project is to identify and characterize blast resistance genes to facilitate the development of blast resistant U.S. cultivars by marker-assisted selection. A combination of genetic, molecular, and pathological approaches was used to identify and map novel, major blast resistance genes. A 'Raminad Str. 3/RU9101001' F_2 population was initially used for pathogenicity tests and mapping. Segregation analysis indicates two major *R* genes from Raminad Str. 3 confer resistance to the race shift isolate TM2 (IE-1k). To establish the frame for the map position, a recombinant inbred population of 'Zhe733'/'Kaybonnet' low phytic acid (KBNT*lpa1-1*) was used to develop the genetic map. One of the major genes designated *Pi-Zhe733 (t)* was tentatively mapped near a known major resistance gene *Pi-z*. Another *R* gene designated *Pi-Zhe733b (t)* was tentatively mapped on chromosome 11 distal to the *Pi-k* locus. Two resistance genes to IE-1k in Zhe733 also were confirmed by an additional Zhe733/C101A51F_2 population and this population is being used for fine mapping.

INTRODUCTION

Rice blast, caused by the hemibiotrophic pathogen *Magnaporthe grisea*, is an important disease in U.S. rice production. Since 1989, the deployment of the major resistance (*R*) gene *Pi-ta* was effectively used to prevent economic losses due to blast. *Pi-ta* confers resistance to a broad spectrum of U.S. blast isolates including the predominant races IB-49 and IC-17 (Jia et al., 2004). For years, researchers observed that the blast race IE-1k (TM2) overcame *Pi-ta*-mediated resistance both in laboratory (IB-33) and field (IE-1k) (Correll et al., 2000; Yan, 2004). In 2004, virulent isolates caused significant damage to the *Pi-ta*-containing cultivar 'Banks' in several rice fields of Banks near Corning, Ark. (Lee et al., 2005).

Breeding for blast resistance is one of the major objectives for rice improvement in Arkansas. A number of major *R* genes, such as *Pi-ta and Pi-b,* are being characterized. DNA markers were developed from portions of the *R* genes for use in marker-assisted selection (MAS) programs (Jia et al., 2002; Jia, 2003; Jia et al., 2004; Fjellstrom et al., 2004). In Arkansas, an MAS program has been established to incorporate the *Pi-ta* resistance into rice cultivars (Johnson et al., 2003).

It is important to identify additional blast resistance genes that can be deployed against virulent blast races that may develop. The objective of this study is to identify the resistance factors to the virulent race IE-1k using polymorphic simple sequence repeat (SSR) markers.

PROCEDURES

Plant Materials and Pathogenicity Assays

Mapping populations used in this study were: 1) F2 populations: Raminad Str. 3/RU910100l and Zhe733/C101A51, and F10/F11 recombinant inbred lines (RIL) of Zhe733/ KBNT*lpa1-1* (Rutger and Tai, 2005). Parents of mapping populations used in this study were Zhe733, Raminad Str. 3, C101A51, and RU9101001. Zhe733 and Raminad Str. 3 are resistant to isolates TM2 (IE-1k), S1 and 94071A. C101A51, KBNT*lpa1-1*, and RU9101001 are susceptible to blast isolatesTM2 (IE-1k), S1, and 94071A. Standard methods described in Valent et al. (1991) were used for pathogen inoculation. Briefly, 7 to 10 seeds were germinated and transplanted to a pot. These seedlings were sprayed with an *M grisea* spore suspension (6 X 10^5 spores/ml). Plants were then incubated in a dew chamber at 21°C, maintaining humidity at 70%. Twenty-four hours after inoculation, plants were moved into a greenhouse for an additional six days. Disease reaction was determined seven days after inoculation based on a rating standard described in Valent (1997).

Simple Sequence Repeat (SSR) Marker Analysis and Mapping

SSR marker analysis was performed using PCR conditions previously described in Lu et al. (2005) except the reaction volume was 25 µl. Amplified products were diluted between 40-2000x and 2 µl of the diluted product were added to 9 µl of formamide containing ROX-labelled size standard. This was run on an ABI Prism 3700 DNA Analyzer according to the manufacturer's instructions (Applied Biosystems, Foster

City, Calif.). Fragment sizing was performed with GenScan 3.1.2, and alleles were called with Genotyper 2.5 (Applied Biosystems, Foster City, Calif.) and binned manually. Mapping of resistance was performed using JoinMap 3.0 (Kyazma, Wageningen, Netherlands).

RESULTS AND DISCUSSION

A Raminad Str. 3/RU9101001 F_2 population of 253 individuals and 344 Zhe733/KBNT *lpa1-1* F_{10}/F_{11} recombinant inbred lines was inoculated with several blast isolates known to overcome *Pi-ta* (Table 1). A ratio of 15 resistant:1 susceptible suggests that resistance in Raminad Str. 3 was conditioned by two major *R* genes to blast isolate TM2. This is consistent with findings of R. Fjellstrom and his colleagues (USDA-ARS, Beaumont, Texas) who also discovered that two major *R* genes in Raminad Str. 3 confer resistance to a blast race IE-1k using the same Raminad Str. 3/RU9101001 F_2 population (R. Fjellstrom, pers.comm). To tag resistance genes, a Zhe733/KBNT *lpa1-1* RIL population consisting of 344 individuals was analyzed and a ratio of 3 resistant:1 susceptible was observed indicating that two major *R* genes in Zhe733 confer resistance to the virulent isolates.

To identify DNA markers associated with resistance, Zhe733 and KBNT*lpa1-1* were genotyped using a total of 162 SSR markers that were distributed among all twelve chromosomes of the rice genome (www.gramene.org; Lu et al., 2005). A total of 125 polymorphic SSR markers were identified for bulked segregant analysis. Ten resistant and ten susceptible plants were bulked and seven SSR markers were identified that were associated with resistance. Co-segregated SSR markers on chromosome 6 were then analyzed for the entire RIL population to determine the genetic distance to the resistance factor. The current data suggest the *R* gene on chromosome 6 is mapped near SSR markers MRG2431, MRG5836, MRG4963, and RM136 which are closely linked with *Pi-z* and the gene was designated *Pi-Zhe733 (t)*. Conway-Bormans et al. (2003) also reported that MRG2431, MRG5836, and MRG4963 are markers for *Pi-z*. A new marker, RM136, identified in this study, was polymorphic between Zhe733 and KBNT*lpa1-1*, and between Zhe733 and C101A51.

On chromosome 11, SSR markers RM144 and RM224 cosegregated with resistance and these markers were also used to genotype all individuals. This *R* gene was tentatively located on chromosome 11. Since RM224 is at the proximal end of the *Pi-k* locus (Fjellstrom et al., 2004) and the resistance factor is loosely linked to RM224, it is distal to the *Pi-k* locus and was designated *Pi-Zhe733b (t)*.

To confirm and extend our mapping studies, a Zhe733/Cl01A51 F_2 population of 263 individuals was used to produce F_3-segregating families. Again, a ratio of 15 resistant:1 susceptible was discovered in F_2 individuals. All resistant F_2 segregating for *Pi-Zhe733 (t)* and *Pi-Zhe733b (t)* have been identified for fine mapping.

SIGNIFICANCE OF FINDINGS

Identification of novel resistance genes in parents of Arkansas rice varieties is important to accelerate the development of new blast-resistant cultivars. Two novel blast-resistance genes were identified in breeding parents, Raminad Str. 3 and Zhe733. The rough location for these two resistance genes was determined by analysis of polymorphic DNA markers in mapping populations. Based on these data, closely linked DNA markers were identified that are suitable for use in marker-assisted selection as part of rice breeding programs.

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Table 1. Segregation ratios of resistance to three *Magnaporthe grisea* races and genotypes in segregating rice populations.[z]

			Disease reaction of F_2 progeny			
Pedigree	Isolate[y]	Total	Resistant	Susceptible	χ^2	*P*
Raminad Str. 3/RU9101001	TM2	253	239	14	0.267[x]	0.625
Zhe733/KBNTlpa[w]	TM2	344	245	99	2.620[v]	0.104
Zhe733/KBNTlpa[w]	S1	341	263	78	0.767[v]	0.400
Zhe733/KBNTlpa[w]	94071A	342	258	84	0.039[v]	0.867
Zhe733/C101A51	TM2	263	245	18	0.266[x]	0.625

[z] Disease reaction was determined based on methods described in Valent (1997).

[y] TM2 is IE-1k, S1 and 94071A are avirulent on Zhe733 and Raminad Str. 3 but are virulent on *Pi-ta*-containing cultivars.

[x] A ratio of 15:1 (resistant:susceptible) was expected.

[w] Zhe733/KBNT*lpl1-1* is a mix of F_{10}/F_{11} recombinant lines of the cross of Zhe733 with KBNT*l-pa1-1* (Rutger and Tai, 2005).

[v] A ratio of 3:1 (resistant:susceptible) was expected.

Flood-Induced Field Resistance in Drew and Related *Pi-ta* Gene Varieties Compromised by New Blast Races

F.N. Lee, M.P. Singh, and P.A. Counce

ABSTRACT

Rice blast, the erratic niche disease incited by *Magnaporthe grisea* Cav., limits rice yield and cultivar options in Arkansas rice-production areas. Arkansas growers unknowingly utilized flood-induced field resistance as their primary blast-control measure when producing record state rough-rice yields growing blast-susceptible cultivars 'Wells', 'Cocodrie', 'LaGrue', and 'Francis' during the blast-conducive years 2000 to 2004. Field resistance permits continued utilization of cultivars lost when the blast fungus adapts to major genes such as the *Pi-ta* gene, which determines resistance in varieties such as 'Katy', 'Drew', 'Kaybonnet', 'Ahrent', 'Cybonnet', and 'Banks'.

The nature of flood-induced blast resistance is poorly understood. Lack of critical data about the mode of inheritance, the relationship between major and minor blast resistance genes, the role of signaling hormones such as ethylene, and methods to detect, induce, and quantify the field response limit our use of common research tools. Our data show leaf lesion severity (measured as a blast index following inoculation with spores of *Pi-ta*-virulent isolates IE-1k, IB-33, and MGS-19) to be more severe on rice varieties growing upland than when growing in a continuous flood, regardless of the *Pi-ta* gene being present or absent in the variety. Some degree of flood-induced field resistance was exhibited by all rice varieties tested.

INTRODUCTION

Arkansas scientists have made significant progress in defining and utilizing the long-observed phenomenon of rice plants becoming blast resistant when growing in saturated or continuously flooded soil (Lee et al., 2004; Singh et al., 2004a; Singh et al., 2004b; Singh et al., 2004c). Within hours of flooding, available soil root-zone dissolved oxygen (DO) is is consumed through plant and microbial metabolism and changed soil conditions to establish anaerobic conditions. Root zone DO levels determine availability and form of plant nutrients, particularly nitrogen, directly linked with blast severity. Ammonium ions, the N-source under low DO, do not increase blast susceptibility while nitrate ions, the N-source during high DO conditions, increases blast susceptibility. Low DO conditions increase root production of ethylene and other hormones associated with disease-resistance mechanisms. High levels of field resistance are induced by application of ethephon, which facilitates ethylene production. In addition, low root-zone DO conditions induce plant morphological changes which enhance oxygen movement to rice roots and limit fungal growth in aerial plant parts such as leaves.

Historically, a primary blast-control strategy has been to develop varieties having major resistance genes which inhibit infection by one or more specific blast fungal biotypes (races) common to Arkansas rice-production areas. The historic problem with R gene resistance, especially as the single resistance source for multiple races, has been the blast fungus's inherent ability to compromise the gene. Currently, blast races IB-49 and IC-17 are routinely encountered while older problem races such as IB-1, IG-1, IH-1, and others are recovered less frequently in Arkansas production areas. In 1989, Arkansas plant breeders released Katy, a rice cultivar containing the *Pi-ta* gene discovered in the wild-type rice, 'Tetep'. When first deployed, the *Pi-ta* gene conferred resistance to all blast races found in Arkansas production areas. For fifteen years, Arkansas growers have continually utilized the *Pi-ta* gene to control rice blast in Arkansas cultivars including Katy, Kaybonnet, Drew, and Ahrent.

True to form, however, the fungus quickly adapted with multiple novel blast races to defeat the *Pi-ta* gene. Two of these races, IB-33 and IE-1k, appeared potentially devastating and have since concerned rice researchers. However, only race IE-1k has been isolated from commercial fields and field-test plots. Although *Pi-ta*-based cultivars became widely distributed in Arkansas and U.S. production areas, these occurrences were infrequent without any known reports of significant race IE-1k field infection beyond the few random plants. However, the need to counter this boom-or-bust cycle is emphasized with the discovery of a *Pi-ta*-virulent race causing very severe rice blast in a Banks field near Corning, Ark., during the very blast-favorable environmental conditions of 2004. This research effort addresses the effectiveness of flood-induced field blast resistance as a disease-control measure when the fungus adapts to major resistance genes.

PROCEDURES

Test varieties were grown in 5 (H)- by 6 (W)-in. plastic pots with four 0.25-in. drainage holes filled with 4 in. Dewitt silt loam field soil (Lee et al., 2004; Singh et al., 2004a; Singh et al., 2004b; Singh et al., 2004c). Single hill plots with 6 to 8 healthy seedlings of each cultivar were spaced equidistantly around the pot perimeter. Herbicides or other chemicals were not applied. Plants were grown for 4 weeks (V4) under simulated upland conditions by watering daily with deionized water and fertilizing with a 1% 20:20:20 N:P:K Peters solution one day prior to applying treatments. Treatments were either upland with sufficient water applied daily to maintain optimal plant growth; a continuous flood where pots of previously upland plants were positioned inside flooded larger pots, 9 in. (H) by 14 in. (W); or plants recieved 50 ppm foliar or drench applications of ethephon prior to establishing upland or flooded conditions.

Pathogenicity tests were conducted using the avirulent race IB-49, *Pi-ta*-virulent races IE-1k, race IB-33, and laboratory isolate MSG-19. Plants were inoculated with spore suspensions of individual isolates at 2 x 10^5 spores/ml in distilled water containing 0.025% xanthan gum (Spectrum Inc., Calif.). Inoculum was applied with an artist airbrush until runoff occurred. Immediately following inoculation, plants were moved into a dew chamber at 20°C and 100% RH in the dark for 18 hours. Plants were then returned to their original test positions. Leaf lesion development was evaluated after about seven days using a zero to one blast severity index.

RESULTS AND DISCUSSION

As indicated by the higher blast index following inoculation with either race IB-49 or *Pi-ta*-virulent isolate MGS-19, blast was more severe in susceptible varieties not containing major resistance genes when growing in upland conditions than when growing in a continuous flood (Fig. 1). Comparable responses were observed when *Pi-ta* varieties Katy, Kaybonnet, Drew, and Ahrent were inoculated with the virulent isolates IE-1k, IB-33, and MGS-19 (Fig. 2). Since the Arkansas *Pi-ta* varieties are closely related, the more distant cultivars Tetep (a parent of Katy), 'CICA 9', and 'Tadukan' were tested for the flood-induced resistance response. When inoculated with race IB-33 and isolate MSG-19, test cultivars growing in flood conditions had a lower blast index than when growing upland (Fig. 3).

Test data presented are from short-term greenhouse tests where the magnitude of treatment response is limited. However, previous research and field observations show induced field resistance to be cumulative with duration and depth of flood and comparable in certain varieties to resistance expressed by major R genes. Thus, results define flood-induced field resistance as an effective blast-control measure in those situations where the blast fungus has compromised R-gene resistance. The overall effect of field resistance is a reduction in number of infections, rate of lesion development, and spores produced per lesion. Thus, flood-induced field resistance appears to limit the development and dispersal of new R-gene virulent blast races.

Although research results presented here demonstrate flood-induced resistance functions in compromised R-gene varieties, a very significant question remains unanswered: Is the observed resistance being expressed by the compromised genes under low DO root-zone conditions or have the race shift isolates completely overwhelmed the R gene and thus the expressed resistance is derived from undefined durable resistance genes? Answers to this basic question are needed to provide direction for future research for the development of this highly effective blast-control measure.

SIGNIFICANCE OF FINDINGS

Arkansas growers relied upon flood-induced field resistance as their primary blast-control measure while producing record rough rice yields in blast-susceptible cultivars Wells, LaGrue, and Francis during the disease conducive years of 2000 to 2004. On the whole, this research data on flood-induced blast field-resistance better defines a poorly understood blast-resistance phenomenon and provides scientific insight about partial resistance mechanisms. Information presented here aids in developing high-yielding blast-resistant varieties and/or practical control recommendations for blast control after the blast fungus has overwhelmed the major resistance genes.

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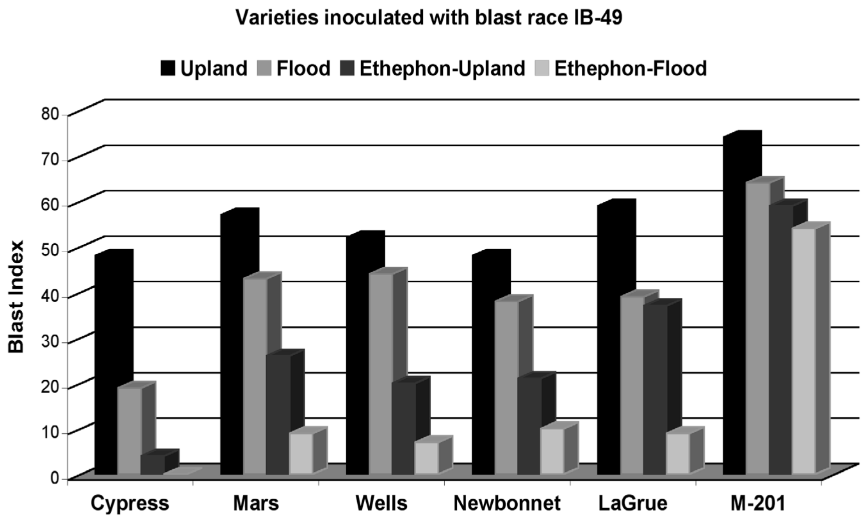

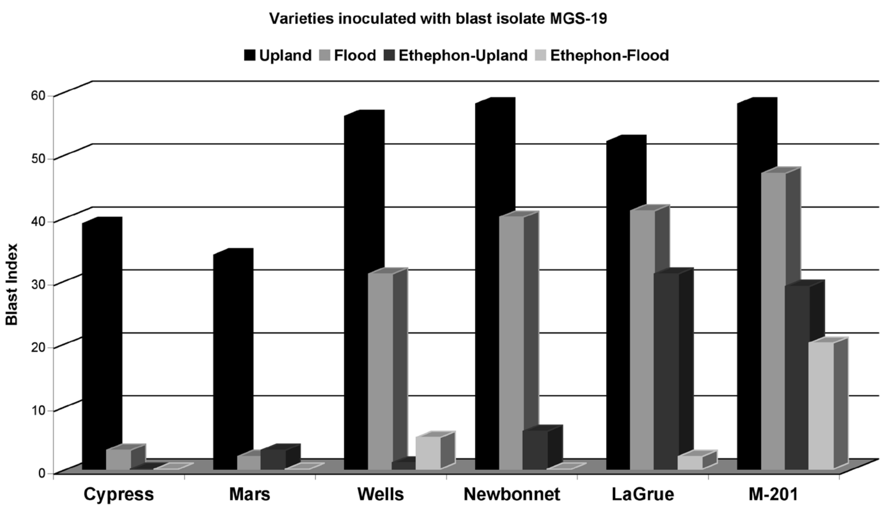

Fig. 1. Blast index comparison of susceptible varieties growing either upland, flooded, upland+ethephon, or flooded+ethephon and inoculated with: A. *Pi-ta*-avirulent *M. grisea* race IB-49 or B. *Pi-ta*-virulent isolate MGS-19.

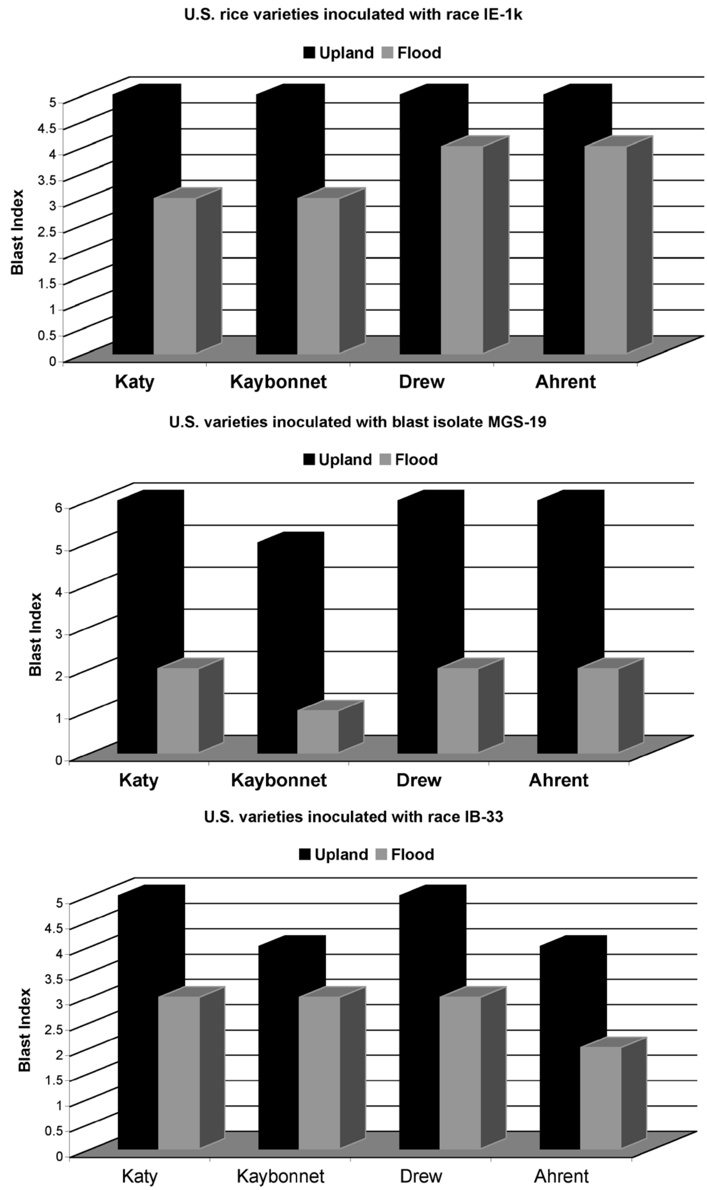

Fig. 2. Blast index comparison of U.S. varieties with *Pi-ta*-gene blast resistance growing either upland or flooded and inoculated with *Pi-ta*-virulent blast races: A. IE-1k; B. MGS-19; or C. IB-33.

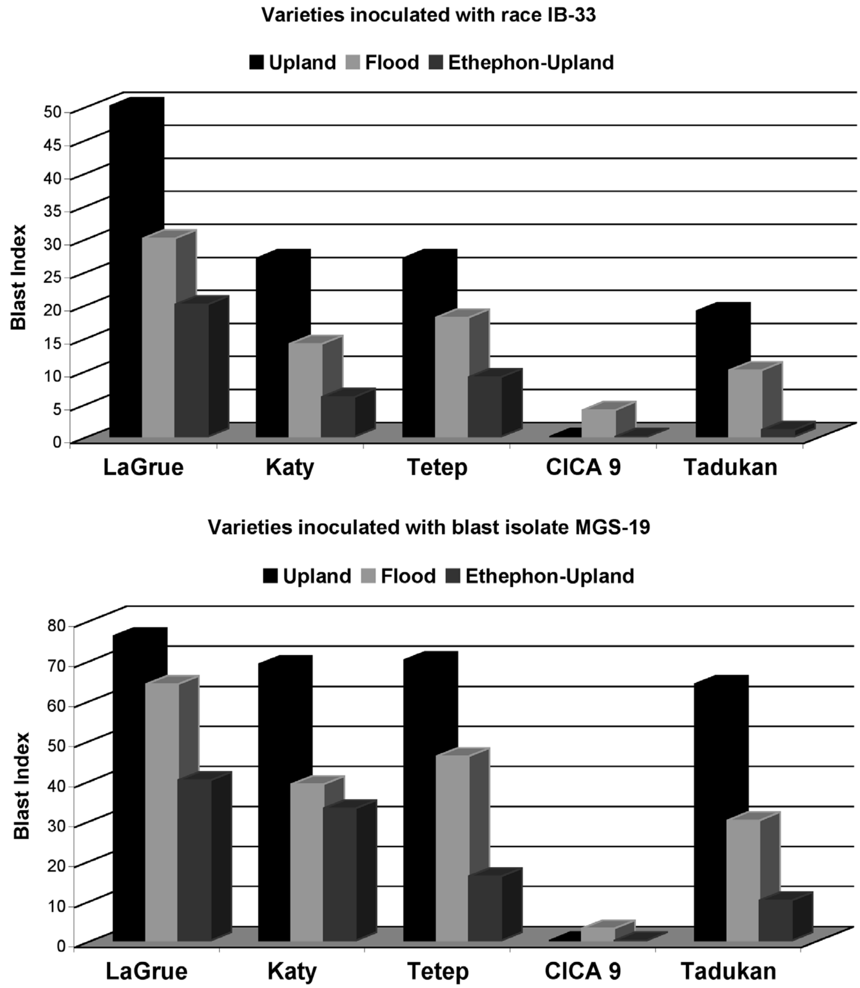

Fig. 3. Blast index comparison of susceptible LaGrue, *Pi-ta*-gene resistant variety Katy, Katy's parent Tetep, and *Pi-ta*-gene resistant varieties CICA 9 and Tadukan when growing either upland, flooded, or upland-ethephon treated and inoculated with *Pi-ta*-virulent blast races: A. IB-33; or B. MGS-19.

A Preliminary Characterization of the Rice Blast Fungus on 'Banks' Rice

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ABSTRACT

'Banks', named after Heartsill G. Banks [the first University of Arkansas Rice Research and Extension Center (RREC) director in 1926], was released to seed growers during 2004. Developed at the RREC, Banks is a high yielding variety with the major blast resistance (R) gene *Pi-ta* and offers a primary advantage over varieties 'LaGrue' and 'Wells' through an increased resistance to the rice blast races such as IB-49 and IC-17 commonly found in Arkansas. Varieties with the *Pi-ta* gene are susceptible to rare races such as IE-1k known to occur infrequently in Arkansas rice production areas.

Under the highly conducive environmental conditions of 2004, approximately 20 acres of a Banks field in Clay County were severely damaged by rice blast. In addition, infrequent, blasted plants were recovered from other Banks fields in Clay and Lawrence counties. Investigations confirmed diseased plants to be Banks. Fungal isolates from blasted plants were tentatively characterized as *Magnaporthe grisea* race IE-1k.

Pi-ta-based cultivars including 'Katy', 'Kaybonnet', 'Drew', and 'Ahrent' were widely utilized in Arkansas production areas during the 15 years since Katy was released in 1989. Race IE-1k, discovered soon after the release of Katy and considered a potential threat to Arkansas rice production, was believed to be "poorly environmentally adapted" because incidence has been limited to a few random plants infrequently recovered from commercial fields and research field plots. Initial pathological characterization of virulent blast isolates from the *Pi-ta*-based Banks variety are presented here.

INTRODUCTION

Rice blast, a niche disease caused by the fungus *Magnaporthe grisea,* significantly reduces rice quality and yield in susceptible varieties grown during environmentally favorable conditions in Arkansas. Historically, the primary blast-control strategy has been resistant varieties with major genes that inhibit infection by one or more specific blast fungal biotypes (races) common to Arkansas rice fields. In 1989, the University of Arkansas Agricultural Experiment Station released Katy rice containing the *Pi-ta* gene discovered in 'Tetep'. The *Pi-ta* gene conferred resistance to all blast races found in Arkansas when deployed. For fifteen years, Arkansas growers successfully utilized the *Pi-ta* gene in blast-resistant varieties Katy, Kaybonnet, Drew, and Ahrent in blast-prone fields. In 2004, new varieties 'Cybonnet' and Banks with *Pi-ta* gene blast resistance were released to seed growers.

A historic problem with major gene resistance, especially as a single resistance source against multiple blast races, has been the pathogen's inherent ability to compromise the gene. True to form, multiple novel blast races compromising the *Pi-ta* gene were discovered soon after Katy was released. Of these, two races, IB-33 and IE-1k, appeared potentially devastating and have since concerned rice researchers. Although *Pi-ta*-based cultivars became widely distributed in Arkansas and U.S. production areas, race IE-1k has been infrequently recovered from commercial fields and field-test plots without any known damage. IB-33 has been observed only in the laboratory. Currently, blast races IB-49 and IC-17 are routinely encountered in Arkansas production areas while older problem races such as IB-1, IG-1, and IH-1 are recovered less frequently. Regardless, ongoing research funded by the Rice Research and Promotion Board has identified multiple sources of resistance to races IE-1k and IB-33 in the rice germplasm pool.

During 2004, very severe rice blast was discovered in approximately 20 acres of a Banks field near Corning, Ark. Also, individual blasted plants were recovered from other Banks fields in Clay and Lawrence counties. Severe blast was unexpected in Banks because experimental greenhouse and field nursery results compared with those of *Pi-ta*-varieties, such as Drew, commonly grown in blast prone production areas of Arkansas.

PROCEDURES

Rice scientists initiated research to determine why blast developed in the Banks seed-rice field, why it was so severe, and to anticipate potential problems with the new or older blast-resistant cultivars. Questions to be resolved included: Was there any evidence for mixed or impure seed? Was the blast race indeed IE-1k? If not IE-1k, did a new blast race or variant develop in Banks to signal loss of *Pi-ta* resistance for blast control? Or did the extremely blast-conducive environmental conditions combine with an adverse field-stress situation to predispose the plants to rice blast?

RESULTS

Field Conditions

Severely diseased plants from the affected field were confirmed as being Banks through careful examination of grower records, comparison of plant characteristics with known Banks plants, and positive molecular assays for the presence of the *Pi-ta* gene. While confirming variety purity in the severely diseased field, a comprehensive examination for blast in Banks fields detected a few random, blasted plants in research plots and in two additional fields in Clay County and one in Lawrence County. Two additional reports of blast in Banks fields in Lawrence County could not be confirmed.

Field conditions were variable in the badly diseased Banks field. Approximately 20 acres near a tree line in the lower part of a 40-acre field were severely damaged by rice blast. Incidence and severity of blast decreased when moving into other parts of the field. An adjacent Banks field had only scattered blast-infected plants. The most obvious difference was the very sandy soil in the badly diseased area compared to the sandy-clay soil type farther up the grade of the field.

Pathogenicity Assays

Seed were collected from severely diseased plants in the Corning Banks field. Diseased plants were also transplanted into the RREC greenhouse for additional testing. When inoculated, typical blast lesions developed on newly developed leaves of transplanted plants when inoculated with race IE-1k but not when inoculated with races IB-49 and IC-17.

Greenhouse tests were conducted to compare relative virulence of 2004 blast isolates from Banks fields with that of known isolates. Assay plants for leaf lesion reactions were grown from seed collected from the transplanted Banks plants, from diseased plants from other Banks fields, from different experimental seed sources of Banks, and from known rice varieties. Assay plants were inoculated with blast isolates from severely blasted plants in the Clay County field, with isolates from the infected plants from other Banks fields in Clay and Lawrence counties, and with races IB-49, IC-17, IE-1k, and IB-33. All 2004 blast isolates recovered from Banks fields caused susceptible-type leaf lesions on plants from the various Banks seed sources and all varieties known to have the *Pi-ta* resistance gene. The Banks isolates infected the same *Pi-ta* varieties as did race IE-1k (Table 1). Varieties 'Jefferson', 'Mars', 'Medark', and 'Saber' were resistant to race IE-1k and the Banks isolates. All test varieties were susceptible to blast race IB-33.

In an initial effort to determine vulnerability of Arkansas production and to define the host range of the Banks isolates, advanced breeding-line selections from the Arkansas variety development program; previously identified, resistant selections from the U.S. rice germplasm and U.S. red rice collection; and the 2004 URRN test entries were assayed in greenhouse tests for reaction to isolates IE-1k, IE-1k from Banks (IE-1k-Banks), and IB-33. All possible combinations for resistance were observed in these tests with many of the advanced breeding lines and the URRN entries being resistant to both IE-1k and IE-1k-Banks. A few test entries were resistant to all isolates tested.

Overall isolate virulence was estimated by comparing resistance of the 200 entries in the 2004 URRN. Five (2.9%) of the URRN entries were resistant to the combination of races IE-1k, IE-1k-Banks, and IB-33, while 23% were resistant to all possible two-race combinations and 18% were resistant to a single race only. When considering resistance to only two races, 14.6 % were resistant to IE-1k and IE-1k-Banks, 15.1 % were resistant to IE-1k and IB-33, and only 5.9 % were resistant to IB-33 and IE-1k-Banks. Over all entries, 31.2% were resistant to IE-1k-Banks, 26.8 % were resistant to race IE-1k, and 12.7% were resistant to race IB-33.

Molecular Assays

In all instances, assays of plant tissue believed to be Banks tested positive for the *Pi-ta*-resistance gene known to be present in Drew, Cybonnet, Ahrent, and Katy. However, gene marker assays indicated Banks differed from these varieties by not possessing additional *Pi-ks* or *Pi-kh* resistance genes (Table 1).

The absence of the *AVR-Pita* gene in molecular assays of the blast fungus provides further evidence that isolates from Banks plants were virulent on *Pi-ta* varieties. Although difficult to analyze and interpret, preliminary results from a PCR-based assay for fungal genetic diversity indicated identifiable molecular similarities and differences between IE-1k-Banks and previously defined *Pi-ta*-virulent blast races (Fig. 1). Preliminary characterization indicated the Banks isolates belong to MGR586 lineage group B, are US-02 Vegetative Compatibility Grouping, are negative for the *AVR-Pita* gene, and exhibit race IE-1k virulence on standard differential cultivars (Correll et.al., 2000; Table 2). A more detailed pathological, molecular, and genetic characterization of IE-1k-Banks isolates is ongoing.

DISCUSSION

Results indicate the blast isolates recovered from the Banks plants are genetically similar to race IE-1k but may have a slightly different race profile from previously characterized isolates of IE-1k. Without doubt, this event may signal the eventual loss of the *Pi-ta* gene as a useful stand-alone blast resistance source. Why Banks was severely damaged in the Corning field remains unclear.

Environmentally, 2004 weather conditions were the most conducive for rice blast in many years. The combination of a nearby tree line and a very sandy soil where flood water could easily percolate downward and be difficult to maintain possibly predisposed the Banks plants to a more severe infection by race IE-1K (Lee, 2005).

Banks resistance comes from a different genetic source other than Katy (Moldenhauer et.al., 2004). Also, Banks lacks the additional resistance genes *Pi-kh* or *Pi-ks* present in previous *Pi-ta* varieties (Table 1). The significance, if any, of these additional genes in expression of *Pi-ta* resistance is unknown. Resistance genes *Pi-z*, *Pi-b,* and others in Jefferson, Mars, Medark, or Saber confer resistance to race IE-1k and IE-1k Banks but not to race IB-33.

Although the capacity of *M. grisea* to adapt to *Pi-ta* has been known and demonstrated experimentally, Arkansas growers have long utilized the *Pi-ta* gene in resistant cultivars under environmental conditions similar to those encountered in 2004. While conventional pathogenicity and modern molecular assays suggest that the blast isolates from Banks are race IE-1k, additional pathological characterization is necessary for a more accurate definition. Whether the isolates from the heavily damaged Banks field in Clay County represent a more aggressive or 'fit' strain of IE-1k or even a new race of the blast fungus awaits more research.

Regardless, the initial search for new resistance sources to IE-1k Banks identified a diverse selection of alternative resistance, some in advanced breeding lines, immediately available to plant breeders for quick release to Arkansas growers.

SIGNIFICANCE OF FINDINGS

It is impossible at this time to predict for 2005 or beyond the relative significance of finding severe blast in Banks. However, these results, generated by coordinated efforts of multiple rice scientists, rapidly bring clarity to a new the disease situation and provide critical information needed for growers to make informed decisions. In any event, funding from the RRPB enabled pathologists to identify novel and significant sources of genetic resistance, some in advanced breeding lines, which plant breeders can quickly release to help manage rice blast and limit potential grower losses.

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Table 1. Comparison of leaf blast susceptibility of seedlings from blasted Banks plants and known varieties inoculated with *M. grisea* races IE-1k, IB-33, IB-49, and IC-17 and unidentified isolates from Banks fields.

Test variety and seed source	Identified resistance genes	Unidentified Banks isolates		Type rice blast isolates				2002-2004 ARPT
		Severe	Random	*Pi-ta*-virulent		Common races		
		Clay Co.	Lawrence Co.	IE-1k	IB-33	IB-49	IC-17	
Seven location summary of progeny of severely blasted plants in Clay Co.	–	S[z]	S	S	S	R	R	–
Summary of four experimental seed sources of Banks	*Pi-ta*, ----	S	S	S	S	R	R	R
Known *Pi-ta*-gene varieties								
Banks (Foundation seed)	*Pi-ta*, ----	S	S	S	S	R	R	R
Ahrent	*Pi-ta, Pi-ks*	S	S	S	S	R	R	R
Cybonnet	*Pi-ta, Pi-kh*	S	S	S	S	R	R	R
Drew	*Pi-ta, Pi-ks*	S	S	S	S	R	R	R
Kaybonnet	*Pi-ta, Pi-ks*	S	S	S	S	R	R	R
Known susceptible cultivars								
LaGrue	None	S	S	S	S	S	S	S
Newbonnet	None	S	S	S	S	S	S	S
Wells	*Pi-kh*	S	S	S	S	S	S	S
Cultivars with different R genes								
Medark	*Pi-ks, Pi-z*	R	R	R	S	S	R	MS
Saber	*Pi-kh, Pi-b*	R	R	R	S	R	R	MR-R?
Mars (other R genes?)	*Pi-z*	R	R	R	S	S	R	S?
Jefferson	*Pi-kh, Pi-z*	R	R	R	S	R	R	MS

[z] R = resistant, S = susceptible, MR = moderately resistant, and MS = moderately susceptible.

Table 2. Current summary of MGR586 linage group, vegetative compatibility group, *AVR-Pita* assay, and race virulence in the ongoing pathological characterization of *Magnaporthe grisea* isolates obtained from Banks in Arkansas during 2004.

Variety source of isolate	Number isolates tested	MGR586 lineage[z]	Vegetative compatibility group	*AVR-Pita* assay[y]	Virulence race ID[x]	Isolates collected Year	Location
Banks	66 (14 assays)	B (44 assays)	US-02 (17 assays)	Negative (15 assays)	IE-1k	2004	Clay and Lawrence counties
Wells and Francis	16	Not tested	US-02 (16 assays)	Not tested	Not tested	2004	Statewide
Overall characteristics of Race IE-1k							
	----	B	US-02	Negative	IE-1k	----	----
Reference isolates for *Pi-ta* virulence							
Control	TM2	B	US-02	Negative	IE-1k	----	TX
Control	18/1-2	B	US-02	Negative	IE-1k	----	AR
Control	94100	B	Not available	Not available	IE-1k	----	AR
Control	94071	B	Not available	Not available	IE-1k	----	AR
Control	S1	B	US-02	Negative	IC-17k	1994	AR
Reference isolates for *Pi-ta* avirulence							
Control	A598	A	US-01	Positive	IB-49	1992	AR
Control	A119	C	US-03	Positive	IB-49	1992	AR
Control	ZN37	A	US-04	Positive	IB-49	1996	LA
Control	A274	B	US-02	Positive	IC-17	1993	AR
Control	A347	D	US-04	Positive	IC-17	1992	AR

[z] MGR586 lineages = DNA restricted with EcoRI, separated by electrophoresis, and transferred to nitrocellulose. The nitrocellulose blot was probed with a chemilluminescent-labeled MGR586 probe.

[y] *AVR-Pita* = Gene-specific primers YL169 (forward) and YI149 (reverse). - indicates *AVR-Pita* missing. + indicates *AVR-Pita* present.

[x] Race identification.

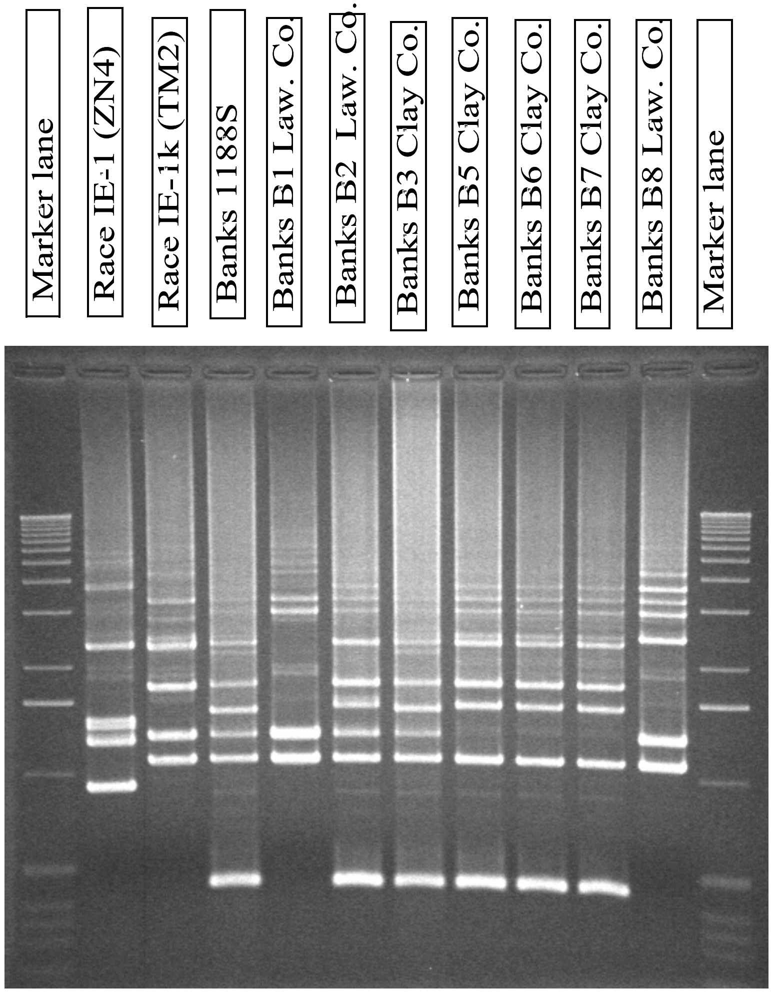

Fig. 1. Rep-PCR DNA comparison of *Pi-ta*-avirulant race IE-1 (ZN4) with *Pi-ta*-virulent isolates from Banks. Race IE-1k (TM2) appears most similar to Banks B1 and B8. Banks isolates 1188S, B2, B3, B5, B6, and B7 appear similar although individual bands may be weakly expressed.

Pathogenic, Molecular, and Genetic Diversity Among *Bipolaris*, *Drechslera*, and *Exserohilum* Species on Rice

I. Ouedraogo, J.C. Correll, E.J. Boza, R.D. Cartwright, F.N. Lee, and P. Sankara

ABSTRACT

A collection of fungal isolates was made from symptomatic rice leaves and panicles from Arkansas, North Carolina, and Burkina Faso (West Africa), as well as from several grass weeds. The collection included *Bipolaris oryzae*, *Drechslera gigantea, Bipolaris maydis*, *Bipolaris sp.*, and *Exserohilum rostratum.* Pathogenicity tests with the various species were conducted in the greenhouse and a considerable degree of variation in virulence was observed. Both *B. oryzae* and *D. gigantea* caused lesions similar to those observed in the field while the other species were not pathogenic. This apparently is the first report that pathogenic strains of the eyespot pathogen, *D. gigantea,* occur on rice in the U.S. Mitochondrial DNA RFLPs distinguished the various species and multiple haplotypes were identified among the isolates of *B. oryzae* from Arkansas and Burkina Faso; some isolates of *B. oryzae* from Arkansas and Burkina Faso had the same mtDNA RFLP haplotype. Preliminary evidence indicates that isolates of *B. oryzae* can be characterized for vegetative compatibility and that populations may be genetically diverse.

INTRODUCTION

Rice is susceptible to several leaf spot diseases that cause important yield losses worldwide. Brown spot, caused by *Bipolaris oryzae* (teleomorph: *Cochliobolus miyabeanus*), is second only to blast disease in economic importance among foliar diseases (Ou, 1985). Brown spot caused up to 90% yield losses in contributing to the Bengal famine in 1942 (Ghoze et al., 1960). In Africa, yield losses due to brown spot vary considerably, and up to 43% yield losses were observed in Nigeria (Aluko, 1975). In Burkina Faso, brown spot is present in all four major rice-growing areas. In Arkansas, brown spot is a common disease but typically is associated with low soil fertility and often is referred to as "poor man's disease" (Lee, 1992). *Bipolaris oryzae* is thought to be primarily seed-borne, but may also persist on weedy grasses. Eyespot disease of rice, caused by *Drechslera gigantea*, is another important foliar rice disease which has been reported in a number of rice-growing areas in Latin America (Ahn, 1980) but has not been reported from cultivated rice fields in the U.S. However, *D. gigantea* has been reported on wild rice (*Zizania aquatica*) (Kardin et al., 1982) from Minnesota. *D. gigantea* has been recovered from symptomatic rice grown in a quarantine nursery in North Carolina. The objective of this study was to examine the pathogenic and genetic diversity among *Bipolaris oryzae, Drechslera gigantea,* and related species on rice.

PROCEDURES

Isolates

A collection of over 150 isolates was made from symptomatic rice leaves and panicles from rice fields in Arkansas, North Carolina, and Burkina Faso as well as from several grass weeds. Several fungal species were recovered from the samples (Fig. 1).

Pathogenicity Tests

A subset of isolates (Table 1), representing *Bipolaris oryzae*, *Drechslera gigantea*, *Exserohilum rostratum*, *Bipolaris maydis*, and *Bipolaris* sp., was selected for pathogenicity tests. Seed of the rice cultivar 'Bengal' were planted in a mixture of 50% Ready-Earth potting mix to 50% field soil that was added to pots (10x10x8.5 cm). The plants were grown in the greenhouse at 28 to 32°C for 25 days. One or two days after planting, each pot received 1 to 2 g of ferrous sulfate; 7 and 14 days after planting, plants were fertilized with 20-20-20 (N, P, K; Peter's soluble fertilizer -1g/L). Twenty- five-day-old rice plants were sprayed with 30 ml of inoculum at a concentration of $1x10^5$ spores/ml and incubated for 36 hours in the dew chamber at 25°C. The inoculum for each isolate tested was produced on sterile sorghum leaves on water agar. The experiment was set up with four replicates per isolate. Disease severity was scored 7 days after inoculation using the IRRI Standard Evaluation System scale (IRRI, 1996) (Fig. 2).

Mitochondrial DNA RFLPs Analysis

A subset of twenty isolates was tested for mtDNA RFLP diversity as previously described (Correll et al., 1993). The band fragments between 0.05 and 1.0 kb were scored for their presence or absence and the data converted in a binary character matrix. The mitochondrial DNA RFLP data were then analyzed using a cluster analysis of the similarity coefficients with the unweighted pair-grouping method with arithmetic averages (UPGMA) to determine the relative relatedness (NTSYS-pc 2.0).

Vegetative Compatibility Test

Vegetative compatibility was used to characterize the genetic relatedness of the isolates of *Bipolaris oryzae* as previously described (Puhalla, 1985; Correll et al., 1987; Leslie, 1993). PDA plugs of growing mycelium were transferred onto minimal media amended with 5% chlorate (MMC) and incubated at 24°C. Sectors originating from the restricted colonies were transferred to minimal media (MM). Those sectors that grew as thin expansive colonies with no aerial mycelium were considered *nit* mutants. Pairings were made by placing mycelia from each *nit* mutant 1 to 3 cm apart on minimal media. *Nit* mutants' pairing plates were incubated for 5 to 14 days at room temperature (22-25°C) and scored for the formation of a heterokaryon where the two *nit* mutants came into contact.

RESULTS AND DISCUSSION

Pathogenicity Test

There was a significant difference in the mean disease severity rating among the isolates tested. Disease severity ranged from a hypersensitive type reaction (1 on the rating scale) to a highly susceptible reaction (8 on the rating scale) (Table 2). All isolates of *B. oryzae* and *D. gigantea* were pathogenic to rice. Isolates of *B. maydis*, *Bipolaris spp.*, and *Exserohilum rostratum* only induced hypersensitive-type reactions. Isolates of *B. oryzae* from Arkansas and Burkina Faso did not show differences in aggressiveness to rice. Isolates of *B. oryzae* from two grass weeds, *Echinochloa crus-galli* and *Leptochloa fascicularis*, were virulent on rice.

Mitochondrial DNA RFLP Analysis

Several haplotypes were identified from the restriction bands (Fig. 4). Isolates of *B. oryzae* segregated into four different haplotypes with 5, 4, 3, and 1 isolates, respectively. Four isolates of *B. oryzae* from Arkansas, including one isolate from grass weed (*Leptochloa fascicularis*) and one isolate from Burkina Faso, had the same restriction pattern while isolates from other species had different haplotypes. On the other hand, the geographic origin did not induce differences among these isolates. *D. gigantea* had the least similarity with *B. oryzae* (Fig. 5).

Vegetative Compatibility Tests

Fast-growing sectors on MMC were recovered from *B. oryzae* within 2 to 4 weeks of incubation. Robust heterokaryons were observed between *nit* mutants on MM after 9 days' incubation (Fig. 3). Complementation tests between *nit* mutants from different isolates resulted in several vegetative compatibility groups (VCGs). One group included isolates from rice as well as from grass weeds (*Echinochloa crus-galli* and *Leptochloa* *fascicularis*) from different locations in Arkansas. No complementation was recorded between isolates from Arkansas and those from Burkina Faso.

The reaction of the rice cultivar Bengal to the tested isolates ranged from resistant to highly susceptible indicating a wide range of aggressiveness between the various species as well as among isolates of *B. oryzae,* as previously reported (Vorraurai and Giatong, 1971). Isolates of *Drechslera gigantea,* pathogenic to rice, have been reported in Latin America (Ahn, 1980) and on wild rice in the United States (Kardin et al., 1982) but not on cultivated rice in the U.S. Several grass weeds were reported as alternate hosts to the brown spot pathogen (Ou, 1985; Sivanesan, 1987); study results confirm two species, *Leptochloa fascicularis* and *Echinochloa crus-galli,* as possible sources of inoculum of *B. oryzae* on rice in Arkansas.

RFLP analysis of mitochondrial DNA revealed that all isolates that were non-pathogenic to rice had different haplotypes (i.e. patterns)and belonged to species other than *B. oryzae* and *D. gigantea*. Four distinct haplotypes were identified among the isolates of *B. oryzae*. The similarity observed between isolates originating from rice and grasses, and at different locations, indicates that the populations of the pathogen are closely related.

Vegetative compatibility was found between isolates of *B. oryzae* originating from different hosts and locations in Arkansas. Although more isolates should be studied, this is an indication of a possible close relationship between the populations of the fungus. The incompatibility observed between isolates from Arkansas and Burkina Faso confirms differences in mtDNA RFLP haplotypes. Therefore, a greater number of isolates need to be tested to assess the degree of genetic diversity among the populations of *B. oryzae* in Arkansas.

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Table 1. List of species, host, and location of the isolates tested for molecular variability.

Isolate designation	Species	Origin host	Location
TS4	*Bipolaris oryzae*	Grass (*Leptochloa fascicularis*)	Poinsett, Ark.
BT1	*B. oryzae*	Rice (cv. Bengal)	Poinsett, Ark.
BT25	*B. oryzae*	Rice (cv. Bengal)	Poinsett, Ark.
DCP24	*B. oryzae*	Rice (cv. Bengal)	Poinsett, Ark.
CL8	*B. oryzae*	Rice (cv. CL161)	Lonoke, Ark.
CL14	*B. oryzae*	Rice (cv. CL161)	Lonoke, Ark.
PT1-2	*B. oryzae*	Rice (line UA99-135)	St. Francis, Ark.
PT4-4	*B. oryzae*	Rice (line 010180	St. Francis, Ark.
201-023H	*B. oryzae*	Rice (cv. FKR19)	Burkina Faso
F32H	*B. oryzae*	Rice (cv. FKR32)	Burkina Faso
02-095S	*B. oryzae*	Rice 9cv. FKR28)	Burkina Faso
201-009C	*B. oryzae*	Rice (cv. Mahiplango)	Burkina Faso
02-003B	*B. oryzae*	Rice (cv. FKR14)	Burkina Faso
DG2	*Exserohilum rostratum*	Rice (line L205)	N. Carolina
DG5	*B. oryzae*	Rice (line M101)	N. Carolina
DG7	*Drechslera gigantea*	Rice (line PI503090)	N. Carolina
DG9	*D. gigantea*	Rice (line PI503090)	N. Carolina
DG14	*D. gigantea*	Rice (line M103-Dilday)	N. Carolina
DG19	*E. rostratum*	*Eleusina indica*	N. Carolina
BG2	*Bipolaris* sp.	*Echinochloa crus-galli*	Poinsett, Ark.

Table 2. Reaction of rice cultivar Bengal to the inoculation with isolates from *B. oryzae*, *B. maydis*, *Bipolaris* sp., and *Exserohilum rostratum* seven days after inoculation. Data represent a mean of four replicates.

Isolate designation	Species	Host	Location	Disease rating
201-009C	*Bipolaris oryzae*	Rice	Burkina Faso	8.0 a[z]
02-095S	*B. oryzae*	Rice	Burkina Faso	8.0 a
DCP8	*B. oryzae*	Rice	Poinsett, Ark.	8.9 a
201-023H	*B. oryzae*	Rice	Burkina Faso	7.7 ab
CL1	*B. oryzae*	Rice	Lonoke, Ark.	7.7 ab
02-103S	*B. oryzae*	Rice	Burkina Faso	7.5 abc
BT28	*B. oryzae*	Rice	Poinsett, Ark.	7.5 abc
20078C	*B. oryzae*	Rice	Burkina Faso	7.5 abc
BT4	*B. oryzae*	Rice	Poinsett, Ark.	7.5 abc
02-003B	*B. oryzae*	Rice	Burkina Faso	7.5 abc
PT1-2	*B. oryzae*	Rice	St. Francis, Ark.	7.5 abc
BT3	*B. oryzae*	Rice	Poinsett, Ark.	7.5 abc
CL8	*B. oryzae*	Rice	Lonoke, Ark.	7.3 cde
PT3-1	*B. oryzae*	Rice	St. Francis, Ark.	7.0 cde
TS3	*B. oryzae*	Weed	Poinsett, Ark.	7.0 cde
TS5	*B. oryzae*	Weed	Poinsett, Ark.	7.0 cde
PT7-1	*B. oryzae*	Rice	St. Francis, Ark.	7.0 cde
DG7	*Drechslera gigantea*	Rice	North Carolina	5.5 f
DG9	*D. gigantea*	Rice	North Carolina	4.7 g
DG14	*D. gigantea*	Rice	North Carolina	3.5 h
DG16	*Bipolaris* sp.	Weed	North Carolina	1.0 i
F42H	*Exserohilum rostratum*	Rice	Burkina Faso	1.0 i
IO-6	*E. rostratum*	Rice	North Carolina	1.0 i

[z] Means with the same letters are not statically different. LSD = 0.7; $P<0.001$

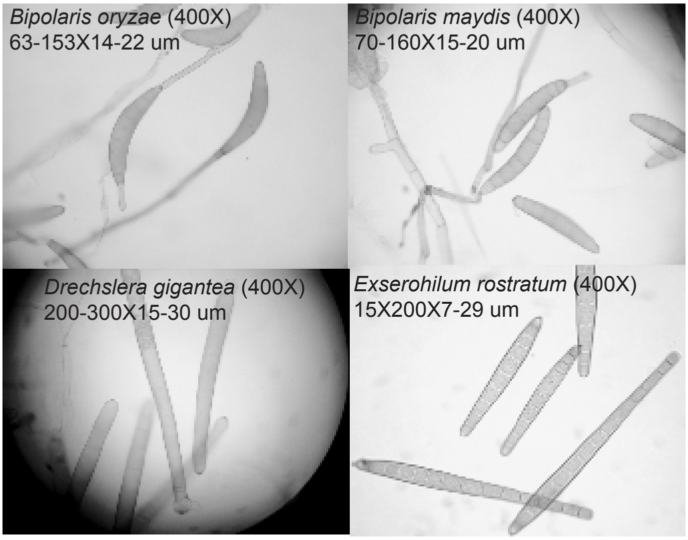

Fig. 1. Conidia from fungal species recovered from symptomatic leaf and panicle field samples: *Bipolaris oryzae*, *Bipolaris maydis*, *Drechslera gigantea*, and *Exserohilum rostratum*.

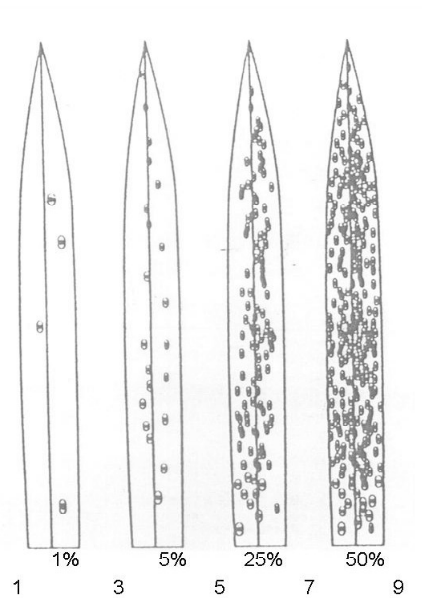

Fig. 2. Disease rating scale (IRRI, 1996). LAI-percent leaf area infected.

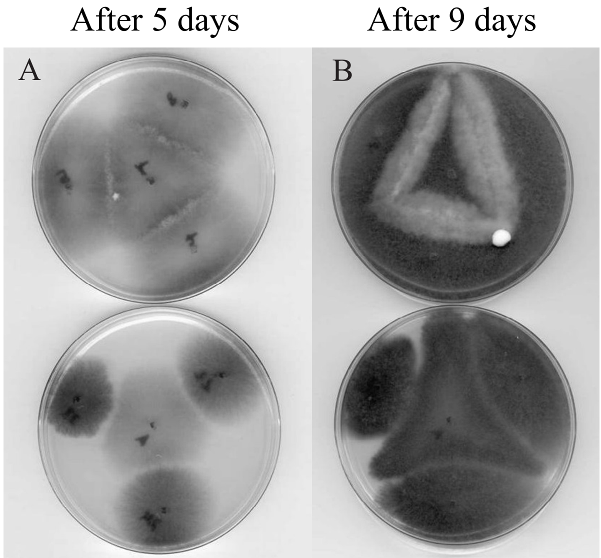

Fig. 3. Vegetative compatibility tests between *nit* mutants from different isolates after 5 and 9 days incubation on MM. A = heterokaryon resulting from complementation between *nit* mutants; B = incompatibility reaction between *nit* mutants.

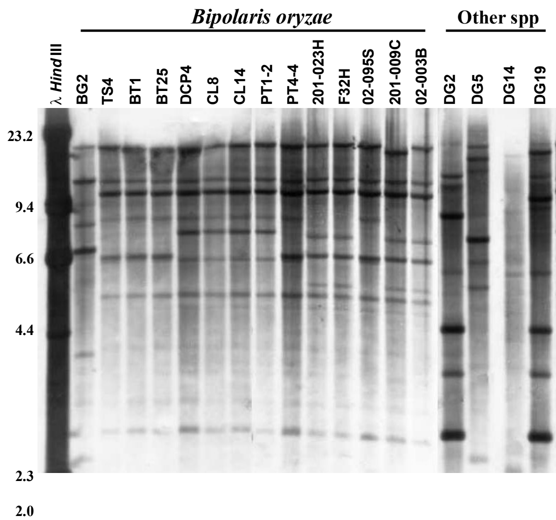

Fig. 4. Mitochondrial DNA restriction fragments length polymorphism (RFLP) patterns of *B. oryzae, B. maydis, Bipolaris* sp., and *Exserohilum rostratum*. Isolates of *Bipolaris oryzae*: (1) from Arkansas, and (2) from Burkina Faso; BG2-*Bipolaris* sp., DG2, DG19-*Exserohilum rostratum*, DG14-*Drechslera gigantea*.

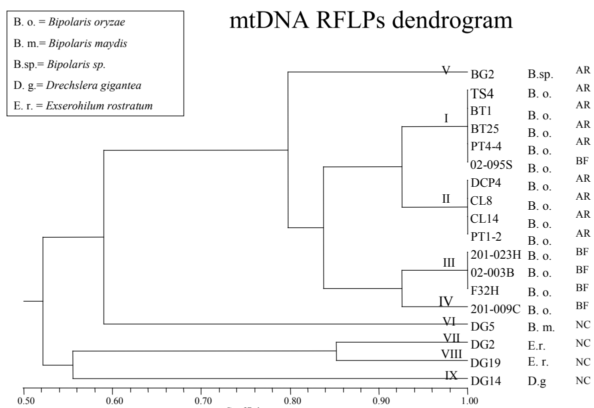

Fig. 5. Mitochondrial DNA RFLPs dendrogram. 1 - 1X different haplotypes, AR - Arkansas, BF - Burkina Faso, NC - North Carolina.

Reaction of Cold-Tolerant Rice Genotypes to Seedling Disease Caused by *Pythium* Species

C.S. Rothrock, R.L. Sealy, F.N. Lee, M.M. Anders, and R.D. Cartwright

ABSTRACT

Stand problems consistently cause significant production losses and management problems in Arkansas rice fields. Previous research funded by the Rice Research and Promotion Board identified the role of environmental factors and soilborne plant pathogens, especially *Pythium* species, in limiting rice stand establishment. *Pythium* species were found to play an important role in stand establishment, especially under cool soil temperatures. Screening genotypes reported to be cold-tolerant and thus adapted to these soil temperatures found about 26% of the cold-tolerant genotypes had at least moderate resistance to the pathogenic *Pythium* isolate used. Another 26% of the genotypes tested were moderately susceptible and 48% of the genotypes studied had extremely low stand counts in the infested treatment, indicating a high degree of susceptibility. From the results, it appears that cold-tolerant genotypes were found to differ in resistance to *Pythium* diseases and that this character will need to be screened for separately as cold-tolerant cultivars are developed.

INTRODUCTION

Stand problems consistently cause significant production losses and management problems in Arkansas rice fields. Previous research funded by the Rice Research and Promotion Board identified the role of environmental factors and soilborne plant pathogens in limiting rice stand establishment, with the goal of determining the conditions where soilborne pathogens, especially *Pythium* species, play an important role in stand establishment. From the ongoing research, it appears that *Pythium* diseases will become more important when planting into cooler soils, with virulence of *Pythium* species increasing tremendously at cooler temperatures (Rothrock et al., 2003). Certain genotypes of rice have recently been found that have the ability to emerge at soil temperatures that are significantly lower than those at which standard cultivars of rice can begin the process of germination and emergence. From early results, it appears that these cold-tolerant genotypes differ in resistance to *Pythium* diseases and that this character will need to be screened for separately as cold-tolerant cultivars are developed (Rothrock et al., 2004). The objective of this study was to screen 346 lines of rice that have demonstrated the ability to germinate and grow at cold temperatures for resistance to *Pythium* seed rot and damping-off.

PROCEDURES

The rice genotypes used in this study are from the program headed by Dr. James Gibbons at the Rice Research and Extension Center at Stuttgart, Ark., and have demonstrated the ability to germinate and grow at cold temperatures, referred to as cold-tolerance. The pathogen used in this study is a *Pythium* species that was isolated from rice seedling roots taken from an Arkansas rice field. From previous work in this laboratory, this isolate has been shown to be virulent to rice seeds and seedlings at various soil temperatures. The pathogen was grown in homemade corn meal broth, amended with <1 g/L of commercially available potato dextrose broth powder (Difco Laboratories) by inoculating flasks with plugs from cultures and incubating at room temperature on a shaker for 8 to 12 days. Inoculum was prepared by harvesting the mycelium by filtration through a sterile Buchner funnel with suction, washing the mycelial mat twice with sterile distilled water (SDW), blending briefly (<10 sec) in a sterile Waring blender, and diluting to approximately 20 g of hyphae/L of SDW. About 12 g of hyphae were mixed in sterilized vermiculite growth medium in each tray for the infested treatment. Ten seeds of each genotype were planted in an individual plot in the growth trays. Infested treatments were performed in triplicate; the noninfested treatments were performed in duplicate. In each growth chamber, three standard genotypes of rice (controls) were included; PI560281 (cold-tolerant and moderately resistant to *Pythium*), Kaybonnet (cold-tolerant, but susceptible to *Pythium)* and Lemont (neither cold-tolerant nor resistant to this pathogen).

After planting, trays were placed in a growth chamber kept at a constant temperature of 15°C with a 13-hr light/11-hr dark period. Data, consisting of stand counts, were collected four weeks after planting. Data were analyzed as a percentage of the stand for a plot compared to the mean for the noninfested controls for that genotype. Germination studies were done with each genotype by placing 20 seeds of each genotype in a sterile Petri dish containing a sterile filter-paper disk moistened with SDW.

RESULTS AND DISCUSSION

Cold-tolerant genotypes were initially evaluated in nurseries established by Dr. Fleet Lee where rice was planted beginning in mid-February, with and without seed treatment fungicides. In general, cold-sensitive genotypes were classified as entries that did not respond to fungicide treatment and established useful stands only under optimal conditions. An intermediate group was characterized as cold-tolerant but seedling disease-susceptible, and only established a suitable stand when treated with an efficacious fungicide. A third group was identified as being tolerant to cold and to seedling disease by the ability to establish a stand for early plantings in the absence of a fungicide. This research emphasized that as growers look to planting earlier with an increased likelihood of cool soil temperatures, rice seedlings will have to overcome low soil temperatures and also the increased disease-inciting activity of *Pythium* spp. In the growth chamber, genotypes were found that varied in susceptibility, percent relative stand of the infested treatment to the noninfested control, at the temperatures of 15°C or 20°C (59°F or 68°F). Several cold-tolerant genotypes were found to be moderately resistant at 15°C (32 to 43% stand) and resistant at 20°C (75 to 100% stand). This research suggested that genotypes can be selected that improve plant stand under colder soil temperatures and with increased *Pythium* pressure.

The results from screening the genotypes provided by Dr. Gibbons showed a reduction in stand count with the infested treatment. Results from one experimental run are shown in Table 1. For the genotypes evaluated, about 26% of the genotypes had stand counts in the infested treatment comparable to or better than those of the resistant control, indicating at least a moderate resistance to the pathogenic *Pythium* isolate used here. Another 26% of the genotypes tested had stand counts exceeding those of the susceptible and cold-resistant standard, but less than those of the resistant control, indicating some degree of resistance to the pathogen. The other 48% of the lines studied had extremely low stand counts in the infested treatment, indicating a high degree of susceptibility to this pathogen.

One complicating factor is the fact that the percent germination studies indicate a wide variation in seed viability. Percent germination varied from <10% to 80%. Some of the low stand counts may reflect low seed viability rather than susceptibility to *Pythium* damping-off. However, using a percentage of the noninfested control in analyses should adjust for seed quality differences. The majority of the genotypes with low stand counts in the infested treatments are indeed very susceptible to damping-off by the *Pythium* isolate used in this study.

This study is ongoing. So far, over 45% of the accessions available through the cold-tolerance program have been tested. Difficulties in characterizing *Pythium* resistance include the limited space for cold-temperature evaluations and standardization of inoculum among runs. Genotypes differing in disease reaction will be screened in the field at the Rice Research and Extension Center, the Northeast Research and Extension Center, and the Pine Tree Station in 2005 to confirm the reaction of selected genotypes and validate the screening procedure.

SIGNIFICANCE OF FINDINGS

These studies have identified specific genotypes with cold-tolerance and *Pythium* resistance holding the promise for more reliable stand establishment for rice in Arkansas. The research also points to the need to screen rice for seedling disease-resistance as new cultivars are being developed.

ACKNOWLEDGMENTS

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Table 1. Influence of temperature on *Pythium* seed rot and damping-off of rice, run 2 (8 August 2004).

Genotype	Relative stand[z]	Disease reaction
	(%)	
PI560281[y]	66.7 a	R
STG03P-02-097	44.4 ab	R
STG03P-07-066	38.9 abc	R
STG03P-10-127	38.1 abc	R
STG03P-07-048	35.9 abcd	R
STG03P-11-010	35.9 abcd	R
STG03F5-09-082	33.3 abcd	R
STG03P-07-045	30.3 abcd	MS
STG03P-07-055	27.4 bcd	MS
STG03P-07-102	25.0 bcd	MS
STG03P-02-098	20.0 bcd	S
Kaybonnet[x]	18.2 bcd	S
STG03PF5-09-084	17.8 bcd	S
STG03P-06-031	14.3 bcd	S
STG03P-06-030	14.0 bcd	S
STG03P-07-065	10.3 bcd	S
Wells	9.5 bcd	S
STG03P-02-069	8.9 bcd	S
Lemont[w]	6.7 cd	S
STG03P-11-064	6.7 cd	S
STG03P–2-096	5.1 cd	S
STG03P-02-056	4.2 cd	S
STG03PF5-09-076	0.0 d	S

[z] Stand calculated as a percentage of stand in the infested treatment compared to the mean of the noninfested control for that genotype.
[y] Control that is both cold-tolerant and resistant to this pathogen.
[x] Control that is cold-tolerant, but susceptible to this pathogen.
[w] Control that is neither cold-tolerant nor disease-resistant to this pathogen.

Real-Time PCR Detection and Quantification of the Rice Sheath Blight Pathogen *Rhizoctonia solani*

R.J. Sayler and Y. Yang

ABSTRACT

Rapid identification of *Rhizoctonia solani*, the causal agent of sheath blight, is required for timely application of fungicides to control the disease in the field. Accurate quantification of pathogen infection is also required for studying host resistance and for breeding sheath blight-resistant cultivars. Oligonucleotide primers unique to the rDNA internal transcribed spacer (ITS) region of rice-specific isolates of *R. solani* have been used to develop a real-time PCR diagnostic assay for rapid identification and quantification of the pathogen on rice. Primer specificity was confirmed by amplification of the target DNA from *R. solani* isolates [in the anastamosis group 1 (AG-1) intraspecific group IA] that infect rice, while no amplification occurred using *R. oryzae* and *R. oryzae-sativa* or *R. solani* isolates that infect other crops. Quantification of pathogen DNA using real-time PCR produced a linear correlation (R^2=0.99) between the log DNA concentration and cycle threshhold value. This technique was also effective in quantifying the amount of pathogen DNA, and thus pathogen infection, in *R. solani*-infected rice tissue.

INTRODUCTION

Sheath blight on rice caused by *Rhizoctonia solani* Kühn [teleomorph *Thanatephorus cucumeris* (Frank) Donk] is a major disease in the southern rice-growing regions of the U.S. and the world (Willocquet et al., 2004). All 6000 commercial rice cultivars grown throughout the world are susceptible to this disease with semi-dwarf cultivars such as 'Lemont' being more susceptible. Resistance to sheath blight in rice is polygenic making selection of resistant cultivars difficult (Eizenga et al., 2002). Sheath blight is currently managed by cultural controls such as the minimization of nitrogen application and by the application of fungicides. In 2003, Arkansas growers applied fungicides on 42% of the total rice acreage to control sheath blight at a cost of $13,813,000.00 ($23.00/acre). However, disease progress is rapid and fungicide application is only effective in the early stage of disease development. Diagnosis of this disease by visual symptoms is difficult at the early stages of lesion development when sheath blight may be confused with sheath rot (*Sclerotium oryzae*) or lesions caused by the rice stem borer (*Scirpophaga* spp.). Rapid and accurate diagnosis of the disease is important if fungicide applications are to be efficacious.

Real-time PCR offers the possibility for rapid diagnosis of *R. solani* infections of rice. This technology has been used to identify numerous fungal, bacterial, and viral pathogens (Schena et al., 2004). A conventional PCR technique has been developed for the identification of *R. solani* (Johanson et al., 1998); however, real-time PCR detection is significantly faster than the conventional PCR method and doesn't require the analysis of amplicons by gel electrophoresis. In addition, real-time PCR can be used to quantify pathogen DNA in infected plant samples providing an unbiased method for rating infection in disease assays. This study reports the development of a real-time PCR identification and quantification method for the rice sheath blight pathogen, *R. solani*.

PROCEDURES

PCR primers specific for *R. solani* AG1-1A were selected by the comparison of sequence alignments from the ITS rDNA region of 23 *R. solani*, 4 *R. oryzae* f. sp. *oryzae*, and 2 *R. oryzae* f. sp. *sativa* isolates (Table 1). Sequence alignments were performed using Vector NTI™ 6 software (Invitrogen Corp., Carlsbad, Calif.). Primers selected for real-time PCR are the forward primer Rs1F (65-92) 5'-CCTTTTCTACCTTAATTTG-GCAG-3' and the reverse primer Rs2R (202-234) 5'-GTGTGTAAATTAAGTAGA-CAGCAAATG -3'.

Rice (cv. Nipponbare) was grown for approximately 8 weeks in the greenhouse to growth stage V9. Three days post-inoculation, infected rice leaves were frozen in liquid nitrogen until DNA extraction was performed. DNA from mycelia and infected plant tissues was extracted using the sarkosyl phenol/chloroform method previously described (Qi and Yang, 2002). Real-time PCR was performed using a Thermo-Fast® 96-well reaction plate and Thermo-Fast® Caps (AB gene Epsom, Surrey, United Kingdom) in the Mx3000P real-time PCR machine from Stratagene Corporation (La Jolla, Calif.). Each well contained a 25-µl reaction mixture that includes 12.5 µl of 2xSYBR Green PCR Master Mix (Qiagen, Valencia, Calif.) and 12.5 µl primer (1 pmole of forward and reverse primer and 1 µl of extracted DNA). Thermal cycling conditions were 95ºC 2 min followed by 40 cycles of 94ºC 15 sec, 60ºC 30 sec, 72ºC 15 sec. Quantification of *R. solani* DNA in infected plant tissue was performed by adding 1 µl of a 100 ng/µl aliquot of extracted DNA.

RESULTS AND DISCUSSION

DNA from the sheath blight pathogen was detected and amplified by primer Rs 1F (65-95) and Rs 2R (202-234) (Fig. 1). All *R. solani* isolates in this study that were pathogenic on rice were successfully detected producing a 137-140 bp product depending on the isolate tested (Fig. 2). However, these primers did not amplify DNA from isolates of *R. solani* that infect other crops (AG 1-IB, 2, 4, 7, 8, 11) or other species of *Rhizoctonia* that infect rice such as *R. oryzae* and *R. oryzae-sativa* (Fig. 2). Real-time PCR quantification of *R. solani* DNA was reliable from a range between 1 pg to 100 ng of purified pathogen DNA (Fig. 3). The correlation (R^2 = 0.9911) between cycle threshold (ct) and the log of *R. solani* DNA concentration was linear, enabling accurate quantification of the pathogen DNA. Pathogen DNA was also quantifiable from infected rice leaves sampled over 6 days post-infection (Fig. 4). To date, most sheath blight disease rating systems have relied on visual estimates or measurements, which may be biased, because scanned images of leaf lesion area don't quantify pathogen multiplication, only leaf discoloration. The ability to quantify pathogen infection using unbiased method, such as the real-time technique described here, may improve the accuracy in assessing the levels of fungal pathogenicity and host resistance.

Pathogen identification and quantification of the *R. solani* DNA were achieved in as little as two hours with real-time PCR and six hours with conventional PCR. The quantification of pathogen DNA in rice tissue by real-time PCR was closely correlated with lesion length measurements in disease assays done in vitro (data not shown). The specificity of these primers ensures not only accurate diagnosis of the sheath blight pathogen, but also the reliable quantification of pathogen DNA in rice tissues.

SIGNIFICANCE OF FINDINGS

Sheath blight is one of the most important diseases limiting the profitability of rice production in Arkansas. Uncontrolled, sheath blight can cause significant yield loss, yet fungicide application costs an average of $23.00/acre for a total of $13,813,200.00 in Arkansas alone. Diagnosis of the disease in the early stages when control measures are most effective is difficult due to the absence of pathogen structures indicative of the disease and the time-consuming nature of isolating the pathogen from diseased rice plants. The real-time PCR protocol described in this report can rapidly and reliably identify *R. solani* isolates that cause sheath blight in rice. The rapid identification of the pathogen can improve the timing and efficacy measures employed to control sheath blight in rice. In addition, the ability to accurately quantify *R. solani* DNA from infected rice samples will facilitate the selection of resistant rice cultivars and aid efforts to understand the fundamentals aspects of sheath blight resistance.

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Table 1. *Rhizoctonia* spp. referenced in this study.

Genus species	Host	Origin	Isolate code	AG/ subgroup	Accession numbers
R. solani	Rice	Arkansas	RR0135	AG-1 IA	AY185115
R. solani	Rice	Arkansas	RR0134	AG-1 IA	AY185114
R. solani	Rice	Arkansas	RR0129	AG-1 IA	AY185113
R. solani	Rice	Arkansas	RR0107	AG-1 IA	AY185108
R. solani	Rice	Arkansas	RR0103	AG-1 IA	AY185106
R. solani	Rice	Arkansas	RR0101	AG-1 IA	AY185104
R. solani	Rice	Arkansas	RR0102	AG-1 IA	AY185105
R. solani	Rice	Arkansas	RR0113	AG-1 IA	AY185109
R. solani	Potato	Alaska	AG-2 1	AG-2 1	
R. solani	Cotton	Arkansas	AG-4	AG-4	
R. solani		Arkansas	AG-7	AG-7	
R. solani	Barley	Washington	AG-8	AG-8	
R. solani	Soil	Arkansas	AG-11	AG-11	
R. solani	Soil	Benin	T6	AG-1 IA	AJ000202
R. solani	Rice	Côte d'Ivoire	T62	AG-1 IA	AJ000200
R. solani	Rice	Vietnam	T5	AG-1 IA	AJ000199
R. solani	Rice	Ghana	T4	AG-1 IA	AJ000198
R. solani	Rice	Philippines	T68	AG-1 IA	AJ000197
R. solani	Soybean	Brazil			AY270013
R. solani	Soybean	Brazil			AY270012
R. solani	Soybean	Brazil			AY270010
R. solani	Soybean	Brazil			AY270006
R. solani	Italian ryegrass	Japan		AG-1 IA	AB122134
R. solani	Rice	Japan		AG-1 IA	AB000200
R. solani	Orchid	Hungary	O-10		AJ549182
R. solani	Leaf litter	Australia	WDa	AG-12	AF153807
R. solani	Bean	Nebraska	PR5	AG-1IB	AF308629
R. solani		Brazil		AG-1 IC	AY154300
R. oryzae	Rice	Japan		AG-1 IA	AJ000195
R. oryzae	Rice	Japan		AG-1 IA	AJ000196
R. oryzae	Rice	Arkansas	1		
R. oryzae	Rice	Arkansas	2		
R. oryzae	Rice	Arkansas	4		
R. oryzae-sativae	Rice	Côte d'Ivoire	C2		AJ000191
R. oryzae-sativae	Rice	W. Malaysia	C1		AJ000192
R. oryzae-sativae	Rice	Japan	C3		AJ000193
R. oryzae-sativae	Rice	Japan	C6		AJ000194

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R. solani Soy AY270013   5'-gttgctgGCCT---TTTCTACCTTAATTTGGCAGgagggg-cat-3'
R. solani 135 AY185115      ...........---..........................g...
R. solani 134 AY185114      ...........---..........................g...
R. solani 129 AY185113      ...........---..........................-...
R. solani 107 AY185108      ...........---..........................g...
R. solani 103 AY185106      ...........---..........................-...
R. solani 101 AY185104      ...........---..........................g...
R. solani T62 AJ000200      ...........---..........................-...
R. solani T5  AJ000199      ...........---..........................-...
R. solani T68 AJ000197      ...........---..........................g...
R. solani AIC AY154300      ...........----C.GGGGA...G...CT.CA-...---...
R. solani Wda AF153807      -----------.AAA.GAA.TTT.....AATTTTcttt..g...
R. oryzae        AJ000196      ..g....TTGC----.GA----C..G.G.TT.TA.tat.tg..c
R. oryzae-sativa AJ000194   ....A......-----------..CC.--CC....ga...-...


R. solani Soy AY270013   5'-catcatcCATTTGCTGTCTACTTAATTTA------Cacacact-3'
R. solani 135 AY185115      .............................------........
R. solani 134 AY185114      .............................------........
R. solani 129 AY185113      .............................------........
R. solani 107 AY185108      .............................------........
R. solani 103 AY185106      .............................------........
R. solani 101 AY185104      .............................------........
R. solani T62 AJ000200      .............................------........
R. solani T5  AJ000199      .............................------........
R. solani T68 AJ000197      .............................------........
R. solani AIC AY154300      ggggg-..--................C.------........
R. solani Wda AF153807      g..ctcc..----T..............------....a..c
R. oryzae        AJ000196      .tctg--.TGAA..A..A....ACG...TTTAC---......a
R. oryzae-sativa AJ000194   ggga.agAGAGA.AG...GC..CCG.C..TCGTCA..t.a.a.
```

Fig. 1. DNA sequence comparison of the rDNA ITS region of *Rhizoctonia solani, R. oryzae*, and *R. oryzae-sativa* along with their GenBank accession numbers. Arrows indicate forward and reverse primers selected in this study for conventional and real-time PCR. The sequence of *R. solani* rDNA ITS regions begins at base 60 and finishes at base 212.

Fig. 2. Primer specificity test for *Rhizoctonia solani* anastomosis group 1 (AG-1) intraspecific group IA. Lane 1. *R. solani* RR0102, 2. *R. solani* RR0113, 3. *R. solani* RR0107, 4. *R. solani* AG-1 intraspecific group IB, 5. *R. solani* AG-2, 6. *R. solani* AG-4, 7. *R. solani* AG-7, 8. *R. solani* AG-8, 9. *R. solani* AG-11, 10. *R. oryzae*, 11. *R. oryzae-sativa*, 12. *R. oryzae* #1, 13. *R. oryzae* #2, 14. *R. oryzae* #4, 15. PCR control.

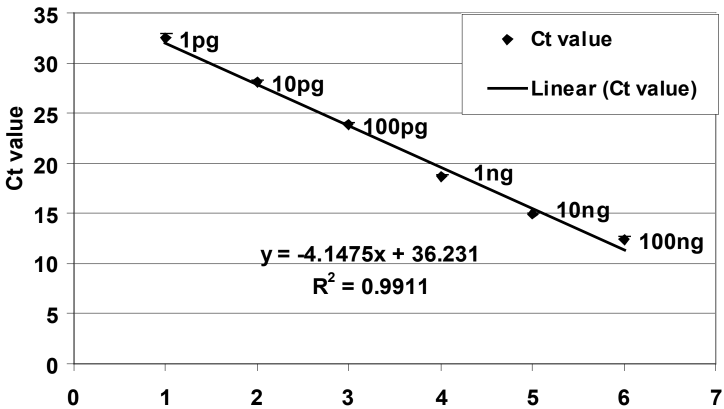

Fig. 3. Correlation of real-time PCR cycle threshold value (Ct) to the log of *Rhizoctonia solani* DNA concentration.

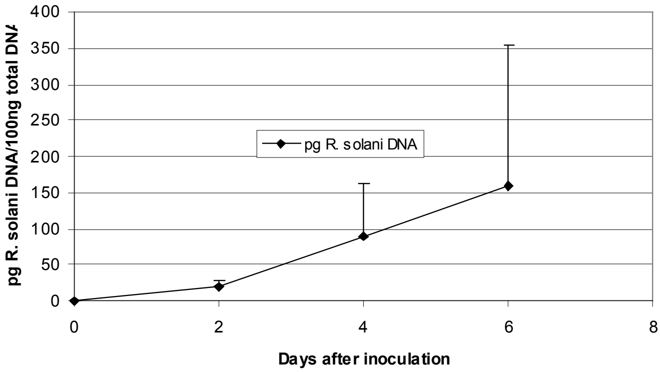

Fig. 4. Quantification of *Rhizoctonia solani* DNA in rice leaf tissue as determined by real-time PCR cycle threshold value.

Evaluation of Seedborne Rice Blast Thresholds in Arkansas

D.O. TeBeest

ABSTRACT

Rice blast, caused by the fungus, *Magnaporthe grisea,* is a serious disease of rice in Arkansas, having reached epidemic proportions previously in Arkansas on susceptible cultivars. It has been established that artificially infected seeds placed on the soil surface initiated significant levels of disease in the field. In recent years, planting rice seeds naturally infected by the blast fungus has led to rice blast.

The research reported here was conducted in 2004 in small replicated plots to continue research to determine if the amount of rice blast in small plots was significantly correlated to the amount of blast on naturally infected seed used to plant the plots. Field experiments consisted of planting samples of seeds that differed in the level of blast infection of rice cultivars 'M201' and 'Wells' with levels ranging from 0.22% to 2.37% and 0% to 2.52% blast, respectively. In addition, seeds from these same seedlots were treated with azoxystrobin to determine if a seed treatment with a fungicide significantly reduced the incidence of the disease during the growing season.

The results of field tests conducted in 2004 show that planting naturally infected seed can result in significant levels of rice blast disease during the growing season. In 2004, rice blast first appeared on leaves in plots of 'M201' by late June and reached an incidence of 52.5% by mid-July. The incidence of leaf blast declined from mid-July through early August while plants were heading. The incidence of panicle blast at harvest ranged from 58% to 88% across the treatments on M201 with the highest incidence found in plots planted with the most heavily infected seeds. In comparison, leaf blast was not found on the more resistant cultivar, Wells, until 14 July, when approximately 1% of the leaves were infected in all treatments. On Wells, incidence of leaf blast remained at very low levels during August. However, by September the incidence of flag leaf and

neck blast on Wells was nearly the same as the incidences on M201, possibly as a result of interplot interference from the nearby heavily infected M201 plots. Results of tests conducted in 2004 with naturally infected seeds treated with azoxystrobin suggest that this fungicide reduced the presence of blast on seeds, delayed the appearance of blast on leaves, and may reduce the incidence of rice blast on panicles.

INTRODUCTION

Rice blast is an economically important disease of rice worldwide and it is also an important disease in Arkansas on many high-yielding but blast-susceptible cultivars (Lamey, 1970; Long et al., 2001). Recently, it was reported that infected seeds were a likely primary source of inoculum for rice blast epidemics in California although infected seeds were not considered to be the most likely source of inoculum for subsequent epidemics (Greer and Webster, 2001). Lamey (1970) and Manandhar et al. (1998) suggested that infection of seedlings after planting infected seed beneath the soil surface was always low and inhibited the infection of seedlings grown from infected seed. However, Shetty et al. (1985) planted seeds of finger millet infected by *M. grisea* that clearly resulted in epidemics in small field plots and showed that the incidence of disease was correlated to the incidence of blast on seeds. Mayee (1974) showed that planting a small number of apparently healthy seeds in highly controlled environments and conditions resulted in infection of some seedlings by 21 days after planting and suggested that the role of infected seeds in development of the disease cannot be completely ruled out. In 2004, Sesma and Osbourn (2004) showed that *M. grisea* could infect roots of seedlings and that this infection could result in leaf lesions later.

Recently, several fungicides have been evaluated for effectiveness as blast control measures when applied to seed and plants in the field (Hayakaka et al., 2002; Serghat et al., 2002). These and similar studies evaluated the effect of fungicides on seed germination, plant vigor, and the incidence of blast over time in the field but did not test the effectiveness of fungicides on the incidence of blast on treated seeds following treatment.

The objectives of this research were to determine 1) if planting naturally infected seeds of two cultivars at different levels of infection resulted in the subsequent development of rice blast, 2) if seed infections could be correlated to the level of infection on plants, and 3) if planting *M. grisea*-infected seeds treated with azoxystrobin reduced the subsequent infection of the rice plants.

PROCEDURES

Thirty-two plots of the rice cultivar M201 and 32 plots of the rice cultivar Wells were planted on 6 May 2004 with seeds infected by the blast fungus and harvested from field plots in 2003. The levels of infection for the seeds harvested in 2003 that were used in 2004 were estimated by visual microscopic examination of seeds incubated on moistened blotter paper, as described by Agarwahl (1989). The levels of infection for seed lots were determined as an average of the number of seeds exhibiting sporulation by *M. grisea* in two replications of 180 seeds.

Treatments for cultivar M201 consisted of planting seeds from seedlots estimated to be 0.22%, 0.67%, 1.11%, and 2.37% infected by blast and for Wells treatments consisted of planting seeds from seedlots estimated to be infected at 0.0%. 0.5%, 0.89% and 2.52%. The levels of seed infection described above were obtained by mixing non-infected seeds with infected seeds in the appropriate amounts to obtain the desired levels of seed infection. Previously, researchers had planted seeds ranging from 0% to 3% infection (TeBeest et al., 2003). All treatments were planted in a randomized complete block design with four replications. All plots were planted with 100 grams of seed in plots nine rows wide by 20 feet long. All plots of Wells and M201 were separated in all directions with plots containing the blast-resistant cultivar, 'Ahrent'. All plots were visually inspected for seeds remaining on the surface three and seven days after planting and again after emergence. Seeds could not be effectively removed by hand from the soil surface of the plots due to continuous bird predation of sprouted seedlings.

Infected seeds of each cultivar at each level of infection listed above were treated with a fungicide to determine if the level of infection of seed could be reduced. Fungicidal treatments were made using the plastic bag method. Azoxystrobin was used based on previous reports of its effectiveness (TeBeest et al., 2002). In this treatment, 0.8 ml of azoxystrobin 100FS was added to 7.2 ml of sterile water and the total mixture added to 400 g of seed for each cultivar and infection level as described above. After 2 minutes of mixing, the treated seeds were air dried in the laboratory as described above. Untreated controls for each infection level for each cultivar consisted of adding 8.0 mls of sterile distilled water to 400 g of seed in a plastic bag. The seeds were thoroughly mixed by hand for two minutes then placed on paper towels on trays to dry. After drying for 48 to 72 hours, 100 g samples of seed were placed in small paper bags, one bag for each plot. Azoxystrobin 100FS was provided as a gift of Syngenta, Inc. (Greensboro, N.C.).

Rice blast was monitored visually within all plots beginning 14 days after emergence and ending at harvest. Panicle samples were collected on 24 August and 23 September for M201 and Wells, respectively. Panicle samples, consisting of 25 to 35 heads (including the flag leaf, collar, neck, and head), were collected from each plot, combined and placed in paper bags, one bag per plot, and taken to the laboratory for additional study. In the laboratory, the incidence of flag leaf, collar rot, neck blast, and panicle blast was determined by visual inspection of each head according to plot. Data on the incidence of rice blast were converted to the percentage of the total number of flag leaves, collars, necks, and heads in the sample from each plot that was visibly infected by the blast fungus. Data presented here are the averages for four plots for each treatment and cultivar. All plots were harvested on 29 September 2004.

RESULTS AND DISCUSSION

In 2003, the first lesions of rice blast on leaves were found on rice cultivars on 30 June, approximately 5 weeks after planting. The incidence of disease was very small, only one or two lesions were found in some plots at that time. The disease became much more evident within the plots by 17 July 2003.

In 2004, rice blast was found in plots of M201 grown from untreated seeds on 28 June, the estimated levels of blast ranging from 1.2% to 3.9% (Table 1). However, blast increased rapidly on M201 and by 14 July the incidence of rice blast on leaves ranged between 36% and 52% from untreated seeds and appeared to have increased very rapidly compared to previous estimates. However, by 5 August, the visual estimates of rice leaf blast had decreased, ranging from only 22% to 37% across the treatments on untreated seeds.

The incidence of rice blast on the head samples that were collected from the M201 untreated seed plots shows that rice blast had infected between 44% and 60%, 53% and 71%, 31% and 51%, and 58% and 84% of the flag leaves, collars, necks and panicles, respectively. In general, there appeared to be higher levels of leaf blast in plots grown from seed samples that were the most heavily infected by blast. Differences in the levels of flag, collar, neck, and panicle blast across treatments appeared to be insignificant. Researchers suspect also that any potential differences between treatments were partially obscured by interplot interference caused by airborne spores.

Rice blast was also found on the susceptible cultivar M201 grown from infected seeds treated with azoxystrobin before planting (Table 1). However, the incidence of infection on M201 in plots grown from treated seeds was significantly lower in some treatments than in plots grown from untreated seeds. In contrast to results from growing untreated seeds, the incidence of rice blast on leaves in plots grown from treated seeds ranged from 0% to 0.5% on 28 June and from 10% to 26% on 5 August although blast appeared to have decreased from the 14 July sample date by August.

In the panicle samples collected from the M201 treated-seed plots on 25 August, the incidence of rice blast ranged from 41% to 61%, from 27% to 54%, from 34% to 46% and from 58% to 88% on flag leaves, collars, necks and panicles, respectively. The overall levels of rice blast on plants grown from treated seeds were higher on M201 than on Wells.

Rice blast remained at very low levels in plots of Wells grown from infected and untreated seeds during the vegetative growing season (Table 2). In all of the untreated-seed treatments for Wells, the average level of infection of 200 leaves remained near zero from 28 June through 24 August. However, significant incidences of rice blast were found in all of the panicle samples collected on 23 September. On that date, the incidence of disease ranged from 62% to 87%, from 53% to 67%, from 23% to 41% and from 56% to 76% for flag leaves, collars, necks, and panicles, respectively, on untreated-seed plots.

Rice blast remained at very low levels in plots grown from treated seeds of Wells throughout the season ending in late August (Table 2). Based on panicle samples collected on 23 September, blast appeared in the Wells plots between 24 August and 23 September. In the panicle samples collected on 23 Sept., the incidence of blast ranged from 42% to 90%, from 11% to 58%, from 26% to 41% and from 55% to 70% on flag leaves, collars, necks, and panicles, respectively, across all treatments. Based on observations, it seems likely that inoculum present in the adjacent M201 plots was responsible for the infection of Wells between 24 August, when the last leaf data were collected, and 23 September when panicle samples were collected. Clearly, treating seeds of Wells at planting did not protect Wells from infection through harvest.

SUMMARY

As reported in 2002 and 2003, the 2004 field data show that significant levels of rice blast were found in replicated plots of two cultivars in which untreated infected seeds were planted. As in 2002 and 2003, it is unlikely that blast originated from an external inoculum since nearby rice plots planted with non-infected seeds of the same cultivars did not have significant levels of the disease. Three years of work show that rice blast is transmitted by infected seeds; however, the subsequent development of epidemics as being based on that inoculum source is less clear and may be more likely dependent on agronomic factors such as disease resistance, fertilization and irrigation and on environmental factors such as rainfall and temperature.

Rice blast appeared in plots of the susceptible cultivar M201 that were planted with seed lots in which blast was in study seed assays at only 0.22%. This level of seed infection of a susceptible cultivar appears to be too high to prevent blast or to significantly reduce the incidence of disease. Shetty et al. (1985) estimated that one infected seed of finger millet in ten thousand (0.01%) was sufficient to cause an epidemic of blast on pearl millet, a plant very susceptible to *M. grisea*. Increased precision in estimating the amount of blast in infected seedlots is required before thresholds can be established for rice blast in Arkansas on susceptible cultivars like M201. Based on the 2004 data and on previous work (TeBeest, 2003), however, it is reasonable to suggest that a blast threshold may be higher for more-resistant cultivars such as Wells.

Lamey (1970) suggested that planting infected rice seed beneath the soil surface inhibited infection of rice by the rice blast fungus. Study data from 2002, 2003, and 2004 suggest that significant levels of disease are possible as a result of planting infected seed using drill planters. Study data suggest that it is very difficult to assure that mechanical planting prevents seeds from coming to the surface of soils. The physical process of loading drill planters and bird predation may simply cause seeds to be left on the surface of the soil, however, infection of seedlings and plants from infected seeds may also occur by mechanisms such as those described by Sesma and Osburn (2004).

The incidences of disease in study field plots in 2004 were higher than those found in field plots of the same two cultivars planted in 2003 (TeBeest et al., 2003). In 2002, the estimated levels of infection of seeds that were used to plant the tests were higher, ranging from 1% to 3% for both M201 and Wells. In 2002, the incidence of head samples of Wells taken just before harvest was much higher in comparison to the samples collected in 2003 from plots planted with seeds with levels of infection ranging from 0% to 0.5%. These differences may be attributed to differences in the level of seed infection and to environmental differences during the growing seasons of 2002 and 2003. Smaller differences were observed for the more susceptible cultivar M201 even with much lower levels of seed infection. Additional work that includes a broader range and lower levels of seed infection will be required to better describe the impact of seed infection on the occurrence and severity of rice blast.

Based on the data from M201 over several years, fungicides that can be shown to effectively reduce the level of seed infection by blast in blotter tests (Agarwahl, 1989) also appear to be effective in reducing or delaying the incidence of blast in the field. They do not appear to be effective throughout the growing season, however, if infected rice is growing nearby.

SIGNIFICANCE OF FINDINGS

The work reported here examined whether rice blast could develop as a result of planting naturally infected seed. Study leaders also conducted the work to determine if fungicides could effectively reduce the incidence of disease on seeds. The data from this work with naturally infected rice seeds appear to support previous research that showed that infected rice seeds are a viable source of the inoculum for rice blast disease in Arkansas. Further, the fact that an effective fungicidal treatment of the seeds reduced the overall level of disease supports this conclusion. The research also suggests that thresholds may be found and established for rice cultivars that are at least moderately resistant to blast to aid in controlling this important disease.

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Table 1. The incidence of rice blast on leaves during the growing season and incidence of blast on flag leaves, collars, necks, and panicles collected near harvest on cultivar M201 resulting from planting infected or treated seeds at different levels of seed infection at the Pine Tree Experiment Station, Colt, Ark., in 2004.

	% seed	Vegetative[y]		Hard dough		Incidence near harvest[y]			
Treatment	infected[z]	17 June	28 June	14 July	5 Aug	Flag	Collar	Neck	Panicle
Untreated									
	0.22	0 a[x]	1.1 ab	41.2 cd	22.5 abc	57.0 abc	70.8 b	51.3 a	58.2 a
	0.67	0 a	1.2 b	52.5 d	35.0 cd	60.0 bc	55.2 ab	31.3 a	84.0 ab
	1.11	0 a	3.9	46.5 d	37.5 d	49.8 abc	53.2 ab	41.8 a	72.8 ab
	2.37	0 a	2.9 c	36.2 bcd	32.5 cd	44.0 abc	53.8 ab	35.5 a	72.8 ab
Treated									
	0.22	0 a[x]	0.1 ab	21.2 ab	12.5 ab	43.0 ab	40.0 ab	36.3 a	58.5 a
	0.67	0 a	0.0 a	35.0 bcd	15.0 ab	41.3 a	54.8 ab	45.3 a	65.0 ab
	1.11	0 a	0.0 a	13.8 a	10.0 a	51.0 abc	27.5 a	34.3 a	88.0 b
	2.37	0 a	0.5 ab	23.8 abc	26.2 bcd	61.0 c	46.5 ab	46.8 a	77.0 ab

[z] The percentage of seeds infected was determined as an average of two replications of 180 seeds taken from infected seedlots. Seeds were incubated on moistened filter paper at 22°C under 12 hr lighting for four days. Individual levels of infection were prepared by mixing seeds from several infected seedlots to obtain the indicated levels. To treat seeds with azoxystrobin, 0.8 ml of azoxystrobin 100FS was added to 7.2 ml of water and applied to 400 grams of seeds in plastic bags.

[y] The incidence of rice blast was determined by estimating the number of leaves from 100 to 200 leaves per plot exhibiting typical blast lesions. The incidence of rice blast on panicles near harvest was determined by collecting 25 to 35 heads (including the flag leaf) and determining the number of flag leaves, collars, necks, and panicles from within each sample that was infected by blast. All data are the averages of four replications of each treatment. The M201 plots were harvested on 24 August 2004.

[x] Means within a column followed by the same letter are not significantly different using the Least Significant Difference Procedure (P=0.05).

Table 2. The incidence of rice blast on leaves during the growing season and incidence of blast on flag leaves, collars, necks, and panicles collected near harvest on cultivar Wells resulting from planting infected or treated seeds at different levels of seed infection at the Pine Tree Experiment Station, Colt, Ark., in 2004.

	% seed	Vegetative[y]		Hard dough		Incidence near harvest[y]			
Treatment	infected[z]	28 June	14 July	5 Aug	24 Aug	Flag	Collar	Neck	Panicle
Untreated									
	0	0 a[y]	0.4ab	0.0 a	0 a	64.0 bcd	53.0 bc	41.8 a	57.2 a
	0.5	0 a	1.0 b	0.0 a	0 a	62.3 bc	68.0 c	38.0 a	76.8 a
	0.89	0 a	1.2b	0.1a	0 a	79.3 cde	58.3 bc	26.3 a	61.0 a
	2.52	0 a	1.25b	0.0 a	0 a	87.5 e	66.8 bc	23.5 a	56.0 a
Treated									
	0	0 a	0.0 a	0.0 a	0 a	51.3 ab	11.0 a	27.5 a	65.2 a
	0.5	0 a	0.0 a	0.0 a	0 a	42.0 a	52.7 bc	26.3 a	62.3 a
	0.89	0 a	0.0 a	0.0 a	0 a	90.5 e	58.0 bc	41.8 a	70.0 a
	2.52	0 a	0.0 a	0.0 a	0 a	81.3 de	42.8 b	33.3 a	55.0 a

[z] The percentage of seeds infected was determined as an average of two replications of 180 seeds taken from infected seedlots. Seeds were incubated on moistened filter paper at 22°C under 12 hr lighting for four days. Individual levels of infection were prepared by mixing seeds from several infected seedlots to obtain the indicated levels. To treat seeds with azoxystrobin, 0.8 mls of azoxystrobin 100FS were added to 7.2 ml of water and applied to 400 g of seeds in plastic bags. Seeds were air dried for two days at room temperature before use.

[y] The incidence of rice blast was determined by estimating the number of leaves from 100 to 200 leaves per plot exhibiting typical blast lesions. The incidence of rice blast on panicles near harvest was determined by collecting 25 to 35 heads (including the flag leaf) and determining the number of flag leaves, collars, necks, and panicles from within each sample that was infected by blast. All data are the averages of four replications of each treatment. The Wells panicles were harvested on 23 Sept. 2004.

[x] Means within a column followed by the same letter are not significantly different using the Least Significant Difference Procedure (P=0.05).

Studies on Isolates of *Rhizoctonia solani* from Arkansas for Management of Rice Sheath Blight Disease[1]

Y.A. Wamishe, Y. Jia, P. Singh, and R.D. Cartwright

ABSTACT

The quantitative nature of rice sheath blight resistance caused by *Rhizoctonia solani* has made screening for resistance difficult. Studying field isolates may facilitate resistance screening. Among 200 *Rhizoctonia*-like fungi obtained from infected rice and two grass species from 19 counties in Arkansas, 102 isolates were identified as *R. solani* using a ribosomal DNA internal transcribed spacers' marker. Fourteen isolates were tested for anastomosis grouping and all fit in AG1-IA. *In vitro* hyphal growth rate ranged from 1.17 to 1.89 mm/h with no significant difference among most of the isolates. The fastest-growing isolates caused longer lesion length on detached rice leaves, rice plants at V11, and 18-day-old rice seedlings (V4 to V5) than did the slowest-growing isolates. A fast-growing isolate in the seedling tests showed disease levels not significantly different from the susceptible control, M202, on 71.4% of the cultivars known to be tolerant to sheath blight in the field. The slow-growing isolate conferred results relatively consistent with the disease reactions observed in the field for 90.9% of the cultivars. The results indicated the possibility of detecting resistance to sheath blight by combining appropriate evaluation techniques with the pathogen isolates.

INTRODUCTION

Rhizoctonia solani Kuhn [teleomorph: *Thanatephorus cucumeris* (Frank) Donk] causes diseases on an array of crop plants and survives in soil for years within host mate-

[1] This is a completed study.

rial or as sclerotia. In rice, it causes sheath blight, a major and widely distributed disease. *R. solani* from rice is in anastomosis group AG1 intra-specific group IA (AG1-IA) with known heterogeneity within an AG. Identification of *R. solani* has been reported to be reliable using a polymerase chain reaction (PCR)-based marker for ribosomal DNA (rDNA) internal transcribed spacers (ITS) (Johanson et al., 1998).

Because of the non-specificity of the pathogen and the susceptibility of rotation crops to *R. solani,* it has been difficult to manage rice sheath blight disease through cultural methods. Moreover, control of sheath blight disease through genetic resistance has not yet been fully successful (Zou et al., 2000). In Arkansas where 48% of rice in the United States is produced, rice sheath blight disease has become more severe since the introduction of dwarf and semi-dwarf rice cultivars. Susceptible cultivars can suffer up to 50% grain loss in an environment conducive to severe sheath blight infection. The disease is more intensive in high-input production systems typical of the U.S. rice industry. Therefore, studying the attributes of regional isolates of *R. solani* to facilitate identification and incorporation of any level of available resistance into high-yielding rice cultivars can be extremely useful.

PROCEDURES

Eighty-two rice plant samples were collected from 2001 to 2003 from rice fields of 19 counties in Arkansas. Two samples were also included from other grass species [*Echinochola crusgalli* (L.) Beauv. and *Panicum dichotomiflorum* Michx.]. An isolate recovered from a rice sample was designated as *Rhizoctonia* from *Rice* (RR), and isolates from the two grass species were designated as *Rhizoctonia* from *Grass* (RG) (Table 1). After isolation and purification of *Rhizoctonia* species using standard procedures, each isolate was examined visually for sclerotia formation, and under a compound microscope for septa and angle of hyphal branching. Genomic DNA was extracted (Promega Corp., Madison, Wis.) according to the manufacturer's instructions, and PCR products were separated by electrophoresis. Primer pairs GMRS-4 (5'-CGGTTCATCTGCATTTACCTT-3') and ITS1 (5'- TCCGTAGGTGAACCTGCGG-3') (Johanson et al., 1998) were used to amplify the rDNA-ITS regions. Moreover, fourteen isolates were tested for anastomosis groupings using a standard set of testers representing 13 anastomosis groups. To measure hyphal growth rate of the isolates, a mycelial agar disk was transferred to PDA plates containing tetracycline and incubated in a fungal-culture-room maintained at 25°C. Hyphal growth rate was calculated as change in diameter of hyphal growth divided by change in time (24 ± 3) h. To compare in vitro hyphal growth rate with virulence, eight isolates (three fast-, two intermediate-, and three slow-growing) were selected based on the maximum, mean/median, and minimum hyphal growth rate mean values, respectively. The isolates were first tested on penultimate detached leaves of Jasmine 85 (moderately resistant) and M202 (susceptible) at V1 using the detached-leaf assay procedure (Jia et al., 2002). The assay was then conducted on detached leaves of nine other rice cultivars. To verify virulence on whole plants, additional experiments were conducted on rice plants of Jasmine 85 and M202 at V11 using press inoculation and on 18-day-old seedlings of 11 rice cultivars. The former were tested using two fast- and two slow-growing isolates and were incubated in a dew chamber for 72 h with continuous light. The latter were tested in a greenhouse using one fast- and one slow-growing isolate by placing mycelial agar disks on a wet soil surface and touching the stem base of each seedling. Each pot with the seedling tests was covered with a clean and clear 2-liter plastic bottle used as microchamber (R. Shank; personal communication). Full culm height and lesion height on the culm were measured using an electronic digital caliper (VWR 12777-830), and data were compared with field sheath blight disease reactions (Yan et al., 2002).

Data on hyphal growth rate in petri dishes, lesion lengths from the detached leaves, percentage lesion length from rice plants at V11, and the percentage lesion length (transformed to arcsine square-root values) from the seedling tests were analyzed using SAS system for mixed models.

RESULTS AND DISCUSSION

Of 82 infected samples, *R. solani* was recovered from 38 samples. Among 200 sclerotia-forming isolates, 102 isolates were distinguished as *R. solani* using rDNA-ITS. The rDNA-ITS marker was more definitive than the microscopic and visual observations to identify *R. solani* from other associated sclerotia-forming fungi as reported by Johanson et al (1998). All the 14 isolates tested for anastomosis groupings belonged to AG1-IA (Table 1), confirming *R. solani* isolates in AG1-IA cause sheath blight disease in rice.

In vitro hyphal growth rate among the tested *R. solani* isolates ranged from 1.17 to 1.89 mm/h (Table 2). Except for the few isolates at the fastest and slowest extremes, there was no significant difference in hyphal growth rate among most of the isolates representing the field population in Arkansas. Generally, in vitro hyphal growth rates did not show correlation to year of collection, habitat/county, or virulence. However, the eight selected isolates produced lesions on detached leaves of Jasmine 85 and M202 that positively correlated ($r = 0.86$ at $P= 0.0059$ and $r = 0.93$ at $P= 0.0001$, respectively) to an in vitro hyphal growth (Table 2). The detached leaves of Jasmine 85 and M202 were maintained uniform in age and segment sizes. However, results were inconsistent when compared with detached leaves of nine other rice cultivars that were tested (data not shown). Some of the differences may be related to the growth stage of the plants. The tests on Jasmine 85 and M202 at V11 with the two fastest-growing isolates (RR0319-8 and RR0321-4) using press inoculation and dew-chamber incubation with continuous light produced significantly different lesion lengths (Table 3). The two slowest-growing isolates (RR0140-1 and RR0141-1) did not produce significant differences in lesion lengths between Jasmine 85 and M202 at V11. However, the slow-growing isolates (RR0140-1 and RR0141-1) were considered useful to detect small differences in resistance among rice cultivars if appropriate screening techniques are used as it was demonstrated in the seedling tests. On seedlings of 11 rice cultivars, results were in agreement with the field response of 90.9% of the rice cultivars when inoculated with one of the slowest-growing isolates (RR0140-1), indicating the likelihood of detecting resistance to sheath blight in rice seedlings using slow-growing isolates (Table 4). The fast-growing isolate (RR0321-4), on the other hand, produced percentage lesion lengths not significantly different from the susceptible control, M202, on 71.4% of the cultivars known to be tolerant to sheath blight in the field.

Among factors that affect disease phenotypes, rice morphological traits such as leaf length or culm height were clearly noticed to affect the accuracy of disease phenotypic data, especially on the rice plants at V11 and the seedling tests. Thus it was necessary to measure lesion lengths relative to the leaf length or culm height. Such effects of morphological traits on lesion length verify the significance of selecting suitable disease-rating methods to obtain reliable disease phenotypic data. Variation in rice sheath blight reactions due to rice morphological traits has been documented in Akino and Ogoshi (1995).

SIGNIFICANCE OF FINDINGS

Well-characterized sheath blight pathogen isolates from Arkansas rice fields would be useful for evaluating resistance from rice germplasm and advanced breeding lines. The greenhouse disease-testing methods would also be useful for plant breeders and pathologists to accelerate the development of resistant cultivars.

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Table 1. A summary of *R. solani* isolated from diseased rice and grass samples.

Sample	No. of isolates	Source (cultivar/farm)	County
RR0101 * [z,y]	1	Unknown	Jackson
RR0102*	1	Unknown	Arkansas
RG0102 *	1	Barnyardgrass[x]	Lonoke
RG0103 *	1	Fall panicum[w]	Lawrence
RR0103 *	1	LGN 14A	Arkansas
RR0104 *	1	95 Kaybonnet	Arkansas
RR0105	1	Wells	Clay
RR0107 *	1	Cocodrie	Lawrence
RR0108	1	Unknown	Lawrence
RR0113 *	1	CL 18	Faulkner
RR0120 *	1	CFX 18	Faulkner
RR0125 *	1	Wells	Arkansas
RR0128 *	1	Cypress	Lafayette
RR0129 *	1	Cypress	Lawrence
RR0133	1	RS409	Arkansas
RR0134 *	1	Wells	Faulkner
RR0135 *	1	BED-Slovok	Arkansas
RR0136	1	Drew	Newton
RR0137	1	Hum-Humnoke	Lonoke
RR0138	1	Unknown	Monroe
RR0139	1	MB-Humnoke	Lonoke
RR0140	1	SLV-Slovok	Prairie
RR0141	1	94SB01	Prairie
RR0204	8	Unknown	Desha
RR0214	2	Unknown	Prairie
RR0215	4	Rull 24	Monroe
RR0217	2	Unknown	Unknown
RR0303	1	Cocodrie	Phillips
RR0304	2	Bengal	Randolph
RR0305	3	Francis	Yell
RR0314	5	Wells	Searcy
RR0315	1	CL161	Greene
RR0316	2	Cocodrie	Lee
RR0318	2	Unknown	Lonoke
RR0319	14	CL161	Lonoke
RR0321	5	Wells	Yell
RR0322	21	Francis	Poinsett
RR0323	7	Cocodrie	Mississippi

[z] An isolate recovered from a rice sample was designated as Rhizoctonia from Rice (RR) followed by the year of collection (as 01 if collected in 2001) and a two-digit sample number. Isolates from grass species other than rice were designated as RG. Multiple isolates were obtained from highly infected samples.
[y] Isolates marked with an * were tested for anastomosis groupings.
[x] *Echinochola crusgalli* (L) Beauv.
[w] *Panicum dichotomiflorum* Michx.

Table 2. Mean lesion lengths (mm) produced by eight isolates of *R. solani* on detached leaves of the rice cultivars Jasmine (moderately resistant) and M202 (susceptible) relative to hyphal growth rate (mm/h).

	Mean lesion lengths[y]		
Isolate[z]	Jasmine 85	M202	Growth rate[x]
	-------------------- (mm)	-----------------	(mm/h)
RR0321-4	71.00 def	121.31 ab	1.89 k
RR0319-8	62.70 ef	109.86 ab	1.85 kl
RR0105-1	52.90 efg	107.77 abc	1.81 klmn
RR0305-27	52.90 efg	100.28 abc	1.54 klmnop
RR0103-1	43.30 fgh	91.89 bcd	1.54 klmnop
RR0316-1	45.00 fgh	79.23 cde	1.20 nop
RR0140-1	30.80 gh	70.25 def	1.19 op
RR0141-1	17.40 h	51.85 efg	1.17 p

[z] An isolate recovered from a rice sample was designated as *Rhizoctonia* from *Rice* (RR) followed by the year of collection (as 01 if collected in year 2001) and a two-digit sample number with hyphenated entry number.

[y] Mean lesion lengths (calculated from three independent experiments replicated three times) followed by the same letter are not significantly different at a 5% level.

[x] Mean hyphal growth rates (calculated from three independent experiments replicated three times) followed by the same letter are not significantly different at a 5% level. *In vivo* mean lesion length ([y]) and *in vitro* hyphal growth rate ([x]) on Jasmine 85 and M202 are positively correlated ($r = 0.86$ at $P = 0.0059$ and $r = 0.93$ at $P = 0.0001$, respectively).

Table 3. Percentage mean lesion length produced by two fast- and two slow-growing *Rhizoctonia solani* isolates on rice cultivars M202 and Jasmine 85 at growth stage V11 using press inoculation and dew-chamber incubation for 72 h with continuous light.

	Percentage lesion length[z]	
Isolate growth	Jasmine 85	M202
Fast[y]	35.92 b	44.95 a
Fast	32.65 b	44.96 a
Slow[x]	14.07 bc	25.59 b
Slow	6.03 c	6.11 c

[z] Means (calculated from four independent experiments replicated twice) followed by the same letter are not significantly different at 5% level.

[y] Fast-growing isolates = RR0321-4 and RR0319-8, respectively

[x] Slow-growing isolate = RR0140-1 and RR0141-1, respectively.

Table 4. Percentage mean lesion length (mm) produced by two selected *R. solani* isolates on seedlings of 11 rice cultivars in the microchamber.

	Percentage mean lesion length[z]		Field disease rate[y]	
	Isolate			
Cultivar	RR0140-1 (slow)	RR0321-4 (fast)	Plant 1	Plant 2
Jasmine 85[x]	28.39 g	44.03 efg	2.0	3.0
CDR210[w]	29.27 g	49.06 defg	4.0	5.0
4484[w]	38.34 fg	75.82 bcde	3.0	5.8
4583[w]	45.37 efg	76.62 bcde	3.0	5.5
4582[w]	59.04 cdefg	81.89 abcd	3.5	5.3
GP-2[w]	52.49 efg	98.44 a	3.3	5.8
Guinean Dao[w]	79.41 bcde	93.50 ab	3.0	5.5
Lemont	72.22 bcdef	95.95 ab	7.8	7.7
Katy	90.05 ab	95.63 ab	6.0	6.0
Labelle	86.83 abc	98.74 a	7.0	7.0
M202[x]	85.98 abc	92.32 ab	7.0	7.0

[z] Means (calculated from three independent experiments replicated three times) followed by the same letter are not significantly different at 0.05% level based on arcsine square-root transformed values using Tukey's test.

[y] Field disease rate based on 0-9 scale (Yan et al., 2002).

[x] Jasmine 85 moderately resistant and M202 susceptible used as point of reference for the level of resistance in the other nine cultivars tested.

[w] Chinese rice germplasm.

Evaluation of Rice Varieties for Performance and Disease Reaction on Farms

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ABSTRACT

The on-farm rice cultivar performance and disease monitoring program was conducted on 14 cooperator farms in 13 counties during 2004. Statewide, blast was more widespread than normal due to frequent rainfall in May and June and the large acreage planted in susceptible cultivars. Overall, sheath blight was moderate, particularly in June and early July. Kernel smut and false smut appeared less severe in the state but were observed on later-planted fields in northeast Arkansas. Bacterial panicle blight was most frequently observed on 'Bengal' but was very erratic in severity. The disease was noted at low incidence in 'Francis', 'Wells', and 'Cocodrie' fields. Other diseases were minor in 2004. Hybrid rice cultivars Wells and Francis had the highest numerical yields across all harvested locations in the Disease Monitoring Program. 'Drew', 'Clearfield 161', and the experimental line RU0104055 had the lowest numerical yields. Yields of the new medium-grain cultivar, 'Medark', were similar to Bengal while 'Cybonnet' was similar to Cocodrie. Clearfield 161 and Cybonnet were the most susceptible cultivars to sheath blight while Francis, Banks, Cocodrie, and 'Cheniere' were most susceptible to kernel smut. The Crittenden County site did not emerge and the Lafayette County site had poor emergence. The Cross County plots were not harvested due to a severe red rice infestation.

INTRODUCTION

Rice diseases remain important constraints to profitable rice production in Arkansas. Based on IPM disease-management methods, researchers encourage the use of host resistance, optimal cultural practices, and fungicides when necessary to reduce disease potential. These options provide growers the maximum profit at the lowest disease control cost, all other factors being equal.

The use of resistant cultivars remains the foundation for rice disease management in the state. With some knowledge of field history, growers can pick the variety that offers the highest yield potential with a minimum of risk for many situations. However, the knowledge to make these selections accurately each year requires ongoing field research. Varieties are bred and developed under controlled experiment station conditions and a large set of data on yield, quality, growth habit, and major disease resistance is collected during the process. Unfortunately, the dataset is incomplete for the many environments where rice is grown in the state because diseases or other problems might not be observed in nurseries conducted on experiment stations.

Thus, researchers began the effort several years ago to better address the many risks faced by newly released varieties by planting replicated plots in grower fields across Arkansas and monitoring them for the development of problems and for their performance under grower management – before the varieties become widely grown.

Rice varieties and management change over time. Research-based change is usually positive overall, but some changes result in increased risks. For example, kernel smut increased over the past decade as more-susceptible but higher-yielding varieties came into play and false smut became a consistent problem where it had never been even noticed before. Blast risk has been increasing as high-yielding, but susceptible, varieties continue to be planted on larger and larger acreage. After several years of progress in reducing sheath blight severity in modern rice varieties, the introduction of a highly susceptible but herbicide-resistant variety has led to a recent increase in concern.

Monitoring these changes allows scientists to provide early warning to researchers and growers and helps scientists prepare management information to cope with increased risks until solid research data are available to solve new problems. To be of value, monitoring of diseases, cultivar reaction, and cultivar performance must be conducted over time and also across different environments. Replicated variety plots on different farms provide research data to make these evaluations but also plots are the basis for hands-on education of county agents, consultants, and farmers and serve as the nucleus for local field days.

The distribution of the different research sites requires considerable travel across much of the rice-production area of the state. This is beneficial in that it establishes area networking for personnel and leads to inspection of nearby sites and problems in addition to the variety plots.

PROCEDURES

Rice varieties/lines planted in on-farm trials during 2004 included ‘AB8198’, ‘AB8649’, ‘AB8684’, ‘Ahrent’, ‘AMS 114-109’, ‘AMS 114-33’, Banks, Bengal, Cheniere, CL161, Cocodrie, Cybonnet, ‘Cypress’, Drew, Francis, ‘LaGrue’, Medark, ‘Spring’, Wells, ‘RiceTec Clearfield XL8’, ‘RiceTec XP710’, ‘RiceTec XP712’, ‘Rice-

Tec XP716', and 'RiceTec XP723'. Sites were on grower farms in Chicot, Craighead, Desha, Faulkner, Lafayette, Lawrence, Lincoln, Mississippi, Monroe, Poinsett (2 sites), Prairie, White, and Woodruff counties. One set of plots planted in Crittenden County never emerged and the site in Cross County was abandoned due to red rice. AB 8198, AB8649, and AB8684 were provided by Mike May of Anheuser-Busch Company in Jonesboro, Ark. CL161 Clearfield rice varieties were provided by Dr. Jennifer Wells of BASF Corporation and Orygen Seed. RiceTec Clearfield XL8, RiceTec XP710, RiceTec XP712, RiceTec XP716, and RiceTec XP723 were provided by Dr. Jim Stroike of RiceTec, Inc. of Alvin, Texas. AMS 114-109 and AMS 114-33 were provided by Kirk Johnson of Bayer Cropscience. Cheniere was provided by Dr. Steve Linscombe of LSU while RU0104055 was provided by Dr. Dwight Kanter of Mississippi State University. All other rice varieties or lines were provided by Dr. Karen Moldenhauer and Dr. James Gibbons of the University of Arkansas Rice Research and Extension Center.

Rice varieties or lines were planted in 8-row (7" spacing) x 25-ft long plots and replicated 3 times in a randomized complete block design. Seeding rate was adjusted to plant 40 seed/ft^2 for conventional rice varieties while all hybrids were planted at 35 lb/acre. Variety plots were established in grower fields selected by the local county agent. Plots were managed by the grower with the rest of the field with respect to fertilization, irrigation, weed, and insect control but in general did not receive a fungicide application. Plots were inspected periodically for disease and other problems, then harvested at maturity with yield adjusted to 12% grain moisture. Data were analyzed using analysis of variance with means separation using a standard LSD test. Milling analysis was conducted by Riceland Foods, Inc.

RESULTS AND DISCUSSION

2004 Statewide Disease Situation

Weather in 2004 was cooler and wetter than normal and very favorable for crop production in much of Arkansas. Heavy rainfall in late spring resulted in the flooding of more than 25,000 acres of emerged rice in parts of northeast Arkansas. For the most part, these fields recovered and produced near-normal yields as a result of careful management and favorable weather the balance of the summer.

Rice blast was more widespread than normal in 2004. Estimates suggest as much as 300,000 acres were treated with a fungicide for blast, compared to approximately 100,000 acres in 2003. Widespread and frequent rainfall in May and June resulted in severe leaf blast in east-central and northeast Arkansas on Francis, Wells, CL 161, LaGrue, and Bengal fields. In response, growers increased flood depth in affected fields and held this deeper flood the rest of the summer, and thus avoided severe neck blast for the most part. A few Francis, Wells, and Bengal fields were severely damaged by neck blast.

Statewide, sheath blight was moderate in 2004. Sheath blight was very severe in certain fields of CL 161, an increasingly popular semi-dwarf rice with resistance to a herbicide allowing control of red rice during the growing season. Severely affected fields suffered up to an estimated 15% yield loss or greater. On this cultivar, the disease was severe shortly after panicle differentiation in the worst fields and the use of lower rates and later fungicide applications did not provide adequate control.

Kernel smut and false smut appeared less severe in 2004 compared to recent growing seasons. Given the widespread use of propiconazole-based fungicides in Arkansas rice at present, it is difficult to estimate the overall severity of both diseases. Later-planted fields in northeast Arkansas that did not receive propiconazole were severely affected in September.

Bacterial panicle blight was very erratic and noted primarily on Bengal rice fields in northeast Arkansas. The cooler-than-normal summer probably minimized this disease, which is favored by very hot, humid summer weather. Symptoms of bacterial panicle blight were also noted at low levels in fields of Francis, Cocodrie, and Wells. As noted in test plots, Francis appears to be very susceptible to this disease.

Other diseases were of moderate to low severity in the state. Damage to rice panicles by glyphosate herbicide drift was widespread and severe in some fields, but the overall yield loss from this increasing problem was not known. Fungicide use increased again in 2004 with an estimated 600,000 acres treated, mostly for sheath blight. Preventative applications to fields affected by leaf blast in June were also made at early heading to minimize neck blast. Propiconazole applications to prevent or minimize the smut diseases were widely used in 2004 but normally tank-mixed or pre-mixed with a sheath blight fungicide.

Variety Performance Results

RiceTec XP710, RiceTec XP723, RiceTec Clearfield XL8, RiceTec XP712, Wells, and Francis had the highest average numerical yields over all the harvested plot sites (Table 1). Drew, CL 161, and STG03IMI-261-177 had the lowest average numerical yields (Table 1). Cheniere appeared to have better yield potential and consistent performance than Cocodrie, which it is intended to replace (Table 1). From a production standpoint, Cheniere appears to have good potential in more environments than Cocodrie. Cybonnet had a lower average yield than comparable cultivars (Table 1) but appeared to have very good yield potential in carefully managed fields. Its outstanding milling quality, moderate susceptibility to straighthead, and blast resistance similar to Drew may make Cybonnet a fit for some of the blast-prone environments in the state. Medark appeared to perform very closely to Bengal (Table 1), with which it will compete for acreage in the future.

Plots in Lafayette County emerged inconsistently and the yields reflect the poor stand density. The Craighead County site also had severe but non-uniform sheath blight while the Poinsett County West location had erratic sheath blight, bacterial panicle blight and leaf smut. Plots in White County had stand problems but developed blast in most of the susceptible varieties.

Milling yields were collected from 11 of the 14 locations. Across all locations, the medium-grain varieties AB8684, Bengal, Medark, and RiceTec XP 716 had the highest head rice yields. The long-grain varieties with the highest head rice yields included Cypress, STG03IMI-261-177, Cybonnet, and CL 161. STG03IMI-261-177, Cybonnet, and CL 161 all contain Cypress in their backgrounds and have retained the excellent milling qualities observed with Cypress. Spring, RiceTec CL XL8, AB8649, RU0104055, and AB8198 were the lowest milling-quality varieties.

Reactions to major diseases and lodging are reported in Table 3. CL161 and Cybonnet were the most susceptible cultivars to sheath blight in the on-farm tests, followed by Cocodrie and Cheniere (Table 3). RiceTec XP 710, RiceTec XP 712, and RiceTec XP716 were the most resistant to sheath blight. Banks, Francis, LaGrue, Cocodrie, and Cheniere were very susceptible to kernel smut. AB8198, AB8649, and CL 161 had the most consistent lodging problems. While Banks was a very tall cultivar, it appeared to have good straw strength and did not lodge any worse than other cultivars. Other disease reactions in Table 3 were determined in inoculated plots or other disease nurseries in 2004. Bacterial panicle blight reaction was based on inoculated plots at the Pine Tree Experiment Station and on-farm observations at the Poinsett County site.

SIGNIFICANCE OF RESULTS

The on-farm rice evaluation and disease monitoring program in 2004 provided additional data to the rice breeding and disease resistance programs. These plots and other field observations associated with the program provided early warning for Arkansas growers about leaf blast epidemics in the state as well as information on sheath blight activity on different cultivars in various regions during the summer. The program provided supplemental performance and disease reaction data on new varieties and hybrids that will be more widely grown in Arkansas during 2005. Plots served as the centerpiece for 9 different local rice field days and data were presented at 29 winter grower meetings.

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Table 1. Cultivar grain yield performance comparisons in on-farm

Cultivar	Chicot	Craig-head	Desha	Faulkner	Lafay-ette	Lawrence	Lincoln
AB8198	174	185	173	185	131	192	212
AB8649	180	184	174	198	132	168	201
AB8684	193	166	194	201	118	166	199
Ahrent	165	171	162	173	127	155	202
AMS114-109	193	186	153	197	116	164	148
AMS114-33	182	139	166	200	103	146	183
AR0101093	186	163	153	182	117	129	167
Banks	193	162	177	211	99	175	192
Bengal	198	180	191	214	113	151	192
Cheniere	198	188	183	199	132	182	177
CL161	182	146	175	181	101	168	164
Cocodrie	201	190	174	222	102	185	146
CyBonnet	186	180	187	203	116	190	166
Cypress	174	175	175	181	104	157	166
Drew				185	99		
Francis	200	197	179	215	100	169	190
LaGrue	195	182	188	191	93	166	194
Medark	196	204	184	199	129	157	199
Rice Tec CL XL8	228	206	197	243	176	198	215
Rice Tec XP 710	226	262	218	224	165	191	244
Rice Tec XP 712	218	236	205	242	155	208	194
Rice Tec XP 716	237	173	216	162	159	184	202
Rice Tec XP 723	239	217	217	259	148	216	225
RU0104055	173	173	147	200	89	159	182
Wells	208	181	176	211	110	171	189
STG03IMI-261-177	172	159	164			153	156
Mean	196	184	181	203	121	172	188
LSD	13.4	23.5	19.8	23.0	36.5	31.0	26.8
C.V.%	4.2	7.8	6.5	6.9	18.3	11.0	8.5

trials conducted in the rice disease monitoring program during 2004.

		Poinsett					
Mississippi	Monroe	East	West	Prairie	White	Woodruff	Mean
148	73	186	133	209	149	214	172
167	146	225	132	166	109	219	175
178	191	210	124	204	155	214	184
155	182	164	147	219	180	216	176
130	211	241	156	257	192	221	188
146	167	195	115	220	193	201	173
146	171	197	145	231	187	164	171
187	142	198	128	204	162	226	181
169	155	207	137	218	170	215	184
166	168	229	131	226	159	205	185
150	124	195	108	212	158	170	164
164	184	185	142	223	187	194	184
172	178	224	102	202	182	181	181
138	151	193	118	200	179	184	169
	93		94	185	176		147
176	212	209	142	234	173	202	192
209	147	207	107	190	172	196	180
148	158	228	139	213	171	204	185
199	147	260	182	248	214	255	215
197	181	264	169	264	237	274	227
213	176	256	170	233	171	242	213
199	76	270	131	240	164	230	191
178	192	272	194	292	214	241	227
138	180	172	102	214	153	191	168
180	183	247	157	244	171	199	194
146		202				181	166
168	160	217	136	222	175	210	184
26.0	46.8	49.4	19.2	36.2	36.4	31.3	
9.6	17.9	13.8	8.6	9.9	12.2	8.9	

Table 2. Cultivar milling yield performance comparisons in on-farm

Cultivar	Chicot	Craighead	Desha	Faulkner	Lafayette	Lawrence
AB8198	50-67	68-73	53-67	61-70	65-70	61-70
AB8649	57-68	66-72	55-66	63-70	64-68	58-69
AB8684	69-72	70-73	67-70	67-72	69-71	67-71
Ahrent	59-69	66-72	60-67	62-70	68-70	62-69
AMS114-109	61-70	69-73	61-69	65-70	68-71	62-70
AMS114-33	60-69	68-72	59-66	64-70	69-71	65-70
AR0101093	43-68	66-71	51-66	61-69	65-68	58-68
Banks	62-70	69-73	59-67	63-69	64-69	63-69
Bengal	67-72	69-73	66-70	67-69	68-69	66-70
Cheniere	59-69	67-73	57-68	63-70	66-70	61-70
CL161	64-70	69-72	59-67	65-70	67-70	62-71
Cocodrie	64-72	70-73	58-68	63-70	67-70	58-71
CyBonnet	63-68	70-73	60-68	63-70	69-71	64-71
Cypress	66-71	70-73	63-68	64-70	69-71	63-71
Drew				65-71		
Francis	58-68	68-73	57-67	61-70	67-70	60-69
LaGrue	61-69	68-72	55-66	65-70	61-66	59-68
Medark	67-71	70-72	66-70	69-71	67-69	67-71
Rice Tec CL XL8	55-69	64-72	53-68	61-71	65-70	59-69
Rice Tec XP 710	59-70	65-72	51-66	61-69	66-71	59-69
Rice Tec XP 712	62-69	69-72	62-68	64-70	68-70	61-70
Rice Tec XP 716	67-70	70-72	65-68	63-68	70-70	65-70
Rice Tec XP 723	59-70	65-72	57-68	66-72	68-72	62-70
RU0104055	58-70	68-73	59-69	61-70	58-66	58-69
Wells	63-73	69-74	58-70	64-72	64-69	61-70
STG03IMI-261-177	65-71	69-73	63-69		69-71	63-72
Mean	61-70	68-72	59-68	64-70	66-70	62-70

trials conducted in the rice disease monitoring program during 2004.

Lincoln	Mississippi	Monroe	Poinsett (East)	Woodruff	Mean
71-75	62-73	64-70	50-67	70-74	62-71
65-74	59-70	59-69	57-68	69-73	62-70
73-75	69-73	67-71	69-72	70-74	69-72
68-73	63-71	63-69	59-69	68-72	64-70
69-73	63-71	64-69	61-70	69-73	65-71
70-74	65-71	64-69	60-69	69-73	65-71
67-73	60-71	60-69	43-68	68-73	60-70
72-74	67-72	64-69	62-70	70-73	65-70
73-75	69-73	67-70	67-72	71-73	68-71
70-74	62-71	63-69	59-69	70-73	64-71
70-74	68-72	65-69	64-70	70-73	66-71
72-74	67-73	62-68	64-72	70-74	65-71
71-74	65-72	65-71	63-68	70-73	66-71
71-74	67-72	66-70	66-71	71-73	67-71
	62-71				64-71
71-74	65-72	62-70	58-68	69-73	64-71
72-74	63-70	63-69	61-69	68-73	64-70
71-73	69-73	67-71	67-71	70-73	68-71
69-74	59-72	62-71	55-69	67-73	61-71
70-74	62-72	65-70	59-70	66-72	63-70
70-72	65-71	65-70	62-69	69-72	65-70
72-74	68-72	68-71	67-70	68-72	68-71
71-75	65-73	65-71	59-70	68-73	65-71
68-73	63-71	57-65	58-70	66-72	62-70
71-75	67-73	64-71	63-73	69-74	65-72
71-74		65-71	65-71	70-74	67-72
70-74	65-72	64-70	61-70	69-73	64-71

Table 3. Disease reactions of rice cultivars included in the 2004 on-farm performance and disease monitoring program.

Variety	Sheath blight[z]	Blast	Stem rot	Kernel smut	False smut	Brown spot	Straight-head	Lodging	Black sheath rot
AB 8198	MS	S	MS	MS	MS	R	VS	S	MS
AB 8649	MS	R[y]	S	MS	MS	R	MS	S	MS
AB 8684	MS	R[y]	MS	MS	MS	R	VS	MS	MR
Ahrent	MS	R[y]	S	MS	S	S	S	MS	MS
AMS 114-33	MS	R[y]	S	MS	MS	R	MS	MR	MS
AMS 114-109	MS	R[y]	S	MS	S	R	MS	MR	MS
Banks	MS	R[y]	S	VS	S	R	MS	MS	MS
Bengal	MS	S	VS	MS	MS	VS	VS	MR	MR
Cheniere	MS	MS	S	VS	S	R	MS	MR	MS
Clearfield 161	VS	S	S	S	S	R	S	S	S
Cocodrie	S	MS	S	VS	S	R	VS	MR	MS
Cybonnet	VS	R[y]	S	S	S	R	MS	MS	S
Cypress	VS	MS	MS	S	S	R	MS	MS	S
Drew	MS	R[y]	MS	MS	S	S	MS	MS	MS
Francis	MS	S	S	VS	S	R	MS	MS	MS
LaGrue	MS	S	MS	VS	S	R	MS	MS	MS
MedArk	MS	MS	S	MS	MS	R	S	MR	MR
RiceTec Clearfield XL8	MS	R[y]	S	MS	MS	R	MS	MS	MS
RiceTec XP710	MR	MR[y]	MS	MS	MS	R	VS	MS	MS
RiceTec XP712	MR	R[y]	S	MS	MS	R	MS	MS	MR
RiceTec XP716	MR	MR[y]	S	MS	MS	R	MS	MS	MR
RiceTec XP723	MS	R[y]	S	MS	MS	R	MS	MS	MS
RU0104055	MS	R[y]	MS	MS	MS	R	MS	MR	MR
Spring	MS	S	S	S	MS	MR		MS	S
STG03IMI-261-177	MS	R[y]	S	S	S	MR		MR	MS
Wells	MS	S	S	MS	S	R	MS	MS	MS

[z] Disease reactions where R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; and VS = Very Susceptible. Using a 0-9 rating scale where 0 = no disease and 9 = very severe disease or plant death - R represents 0 – 2 ratings; MR 3-4; MS 5-6; S 7-8 and VS 9. Reactions are based on observations made during 2004 at selected on-farm evaluation sites, URRN disease nurseries, commercial fields, or other experimental disease nurseries around the state.

[y] Resistant to common strains of the rice blast fungus in Arkansas. Susceptible to an unusual variant strain of the rice blast fungus that has been rare in the field to date or reaction to the variant strain not known at the time of publication.

Screening Rice Lines for Susceptibility to Rice Stink Bug: Results from the Arkansas Rice Performance Tests

J.L. Bernhardt, K.A.K. Moldenhauer, and J.W. Gibbons

ABSTRACT

Rice lines were evaluated for susceptibility to causes of kernel discolorations. Advanced rice lines in the Arkansas Rice Performance Trials (ARPT) were compared to check varieties for susceptibility to feeding by rice stink bugs, *Oebalus pugnax* (F.). Susceptibilities were assessed by manual evaluation of brown rice kernels for discolorations that result from rice stink-bug feeding probes. Results of the ARPT evaluations in 2003 could be categorized as excellent for evaluating susceptibility to rice stink bugs because natural infestations were high. Based on these results, the new rice variety 'MedArk' had typical medium-grain susceptibility (highly susceptible) to damage from rice stink bugs; the new variety 'Cybonnet' should be considered susceptible to damage from rice stink bugs but slightly less so than the moderately susceptible 'Cypress' and 'Wells'; and the new variety 'Banks' should be considered as susceptible as 'Drew' to rice stink bug damage. These data from yearly evaluations of rice lines and varieties are given to rice breeders and can be used to help in the selection of lines to continue in the breeding program. Rice growers can use the information to select varieties and use management practices that will reduce quality reductions due to rice stink bugs.

INTRODUCTION

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

The entomology research program has placed emphasis on the development of control strategies that integrate control methods such as less-susceptible rice lines, insecticides, and rice stink bug parasites. This portion of the program evaluates rice lines for susceptibility to rice stink bug feeding and other causes of kernel discoloration. The overall objective is to provide information to breeders and, perhaps, to safeguard against the release of more-susceptible varieties from breeding programs than exist at the present time, and to evaluate the rice germplasm for sources of resistance.

To accomplish the objectives, rice grain samples must be obtained from several sources for several years and evaluated for the amount of discolored kernels. Results from the evaluations of rice lines are compared and conclusions made on the relative susceptibility of rice lines based on the amounts of discolored kernels. This report is a summary of the annual evaluation of rice lines in the Arkansas breeding program for susceptibility to rice stink bug damage.

PROCEDURES

Rice samples from the following sources and years have been evaluated: (1) rice lines from the rice breeding program of the University of Arkansas placed in the Arkansas Rice Performance Trials (ARPT) (1988-2003); (2) rice lines from breeding programs of other universities and private seed companies in the ARPT (1988 - 2003); and (3) advanced rice lines placed in the Uniform Regional Rice Nursery (URRN) (1993-2003). Locations of the ARPT in 2003 were the Rice Research and Extension Center, Stuttgart (RREC, Arkansas Co.); Clay County, Ark.; Jackson County, Ark.; Pine Tree Branch Experiment Station, Colt (PTBES, St. Francis Co.); Northeast Research and Extension Center, Keiser (NEREC, Mississippi Co.); and the Southeast Branch Experiment Station, Rohwer (SEBES, Desha Co.). Evaluations of the URRN grown at the RREC started in 1993 and have been evaluated yearly through 2003. Check varieties interspersed among the rice lines in the ARPT and URRN are used for comparisons.

Uncleaned rough rice samples are taken and then hulled. Brown rice was passed three times through an electronic sorting machine that separated discolored kernels from other kernels. The discolored kernels were examined with magnification to determine the cause of the discoloration. The categories of discolored kernels were (a) kernels discolored by rice stink bug feeding, (b) kernels infected with kernel smut, (c) all other discolorations of which most had the discoloration confined to the bran layer, and (d) linear discolored kernels. Linear discolored kernels had a straight (linear) 'cut' in the kernel that was surrounded by a dark brown to black area (Douglas and Tullis, 1950). The amount of discolored kernels in a category was weighed and expressed as a percentage of the total weight of brown rice.

Data included in this report are amounts of discolored kernels in check varieties from 1990 through 2003 and advanced rice lines in the ARPT from 2003.

RESULTS AND DISCUSSION

In 2003, rough rice samples were evaluated from all entries at five of the six locations in Arkansas (RREC, Clay Co., SEBES, NEREC, and Jackson Co.). No samples were evaluated from the PTBES. Large-field tests such as the ARPT rely on natural infestations of the rice stink bug. In 2003, infestations varied from low, in Clay Co., to moderate at the RREC, SEREC, and Jackson Co., and to high at NEREC. General trends of varietal susceptibility that were noted in other years of the ARPT and other varietal studies (Bernhardt, 1992) remained the same (Table 1). For example, the amount of discolored kernels in medium-grain varieties was more than that in most long-grain varieties (Tables 2 and 3). It is also evident that although lines have different amounts of damage, there are no varieties or lines that are truly resistant to the rice stink bug. However, long-grain varieties that routinely have less damage from rice stink bug in previous years, such as 'Katy', 'Kaybonnet' and 'LaGrue', had lower amounts of damage when compared to most advanced rice lines.

Early-Season Maturity Group

This maturity group had 18 advanced lines that were distributed as 5% short-, 5% medium-, and 90% long-grain, seven check varieties, and one Clearfield® variety (Table 2). Among the 16 long-grain lines, several lines had damage numerically lower, but none had damage levels statistically significantly lower than the check 'Jefferson'. Many lines were numerically lower in damage than the check 'Cocodrie' but five lines (RU0301161, RU9903092 from Texas, RU0301093, RU0301096, and RU0101093) had statistically significant damage lower than that of Cocodrie. All five lines were tested again in 2004. Also, among those five lines, RU0101093 is being released in 2005 as the variety 'Spring'. The Clearfield line 'CL-XL8' had a moderate level of damage that was similar to that of the parent variety, RiceTec 'XL8'.

Very Short-Season Maturity Group

The 19 advanced rice lines in this maturity group were distributed as 11% medium- and 89% long-grain (Table 2). Neither of the medium-grain lines, 'RiceTec XP712' nor RU0301127, had a level of damage that was significantly lower than either of the check lines 'Bengal' or MedArk. However, RiceTec XP712 had approximately 30% less damage than the medium-grain check lines. None of the long-grain lines had a level of damage that was statistically significantly lower than the check line LaGrue. The check variety LaGrue usually has a low amount of damage and in this test it had the lowest amount of damage of all checks and advanced lines.

Short-Season Maturity Group

The 21 advanced rice lines in this maturity group were composed of 10% medium- and 90% long-grains, respectively (Table 3). None of the lines had statistically significantly lower levels of damage than the check lines LaGrue or Wells. However, RU0101148 and RU0101105 both had amounts similar to that of LaGrue. The medium-grain lines had typical levels for medium-grains. The new release Cybonnet, a cross between Cypress and 'Newbonnet' crossed with Katy, had damage levels slightly less than Cypress.

Mid-Season Maturity Group

Of the 23 advanced long-grain lines in this maturity group, none had significantly lower amounts of damage than the check variety Drew or 'Banks' (Table 3). One line, STG99F5-02-132, had a damage amount numerically lower than the amount of damage in Drew and similar to that of Banks. However, the line was cut from further consideration.

SIGNIFICANCE OF FINDINGS

Evaluations of advanced rice lines provide rice breeders with information on the susceptibility of lines to rice stink bug damage. If they wish, breeders can then use the information in the selection of lines for further tests and the elimination of lines that are clearly more susceptible to damage than exist at the present time. Rice growers can use the information to select varieties and use management practices that will reduce quality reductions due to rice stink bugs. For example, medium-grain and a few long-grain rice varieties are very susceptible to rice stink bug damage and other types of kernel discolorations. Careful scouting and use of insecticides for rice stink bug, when necessary, would prevent excessive discounts due to discolored kernels.

The new rice variety MedArk has typical medium-grain susceptibility (highly susceptible) to damage from rice stink bugs. The new variety Cybonnet should be considered susceptible to damage from rice stink bugs but slightly less than the moderately susceptible Cypress and Wells. The new variety 'Banks' should be considered as susceptible as 'Drew' to rice stink bug damage. If growers have been discounted in the past for high levels of 'pecky rice' (a term that refers to all discolored kernels regardless of cause), all three new releases may require applications of insecticide to reduce excessive discounts due to discolored kernels.

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Table 1. Average percent, by weight, of kernels discolored by rice stink bugs in brown rice samples of rice varieties in the Arkansas Rice Performance Trials from 1990 to 2003.

Maturity group and variety	Grain type[z]	Year													
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
		(% discolored)													
Mid-season															
Lemont	L	0.64	0.45	0.30	1.14	0.43	0.74	1.40	0.70	1.56	2.18	0.85	2.85	-	-
Katy	L	0.40	0.31	0.21	0.98	0.41	0.51	0.85	0.36	0.88	2.25	0.63	2.85	-	-
Drew	L	-	-	-	0.82	0.48	0.67	1.26	0.55	1.17	2.08	0.67	2.43	1.58	0.70
Banks	L	-	-	-	-	-	-	-	-	-	-	0.31	2.27	1.87	0.64
Short-season															
Kaybonnet	L	-	-	0.31	0.92	0.28	0.48	0.93	0.39	0.89	1.45	0.77	1.61	1.48	0.81
LaGrue	L	-	0.36	0.30	0.78	0.31	0.51	0.71	0.42	0.94	1.59	0.68	1.49	1.64	0.77
Wells	L	-	-	-	-	-	-	0.60	0.88	1.83	1.97	0.83	2.41	2.02	1.12
Cybonnet	L	-	-	-	-	-	-	-	-	-	-	0.70	2.03	1.84	1.02
Cypress	L	-	-	-	-	-	-	-	-	-	2.02	0.88	2.14	2.50	1.39
Very short season															
Bengal	M	-	-	1.24	2.36	1.42	1.69	2.18	1.09	2.80	2.30	1.28	5.34	2.70	2.97
MedArk	M	-	-	-	-	-	-	-	-	-	-	1.14	4.51	2.88	2.57
LaGrue	L	-	-	-	-	-	-	-	-	-	-	0.50	2.01	1.40	0.80
Ahrent	L	-	-	-	-	-	-	-	-	-	2.32	1.55	2.63	1.94	1.55
Francis	L	-	-	-	-	-	-	-	-	-	1.87	-	2.10	1.71	1.05
Early season															
M202	M	-	-	-	-	-	-	2.41	1.44	2.63	2.17	1.58	4.43	3.60	2.57
Maybelle	L	0.70	0.71	0.32	0.92	0.78	0.49	-	-	-	0.89	0.65	1.36	0.95	1.09
Jefferson	L	-	-	-	-	-	-	0.87	0.47	1.21	0.87	0.52	1.77	0.67	1.22
Cocodire	L	-	-	-	-	-	-	-	0.76	1.99	1.90	1.07	3.89	0.99	1.89

[z] L = long-grain and M = medium-grain.

Table 2. Average percent, by weight, of kernels discolored by rice stink bugs in brown rice samples of varieties and advanced lines from two maturity groups in the 2003 Arkansas Rice Performance Trials.

Early season lines	Grain Type[z]	% discolored	Very short season lines	Grain type	% discolored
Jefferson	L	1.22	Bengal	M	2.97
RU9601099	S	1.80	Cheniere	L	1.14
Maybelle	L	1.09	XP712	M	1.87
Cocodrie	L	1.89	LaGrue	L	0.80
RU0101093	L	0.61	RU0301127	M	2.25
RU0301090	L	1.54	RU0301027	L	1.12
Pirogue	S	2.25	RU0101084	L	1.28
STG00F5-05-096	M	1.95	RU0301145	L	1.80
RU0101108	L	0.98	RU0301151	L	1.00
RU0301093	L	1.05	Francis	L	1.05
RU0301001	L	0.92	RU0301030	L	1.13
XL8	L	1.49	MedArk	M	2.57
RU0301096	L	0.78	RU0301041	L	1.07
RU0301105	L	1.19	STG00L-16-134	L	1.06
RU0301111	L	1.11	RU0301044	L	1.10
RU0301124	L	1.22	RU0301121	L	1.65
STG00L-22-066	L	1.34	XP710	L	1.62
STG99L-41-009	L	1.11	RU0301047	L	1.14
CL XL8	L	1.25	Ahrent	L	1.55
RU0202008	L	1.49	RU0301164	L	0.94
M202	M	2.57	RU0301050	L	0.98
RU0104055	L	1.39	RU0301167	L	1.02
ZHE 733	L	3.06	RU0201133	L	1.32
RU0301099	L	1.56	RU0301170	L	1.06
RU9903092	L	0.75	RU0301061	L	1.02
RU0301161	L	0.94	RU0301064	L	1.18

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

Table 3. Average percent, by weight, of kernels discolored by rice stink bugs in brown rice samples of varieties and advanced lines from two maturity groups in the 2003 Arkansas Rice Performance Trials.

Short season lines	Grain Type[z]	% discolored	Mid season lines	Grain type	% discolored
Wells	L	1.12	Drew	L	0.70
LaGrue	L	0.77	RU0301067	L	1.02
Kaybonnet	L	0.81	aromatic SE 1	L	1.93
RU9803181	L	1.17	STG00L-16-039	L	1.09
Cypress	L	1.39	STG00L-16-025	L	1.06
STG00F5-05-079	M	2.37	STG00F5-08-062	L	1.42
STG00F5-09-128	L	1.15	Banks	L	0.64
GLPA	L	1.36	RU0101099	L	1.07
STG00F5-07-007	L	1.34	STG99L-34-089	L	0.81
RU0101102	L	1.38	STG00L-03-069	L	0.93
RU0301173	L	1.05	STG00L-22-029	L	1.04
Cybonnet	L	1.02	RU0201142	L	1.88
RU0301176	L	1.07	STG00L-14-039	L	0.78
STG00L-16-114	L	0.98	STG99F5-02-110	L	1.29
AB-8649	L	1.94	RU0201130	L	1.25
RU0201136	M	2.40	RU0301070	L	0.88
STG00F5-05-111	L	1.67	STG00P-01-132	L	0.65
RU0101105	L	0.79	RU0201139	L	1.65
STG00L-16-063	L	1.33	STG00L-15-133	L	1.12
AB-8198	L	1.90	STG99L-20-123	L	0.95
STG00L-23-021	L	0.89	Saber	L	0.60
STG99L-21-038	L	0.95	STG99L-27-022	L	1.99
RU0101148	L	0.69	STG98L-06-021	L	1.00
STG00L-25-029	L	1.04	RU0301081	L	1.02
CL-161	L	1.32	STG00L-05-131	L	1.05
RU0301185	L	0.90	RU0301087	L	1.08

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

Outcrossing Potential of Clearfield™ Rice Varieties with Red Rice

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

ABSTRACT

Experiments were conducted at the Rice Research and Extension Center (RREC), Stuttgart; Vegetable Substation, Kibler; Cotton Branch Station, Marianna, Ark., in 2002 to 2003 to evaluate the effects of cultivar, distance from pollen source, and planting date on the extent of natural outcrossing between Clearfield™ (CL) rice and Stuttgart strawhull red rice. Planting dates were 25 April and 21 May 2002. CL cultivars CL161 and CL121 were planted in circles, 33 ft in diameter with three replications. A natural red rice population was maintained in the outer concentric circle, 66 ft in diameter. There was synchronization in flowering between red rice and CL rice cultivars in both planting dates. Red rice panicles were hand-collected at 0, 1.5, 3.0, 6.0, 10.0, 13.0, and 16.0 ft from the interface of CL rice. At maturity, CL rice was removed from the inner circles and red rice was allowed to shatter. In the spring of 2003, volunteer red rice in field plots and seedlings from hand-collected samples were sprayed with three applications of Newpath® 0.063 lb ai/acre. Survivors were counted, morphologically characterized, and genetically tested for hybridization. Outcrossing was higher with CL161 (0.008%) than with CL121 (0.003%) regardless of planting date. Averaged over cultivars, there was no significant difference in outcrossing rate between April (0.004%) and May (0.006%) plantings. Hybrids were located within 20 ft from CL rice, which was the limit of detection in these experiments. All the F_1 hybrids were taller and had longer flag leaves than their parents. The F_1 hybrids had rough-textured, pale-colored leaves similar to the red rice parent.

[1] This is a completed study.

INTRODUCTION

The introduction of CL rice provided a selective approach to red rice control. The increasing popularity of herbicide-resistant rice has raised concerns about its potential hybridization with red rice, possible increased weediness of red rice crosses, and its impact on the future of herbicide-resistant technology in rice. Natural hybridization between cultivated rice and its weedy and wild relatives, red rice and *O. rufipogon,* has been reported in many studies (Chen et al., 2004; Messeguer et al., 2004; Song et al., 2002, 2003). In a red rice-infested rice field, there is no spatial separation between weedy and cultivated rice and the pollen load is high enough to ensure maximum chance of cross-pollination if there is synchronization in flowering. An isolation distance of 20 ft is considered safe for rice hybrid seed-production fields to avoid contamination with pollen from adjacent fields (Khush, 1993), although outcrossing has been recently documented up to 105 ft between Minghui-63 and *O. rufipogon* under field condition in China (Song et al., 2003). Hybrids between red rice and cultivated rice were observed to be taller, with more flag leaf area , and more tillers than their parents (Langevin et al., 1990; Zhang et al., 2003). Since resistance to acetolactate synthase (ALS)-inhibiting herbicides, such as imidazolinones, is generally a dominant trait, all of the red rice hybrids and a majority of the succeeding generations will be herbicide-resistant.

With increasing acreage planted to CL rice in production areas where red rice is a problem, it is important to know how various factors affect effective pollen movement from CL rice to red rice. Understanding the gene flow between CL rice and red rice would help in making management plans and minimizing ecological risks. The objectives of this study were to determine the effects of CL cultivars, planting date, and distance from pollen source on the outcrossing rate between CL rice and red rice.

PROCEDURES

Field experiments were conducted at the RREC, Stuttgart, Ark., in 2002 and 2003. The experiments were planted in a split-plot design with planting date as main plot and cultivar as subplot, with three replications, using an encircle-population combination technique (Fig. 1). The soil at the experimental site is a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) with 0.9% organic matter and a pH of 6.2. The first experiment was planted on 25 April, and the second on 21 May 2002. Clearfield™ cultivars CL 161 and CL121 were drill-seeded in 33-ft diameter circles at 100 lb/acre. Natural population of Stuttgart strawhull red rice was allowed to grow in the outer concentric circle of 66-ft diameter at 2 to 3 plants/ft^2. In the inner circle, starting at two- to three-leaf stage, Newpath® was applied at 0.063 lb ai/acre for two consecutive weeks to keep the inner circle red rice-free. Other standard agronomic and pest management practices were implemented through the growing season.

Dates of flowering in red rice and CL rice cultivars were recorded. Each circle was divided into six sections to observe the effect of wind direction on pollen movement (Fig. 1). At maturity, 50 red rice panicles were hand-harvested from 0, 1.5, 3.0, 6.0, 10.0, 13.0, and 16.0 ft from the interface of CL rice and red rice. The panicles were threshed by hand, and the seeds were cleaned and stored for planting in the field. These samples should provide accurate information on the distance of effective pollen flow from CL rice if hybrids are detected. At maturity, CL rice was removed from the inner circle and red rice was allowed to shatter. The field was left undisturbed during the fall and winter of 2002. Volunteer red rice population was sprayed with Newpath® at 0.063 lb ai/acre three times at weekly intervals starting from the one- to two- leaf stage. The F_1 hybrids were counted and characterized morphologically. The distance of F_1 hybrids from the CL rice was also recorded.

Approximately 2,500 seeds were randomly taken from each hand-collected sample and were planted in the field also to detect hybrids. Due to space limitations, this was done in two batches; the first in 2003 at the Vegetable Research Substation, Kibler, Ark., and the second in 2004 at the Cotton Branch Station, Marianna, Ark. At both locations, red rice seedlings starting at two- to three-leaf stage were sprayed with Newpath at 0.063 lb ai/acre for three consecutive weeks. Survivors from hand-collected samples and from among the volunteer red rice at the RREC experimental site were confirmed as F_1 hybrids using simple sequence repeat (SSR) DNA-fingerprinting technique (Rajguru et al., 2002). Percent outcrossing was estimated based on the number of hybrids detected relative to the total number of red rice seedlings sprayed.

Data on number of F_1s detected were analyzed using GLM procedure in SAS (SAS, 2004). Data from volunteer red rice plants and the hand-collected samples were combined for the overall outcrossing frequency and effective distance of CL rice pollen flow. Data on morphological characteristics of F_1s were combined across April and May planting because planting date had no effect on the plant traits observed.

RESULTS AND DISCUSSION

Outcrossing Rate in Volunteer Red Rice Plots

PCR amplification with the SSR primer RM 180 produced one DNA fragment of about 100 to 120 bp in red rice, but produced a larger fragment (about 160 to 180 bp) in CL rice (Fig. 2). F_1 hybrids showed two fragments, one corresponding to each parent. There was no interaction between planting date and cultivar on the outcrossing rate, so only the main effects are discussed here. Averaged over cultivars and replications in volunteer red rice plots, there was no significant difference in outcrossing rates detected in April (0.0011%) and May (0.0019%) planting (Table 1). The combined outcrossing rate (total 0.55 acre in the experiment)was 0.001% in April and 0.002% in May planting. The average outcrossing rate of CL161 (0.0022%) was higher than CL121 (0.0009%), averaged over planting date and replications. Averaged over two planting times, 6 hybrids in CL121 and 16 in CL161 were found at the interface (0 ft) of the CL rice and red rice (Fig. 3). The number of hybrids found were higher in CL161 plots than CL121 but the trend of decreasing number of hybrids as the distance increased from the interface was similar in both cultivars. Most of the hybrids were late in flowering and their seeds did not mature in the field due to the onset of cold weather.

Outcrossing Rate in Hand-Collected Samples

Outcrossing rate was not significantly different between planting dates as well as between CL121 and CL161 cultivars based on the average of three replications (Table 1). The combined outcrossing rate over both cultivar and replications was 0.007% and 0.012% in April and May planting, respectively. The combined outcrossing rate over two planting dates and replications was 0.01% and 0.02% for CL121 and CL161, respectively. These figures were higher than the outcrossing rate estimated from volunteer red rice plants. The average number of hybrids found in CL121 ranged from one to two at any distance from the interface, whereas in CL161 the range was from one to five (Fig. 4).

Grand Total Outcrossing Rates

The grand total outcrossing rate was calculated by combining the number of hybrids detected from hand-collected samples and hybrids documented among the volunteer red rice plants in each plot. Averaged over cultivars and replications, there was no significant difference between the two planting dates (Table 1). Outcrossing rate of 0.004% and 0.006% was found in the April and May planting, respectively, in the total experimental area under each planting date. CL161 showed significantly higher outcrossing (0.0028%) than CL121(0.0012%) when averaged over three replications. The combined outcrossing in the 0.56 acre area was 0.003% and 0.008% for CL121 and CL161, respectively. The overall outcrossing rates observed in this study were very close to rates reported between Mediterranean GM rice to conventional rice and red rice (Messeguer et al., 2004) and the outcrossing between glufosinate-resistant rice and red rice (Zhang et al., 2003). A significant difference was detected between CL rice cultivars. Hybrids were detected among volunteer plants up to this distance. Higher outcrossing in CL161 than CL 121 suggests that factors other than synchronization in flowering contributed to the difference in outcrossing rates between the two CL rice cultivars. This could be the height difference between pollen donor and pollen acceptor. Difference in morphology of flowers of CL161 and CL121 could be another reason for the difference in outcrossing rate. A detailed study of floral structure and anatomy of CL121 and CL161 can shed light on the difference in outcrossing potential of these two cultivars. The amount of pollen production and longevity are also factors to consider. CL rice pollen could potentially move into red rice-infested ditches or adjacent production fields. On-farm observation experiments will be required to determine how far this distance could actually be.

Morphological Characteristics

The F_1 plants from both CL121 and CL161 plots were significantly taller than their CL rice parent (Table 2). The average flag leaf length (35 cm) was greater in F_1s from both cultivars than their parents. The average flag leaf width of F_1s was the same as that of CL161 (16 mm). The red rice parent had the narrowest flag leaf (13 mm). Hybrids, either from CL121 or CL161, had significantly longer panicles than the red rice parent. All the hybrids had pale-colored, rough-textured leaves, which were similar to the red rice parent. Increase in plant height of F_1 hybrids of CL rice and red rice is consistent with observations in other studies conducted between crosses of herbicide-resistant rice, wild rice, or red rice (Langevin et al., 1990; Oard et al., 2000; Zhang et al., 2003). Due to increased height, flag leaf length, and general plant size, hybrids should be more competitive in terms of space, light interception, nutrient uptake, and availing themselves of other resources in the field compared to red rice and CL rice cultivars. However, the hybrids exhibited some reduced fitness in terms of delayed maturity, which prevented most of them from producing viable seed.

SIGNIFICANCE OF FINDINGS

Results of this study suggest that CL rice cultivar and distance from pollen source influence the outcrossing rate. Although the outcrossing rates are very low, in a field situation this low rate can result in approximately 70 resistant plants/acre based on data from CL161 planted in May. These numbers are significant where rice is planted in hundreds of hectares. Scott and Burgos (2004) already reported a confirmed outcrossing between CL 161 and red rice in a farmer's field in Arkansas, which corroborates the findings of this study. Given enough warm days, and without further intervention after rice harvest, some F_1 plants can produce viable seed toward late fall. Control of herbicide-resistant gene flow from CL rice to red rice is critical for a sustainable herbicide-resistant rice technology.

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Table 1. Estimated outcrossing rates as affected by cultivar and planting time at the Rice Research and Extension Center, Stuttgart, 2002; Vegetable Substation, Kibler; and Cotton Research Branch, Marianna, Ark., 2003 and 2004.

	Outcrossing rate[z]					
	Volunteer red rice plots[y]		Hand-collected[w]		Grand total[v]	
Main effects	Average	Combined[x]	Average	Combined	Average	Combined
	(%)					
Planting date						
25 April 2002	0.0011 a	0.001	0.008 a	0.007	0.0016 a	0.004
21 May 2002	0.0019 a	0.002	0.014 a	0.012	0.0023 a	0.006
Cultivar						
CL 121	0.0009 b	0.003	0.008 a	0.01	0.0012 b	0.003
CL 161	0.0022 a	0.007	0.013 a	0.02	0.0028 a	0.008

[z] Means followed by the same letter in columns are not significantly different (= 0.05), student's t-test.

[y] Outcrossing based on the hybrids detected among red rice volunteers.

[x] Combined outcrossing based on total area of the three replications.

[w] Outcrossing based on the hand-collected seed samples.

[v] Grand total outcrossing is based on the total number of hybrids detected among red rice volunteers and hand-collected samples.

Table 2. Description of morphological characteristics of F_1 hybrids, Clearfield[TM] (CL) rice, and red rice found in the experiment at the Rice Research and Extension Center, Stuttgart, Ark., 2002.

	Morphological characteristics[z]					
Cultivar	Height	Flag leaf length	Flag leaf width	Panicle length	Leaf Color[y]	Leaf Texture[x]
	---------- (cm) ----------		(mm)	(cm)		
CL121 F_1	117 a	35 a	16 a	25 a	P	R
CL161 F_1	122 a	35 a	16 a	25 a	P	R
CL121	84 c	25 c	15 b	23 a	P	R
CL161	93 b	31 b	16 a	23 a	G	S
RR	108 a	27 c	13 c	21 b	P	R

[z] Means followed by the same letter in columns are not significantly different (= 0.05), student's t-test.

[y] P = pale; G= green.

[x] R= rough; S= smooth.

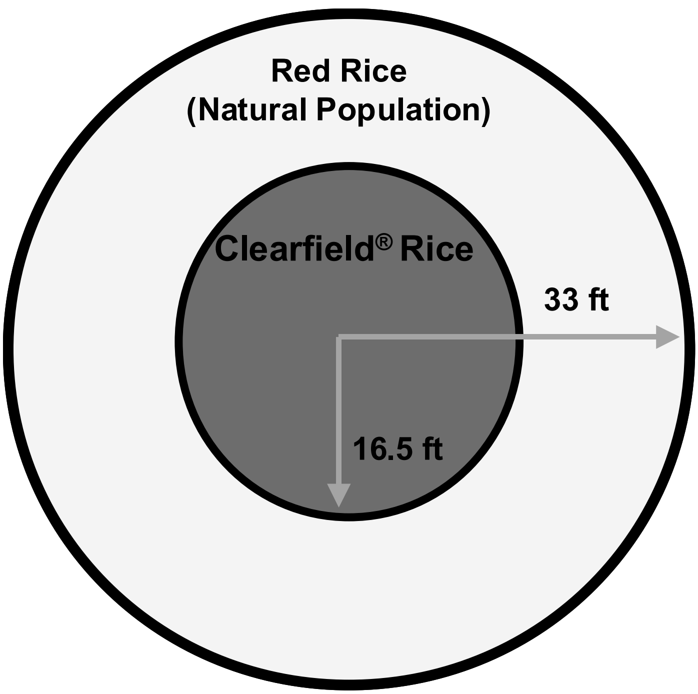

Fig. 1. Inner circle represents Clearfield rice and outer circle represents natural population of red rice at the RREC, Stuttgart, Ark., 2003.

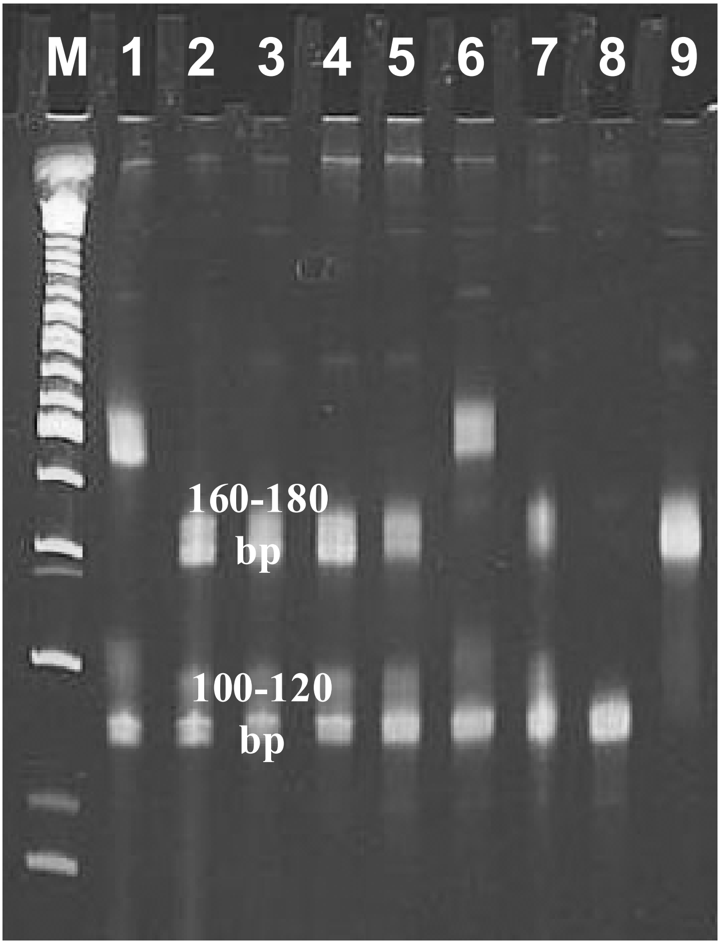

Fig. 2. Representative DNA banding pattern of red rice (Lane 8), Clearfield rice (Lane 9), and hybrid (Lanes 1-7) genomic DNA amplified by PCR using SSR primer RM 180.

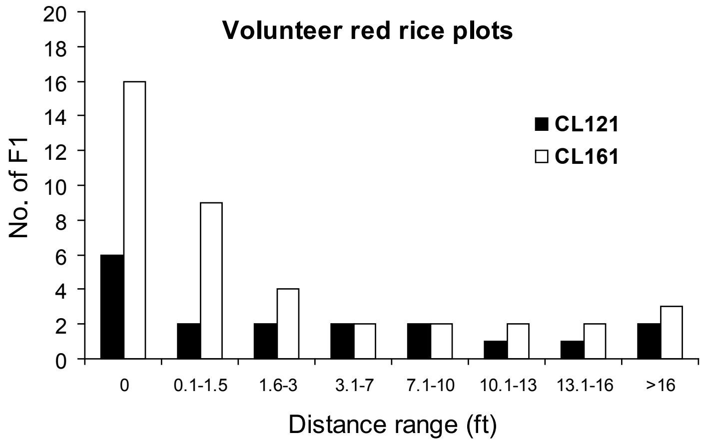

Fig. 3. F_1s from average of April and May planting dates, and three replications among volunteer red rice plots in CL121 and CL161 plots as affected by distance from pollen source at RREC, Stuttgart, Ark., 2002.

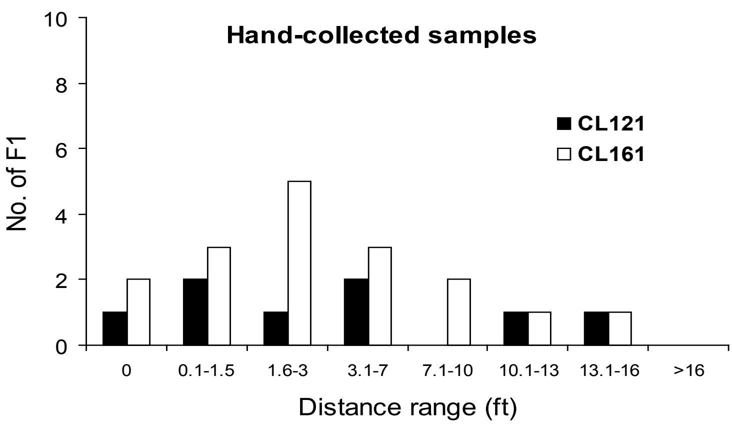

Fig. 4. F_1s from average of April and May planting dates, and three replications in hand-collected seed samples from CL121 and CL161 plots as affected by distance from pollen source at Kibler and Marianna, Ark., 2003 and 2004.

Postemergence Herbicide Programs for Control of Non-Traditional Broadleaf Weeds in Rice

A.T. Ellis, B.V. Ottis, R.C. Scott, and R.E. Talbert

ABSTRACT

Experiments were conducted in the summer of 2004 to evaluate the performance of several postemergence broadleaf rice herbicides on sicklepod, cutleaf groundcherry, and pitted morningglory at the Rice Research and Extension Center, Stuttgart, Ark., and University of Arkansas Pine Bluff Experiment Station, Lonoke, Ark. At Stuttgart and Lonoke, weeds were sown in rows perpendicular to the drilled rice rows. A separate experiment was conducted on a natural population of Palmer amaranth at the Arkansas Agricultural Research and Extension Center, Fayetteville, Ark.

Postemergence applications were made at two separate timings, an early postemergence (EP) on 1- to 2-in. weeds and late postemergence (LP) on 12- to 14-in. weeds at labeled rates. The plots were periodically flushed when the soil moisture level was low; both studies were never under flooded conditions. Control (>71 %) of cutleaf groundcherry at the EP timing was shown with carfentrazone, acifluorfen, quinclorac, imazethapyr, propanil, penoxsulam, and bispyribac-sodium. Applications of carfentrazone, imazethapyr, triclopyr, and propanil controlled cutleaf groundcherry at the LP timing. The EP post-applications of halosulsfuron, acifluorfen, carfentrazone, quinclorac, bispyribac-sodium, imazethapyr, triclopyr, and propanil controlled (>79 %) pitted morningglory. Pitted morningglory was controlled with LP applications of carfentrazone, quinclorac, imazethapyr, triclopyr, and IR 5878. Early postemergence applications of quinclorac and propanil controlled sicklepod. Control of sicklepod at the LP timing was given by quinclorac and triclopyr. At the EP timing, Palmer amaranth was controlled by carfentrazone, penoxsulam, imzethapyr, propanil, and bispyribac-sodium. All LP treatments failed to control Palmer amaranth.

INTRODUCTION

Over the past few years many growers have been using clomazone (Command) instead of propanil and quinclorac for control of grass weeds, especially the herbicide-resistant barnyardgrass. This dependance upon Command is allowing broadleaf weeds to become more of a problem in rice fields. Arkansas rice is mostly grown in rotation with soybeans. Several broadleaf weeds can be a problem with this rotation. Weeds such as cutleaf groundcherry, if not controlled, can reduce soybean yield by 69% (Bell and Oliver, 1979). Riley and Shaw (1988) found that pitted morningglory reduced soybean yield by 50% if uncontrolled. Sicklepod infestations have been found to reduce soybean yield by as much as 25% (Shaw et al., 1997). Klingaman and Oliver (1994) found that soybean yields were reduced 60 to 70% by Palmer amaranth densities of 4 to 10 plants/3 ft of row. Infestations of these weeds in a soybean crop will infest a rice crop the next year. Levees in rice fields can have these weeds, because levees are not flooded. If improperly managed for weed control, rice yields on levees can be seriously reduced, especially where levees compose a large proportion of the area in the field. These weeds generally do not survive after the flood is established but before flooding, these weeds can also compete with rice. Also these types of weeds can be expected to be a greater problem under alternative methods of irrigation such as furrow and intermittent irrigation.

PROCEDURES

At the Stuttgart and Lonoke locations, cutleaf groundcherry, pitted morningglory, and sicklepod were each drilled in two rows perpendicular to the drilled rice rows. The Clearfield 161 variety was drill-seeded at 90 lb/acre. The test was flushed regularly when soil moisture level was low instead of adding a permenant flood. Flushing allowed the weeds to survive throughout the growing season. The separate location for Palmer amaranth was a natural population. Herbicide treatments were applied with a CO_2 backpack sprayer calibrated to deliver 10 gal/acre. The EP and LP herbicide treatments included halosulfuron at 0.056 lb ai/acre, acifluorfen at 0.094 lb/acre, carfentrazone at 0.25 lb/acre, quinclorac at 0.38 lb/acre, bentazon at 0.75 lb/acre, bispyribac-sodium at 0.063 lb/acre, imazethapyr at 0.063 lb/acre, triclopyr at 0.25 lb/acre, propanil at 4 lb/acre, penoxsulam at 0.031 lb/acre, and IR 5878 at 0.067 lb/acre. Weed heights at the EP application timings were 1 to 2 inches and at LP were 12 to 14 inches. Herbicide efficacy was rated on a 0 to 100% scale with 0 representing no control and 100 representing death of the weed. The EP and LP timings were about 28 d apart. Visual ratings on cutleaf groundcherry, pitted morningglory, and sicklepod were taken at 7 d after treatment (DAT) and then in 7 d increments until 21 d after the LP treatments. The EP and LP applications on Palmer amaranth were applied 14 d apart. Ratings on Palmer amaranth were taken 7, 14, 21, and 28 d after EP timing and 7 and 14 d after LP timing. Clincher at 0.25 lb/acre was applied when needed for grass control within plots at Stuttgart and Lonoke. Maximum efficacy for cutleaf groundcherry, pitted morningglory, and sicklepod was reached at 3 wk after treatment (WAT) and at 2 WAT for Palmer amaranth. These data were subjected to ANOVA using Fishers' protected LSD with p= 0.05.

RESULTS AND DISCUSSION

Data were combined across locations for cutleaf groundcherry and sicklepod as the interaction between location and herbicide was not significant. At the EP timing, cutleaf groundcherry was controlled (>90%) by carfentrazone, quinclorac, imazethapyr, and propanil. Moderate control (60 to 70%) of cutleaf groundcherry was shown with halosulfuron, acifluorfen, bispyribac-sodium, and penoxsulam at the EP timing. Cutleaf groundcherry at LP timing was controlled (>80%) by carfentrazone and imazethapyr. Acifluorfen, triclopyr, and propanil gave moderate (60 to 77%) control of cutleaf groundcherry for the LP timing. At the EP timing, control of sicklepod was only moderate (60 to 70%) with applications of propanil and bispyribac-sodium. Quinclorac and triclopyr treatments gave moderate control (71 to 78%) of sicklepod for the LP timing.

Pitted morningglory control varied with treatment at the two locations (Table 1). Quinclorac was effective applied EP at both locations (95 to 99%). At Lonoke, EP treatments of carfentrazone, imazethapyr, propanil, and IR 5878 showed moderate (68 to 78%) control of pitted morningglory. At Stuttgart, EP treatments of halosulfuron, acifluorfen, carfentrazone, bispyribac-sodium, imazethapyr, triclopyr, and propanil controlled (>79%) pitted morningglory. At Lonoke, no LP treatments were effective in the control of pitted morningglory. Pitted morningglory at Stuttgart was controlled at the LP timing by carfentrazone, quinclorac, imazethapyr, and triclopyr. At Stuttgart, higher control of pitted morningglory was observed with many more herbicides than at Lonoke. This can be attributed to an early-season hail storm at Stuttgart which damaged the pitted morningglory severely and apparently this damage resulted in greater sensitivity of the pitted morningglory to these herbicides.

Palmer amaranth at the EP timing was controlled (>80%) by carfentrazone, penoxsulam, imzethapyr, propanil, and bispyribac-sodium (Table 1). At the LP timing, Palmer amaranth was not adequately controlled, <40% with all herbicides. At the LP timing, the Palmer amaranth population was very dense and large (>12 inches tall) and tolerated all the herbicide treatments.

SIGNIFICANCE OF FINDINGS

Cutleaf groundcherry, pitted morningglory, sicklepod, and Palmer amaranth efficacy data from this research can and have been used for updating weed control ratings in the Arkansas Weed and Brush Control Guide (MP-44).

ACK\NOWLEDGMENTS

The authors would like to thank Jamie Branson and Danny Boothe at the RREC in Suttgart and Troy Dillon and Kurt Meins at the U of A Pine Bluff farm for their assistance. The research was partially funded by rice grower check-off funds through the Arkansas Rice Research and Promotion Board.

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Table 1. Broadleaf weed control with postemergence rice herbicides.

			Weed control				
					IPOLA		AMAPA
Treatment	Rate	Timing	PHYAN[z]	CASOB	Stutt[y]	Lon	Fay
	(lb ai/acre)		(%)				
Halosulfuron	0.056	EP[x]	64	29	100	49	39
		LP	19	18	11	26	18
Acifluorfen	0.094	EP	76	34	91	49	71
		LP	66	23	51	40	19
Carfentrazone	0.25	EP	97	27	94	69	91
		LP	84	37	81	66	16
Quinclorac	0.38	EP	95	53	99	95	23
		LP	44	71	76	26	0
Bentazon	0.75	EP	42	20	50	33	1
		LP	19	11	11	23	0
Bispyribac-sodium	0.063	EP	75	62	100	23	95
		LP	28	36	10	36	19
Imazethapyr	0.063	EP	100	37	79	71	88
		LP	81	18	75	24	18
Triclopyr	0.25	EP	42	52	81	49	39
		LP	77	78	98	68	3
Propanil	4	EP	100	70	94	46	100
		LP	70	41	24	40	20
Penoxsulam	0.031	EP	71	39	41	19	98
		LP	45	29	16	5	23
IR 5878	0.067	EP	36	10	0	78	44
		LP	22	34	69	15	14
Non-treated			0	0	0	0	0
LSD (0.05)			34	43	30	44	20

[z] PHYAN = cutleaf groundcherry; CASOB = sicklepod; IPOLA = pitted morningglory; and AMAPA = Palmer amaranth.

[y] Stutt = Stuttgart location; Lon = Lonoke; and Fay = Fayetteville.

[x] EP = early postemergence, weed heights 1 to 2 inches; LP = late postemergence, weed heights 12 to 14 inches.

Rice Cultivar Rooting Tolerance to Penoxsulam

A.T. Ellis, B.V. Ottis, R.C. Scott, and R.E. Talbert

ABSTRACT

Two separate studies were conducted at the Rice Research and Extension Center in Stuttgart, Ark., in 2004 to assess the effects of penoxsulam on root development of rice. In one experiment observations were made on the effect of penoxsulam (Grasp) on rice rooting tolerance (root pruning) of the 'Wells' cultivar at four timings: 1- to 2-leaf (lf), 4- to 5-lf, postflood (POFLD) 1 wk, and at panicle iniation (PI) rice stages, each at two rates [0.031 ai lb/acre (1X) and 0.062 lb/acre (2X)]. Root pruning ratings were taken at one-wk increments for five wk starting on July 5, one wk after flood (WAF). At 2 WAF, root pruning was 38 to 58% compared to 1 WAF. By 3 WAF, rice roots had recovered and appeared normal. The PI application did not cause observable root pruning. The root pruning observed during the vegetative stage of the rice plants had no effect on yield. The second study evaluated the response of four cultivars, Wells, 'Cocodrie', 'XL8', and 'Bengal', to 1X and 2X rates of penoxsulam applied at the 4- to 5-lf rice stage. XL8 was the most tolerant to root pruning from penoxsulam with 7% pruning with the 2X rate 2 WAF. Cocodrie was the least tolerant with 77% root pruning from the 2X rate and Wells and Bengal were intermediate with 63% root pruning with the 2X rate of penoxsulam at 2WAF. Root growth with all rates, treatment times, and cultivars had fully recovered by 3 WAF. Root pruning from penoxsulam did not affect rice yield of the four cultivars studied.

INTRODUCTION

Penoxsulam, a sulfonylurea herbicide, received a Section 3 registration from the EPA in October of 2004 as a selective postemergence herbicide in rice for Arkansas, Florida, Mississippi, Missouri, Louisiana, and Texas. The mode of action for penoxsulam is inhibition of acetolactate synthase (ALS) which is used in branched amino-acid synthesis vital to plant growth (Ottis et al., 2004). Penoxsulam controls many broadleaf and grass weeds including arrowheads, pigweeds, smartweed, hemp sesbania, ducksalad, rice flatsedge, and barnyardgrass (Lassiter et al., 2004). However, penoxsulam has been reported to cause rice root growth inhibition (pruning) effects (personal communication with Ralph Lassiter, Dow AgroSciences, LLC Representative). Bensulfuron-methyl (Londax) is a member of the sulfonylurea family of herbicides and shares the same ALS mode of action as penoxsulam. Yim and Bayer (1996) observed significant inhibition of rice root growth with bensulfuron-methyl applied 3- to 4- days after emergence of rice seedlings. Omokawa et al. (1999) also noticed reduced root growth of rice due to applications of bensulfuron-methyl. Bispyribac-sodium (Regiment), a selective rice herbicide from Valent, also has similar mode of action as penoxsulam. Rice root pruning has been documented due to applications of bispyribac-sodium (personal communication, Valent representative, F. Carey).

Field studies were established to compare rates and timings of penoxsulam application on rice root growth over time and to assess the effects of root pruning on rice yield.

PROCEDURES

Two field experiments were conducted at the Rice Research and Extension Center located in Stuttgart, Ark., on a Dewitt silt loam soil with 1% organic matter, 8% sand, 75% silt, 16% clay, and a pH of 5.6. In the first study, penoxsulam was applied at 0.031 lb/acre (1X) and 0.062 lb/acre (2X) rates at the 1- to 2-lf (8 June) , 4- to 5-lf (22 June),1 wk after postflood (POFLD 1 wk; 5 July), and at panicle-iniation (PI; 28 July) rice stages. The rice cultivar Wells was drill-seeded at 90 lb/acre. In the second study, cultivars Wells, Cocodrie, XL8, and Bengal were drill-seeded at 90, 90, 30, and 90 lb/acre, respectively, and penoxsulam was applied at the 1X and 2X rates at the 4- to 5-lf rice stage only. Each experiment was a factorial arrangement with a randomized complete block design replicated four times and a non-treated check was included. Plot size was 4 by 6 ft. Prior to flood, triclopyr (Grandstand) at 0.25 lb/acre + halosulfuron (Permit) at 0.047 lb/acre + crop oil was applied for broadleaf weed control, and cyhalofop-butyl (Clincher) at 0.25 lb/acre + crop oil was applied for grass weed control for both studies. Herbicides were applied with a CO_2 backpack sprayer calibrated to deliver 10 gal/acre. Visual ratings of root pruning were taken at 1, 2, 3, 4, and 5 WAF by gently pulling plant roots and then washing the soil root mass. Ratings were based upon amount of root mass present on the treated samples compared to the root mass on the untreated check. Data were entered as a percentage of reduction in root mass. Rice was harvested by cutting a 4-ft swath in each plot with a small-plot combine. Data were analyzed by ANOVA using SAS, and then were separated using Fishers' protected LSD at p = 0.05.

RESULTS AND DISCUSSION

Root pruning was observed from all treatments except for the PI timing (Table 1). Root pruning at 1 WAF from the 1- to 2-lf and 4- to 5-lf treatments was similar, 20 to 31% for the 1X and 2X rates. By 2 WAF root pruning had increased to 38 to 58% from these treatments for both rates; however, by 3 WAF there was no noticeable root pruning any for treatments. At 1 wk after the POFLD 1 wk treatment, 44-45% root pruning was observed, but there was full recovery by 2 wk after treatment. At 1 wk after the PI application no root pruning was observed. Yields were not affected by early injury to the rice roots (Table 1).

Root pruning on the Wells and Bengal cultivars treated with penoxsulam at the 4- to 5- lf stage was moderate (13 to 30%) from the 1X and 2X rates at 1 WAF (Table 2). By 2 WAF, root pruning on Wells increased slightly for the 1X rate, but nearly doubled (69%) for the 2X rate; however, by 3 WAF, no pruning was visible. Root pruning for Cocodrie at 1 WAF was moderate (25%) for the 1X rate and high (51%) for the 2x rate. At 2 WAF, root pruning on Cocodrie increased dramatically to 65% for the 1X rate and 77% for the 2X rate; however, by 3 WAF no pruning was evident. XL8 was most tolerant to penoxsulam with pruning at 1 WAF of only 18% for the 1X rate and 28% for the 2X rate, but in contrast to the other cultivars root pruning decreased to <7 % by 2 WAF. Yields of all cultivars evaluated were not affected by root pruning. One possibility for the no reduction in yield from the earlier root pruning is that this effect was very transient.

SIGNIFICANCE OF FINDINGS

The XL8 hybrid rice cultivar seems to have more of a tolerance to penoxsulam than other cultivars observed in this study. Rice yields are not affected when penoxsulam was applied to rice even at twice the labeled rate. These results generally support the safe use of this new herbicide tool in rice.

ACKNOWLEDGMENTS

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Table 1. Root pruning and yield of rice as affected by application time and rate of penoxsulam.

		Rating date					
Timing	Rate	1 WAF[z] 5 July	2 WAF 12 July	3 WAF 19 July	4 WAF 26 July	5 WAF 2 Aug	Rice yield
		---------- (% pruning)	----------	----------	----------	----------	(bu/acre)
Non-treated	0	0	0	0	0	0	105
1- to 2-lf[y]	1X[x]	25	38	0	0	0	101
	2X	26	41	0	0	0	106
4 to 5 lf	1X	31	58	0	0	0	109
	2X	20	52	0	0	0	110
POFLD 1 wk	1X	-	45	0	0	0	104
	2X	-	44	0	0	0	106
PI	1X	-	-	-	-	0	111
	2X	-	-	-	-	0	107
LSD (0.05)		14	NS	NS	NS	NS	NS

[z] WAF = weeks after flood. Flood applied on 28 June.
[y] 1- to 2-lf applied on 8 June; 4- to 5-lf applied on 22 June; POFLD 1 wk = 1wk after postflood applied on 5 July; PI = panicle initiation applied on 27 July.
[x] 1X rate, 0.031 lb ai/acre; 2X rate, 0.062 lb/acre.

Table 2. Root pruning and yield of rice as affected by cultivar and rate of penoxsulam applied at 4- to 5-lf rice stage on 22 June.

		Rating date			
Rice cultivar	Penoxsulam rate	1 WAF[z] 5 July	2 WAF 12 July	3 WAF 19 July	Rice yield
		---------- (% pruning)	----------	----------	(bu/acre)
Wells	0	0	0	0	116
	1X[y]	29	38	0	109
	2X	30	63	0	110
Cocodrie	0	0	0	0	122
	1X	25	65	0	127
	2X	51	77	0	141
XL8	0	0	0	0	126
	1X	18	4	0	128
	2X	28	7	0	133
Bengal	0	0	0	0	125
	1X	13	53	0	135
	2X	30	63	0	134
LSD (0.05)		20	14	NS	11

[z] WAF = weeks after flood. Flood applied on 28 June.
[y] 1X rate = 0.031 lb ai/acre; 2X rate = 0.062 lb/acre.

Growth, Development, and Physiological Characteristics of Selected Red Rice (*Oryza sativa*) Accessions from Arkansas

D.R. Gealy

ABSTRACT

Seed of 13 awnless strawhull, 5 awned strawhull, and 8 awned blackhull red rice accessions were obtained from Arkansas and other southern rice-producing states and evaluated for growth, development, and physiological characteristics in field experiments at Stuttgart, Ark. Maximum plant heights ranged from 118 to 161 cm compared with 101 cm for the long-grain cultivar 'Kaybonnet'. Days to heading for these accessions ranged from 83 to 108 days compared with 96 days for Kaybonnet. As a group, awned blackhull accessions headed later than the awnless strawhull accessions. All red rice accessions except for a rice-red rice cross, KatyRR, experienced significant seed shattering before harvest. Chlorophyll content in red rice seedlings averaged 15% less than in Kaybonnet, accounting for the lighter green coloration of red rice. When expressed on a per-leaf-area basis, leaf transpiration and photosynthesis rates were similar for five diverse accessions of red rice, but were 12 to 13% less than for Kaybonnet. The relatively low leaf-gas exchange values for red rice were consistent with their relatively lower chlorophyll contents compared to Kaybonnet. However, red rice's low gas-exchange rates per leaf area were more than compensated for by its greater production of tillers and total biomass which generally ranged between 2 and 3.5 times that of Kaybonnet. Most of the red rice accessions were categorized as 'medium-grain' types based on their seed dimensions. This research quantified several key biological traits among distinct types of red rice and established baseline comparisons with commercial rice in Arkansas.

INTRODUCTION

Native to the Asian continent, red rice (*Oryza sativa* L.) is a weedy relative of commercial rice and was found in North America in rice-producing areas of the Carolinas as early as the mid 1800s (Dodson, 1900; Stubbs et al., 1904). By the late 1800s, red rice had been introduced into rice-producing areas of Louisiana (Dodson, 1898, 1900) and Texas (Laude, 1918), and by the early 1900s, it was present in rice fields in Arkansas (Vincenheller, 1906). Since that time, it has become one of the most troublesome weeds of rice in the southern U.S. (Bridges and Baumann, 1992; Dowler, 1997; Webster, 2000), causing losses estimated at $50 million annually in the U.S. (Smith, 1979), and $10 million annually in Arkansas alone (Baldwin et al., 1989). Red rice was estimated to infest 30 to 40% of rice acreage in Arkansas, about 50% in Mississippi, 40 to 50% in Texas, and almost all the rice acreage in Louisiana (Deshaies, 1996).

It has been a troublesome weed in commercial rice because it is a vigorous competitor, produces numerous dormant red seeds that shatter to the ground before harvest, and has not traditionally been controllable in rice by available herbicides (Baldwin et al., 1995; Baldwin et al., 1989). It is readily distinguishable from commercial rice because red rice plants are typically taller and more robust than those of commercial rice, and have lighter green leaves with a rough texture.

Red rice and other weedy rice species are major weed problems in rice worldwide, particularly in dry-seeded, irrigated cropping systems and other systems where rice is not planted or transplanted directly into standing water (Global Workshop on Red Rice Control, 2000; Vaughan et al., 1999). Presently, red rice and other weedy rice species affect rice in areas of North America, Central America, South America, Europe, Africa, and Asia. Nonweedy rice cultivars with red bran color (generally lacking seed dormancy and shattering) have long been grown for human consumption elsewhere in the world and potentially could be genetically similar to weedy U.S. red rice. The USDA-ARS rice collection (housed and maintained at Aberdeen, Idaho, and Stuttgart, Ark., respectively), presently consists of approximately 18,000 entries, of which about 2,950 have red bran color and represent several species, including 2,817 entries of *Oryza sativa* as well as entries of *O. glaberrima*, *O. nivara*, *O. rufipogon*, *O. barthii*, *O. alta*, *O. glumaepatula*, and *O. latifolia* (GRIN, 2000). More than 50% of these 'red' *Oryza* entries are from India, Bangladesh, China, and Pakistan.

With the commercial introduction of imazethapyr-resistant rice ('Clearfield') in 2002, red rice can now be controlled in a growing rice crop (Gealy, 2005). Red rice and commercial rice intercross naturally at a maximum rate averaging about 0.17% (Gealy, 2005). Thus, herbicide-resistance genes are likely to move into red rice populations over time (Gealy et al., 2003a). Repeated use of an herbicide used on a corresponding herbicide-resistant cultivar will create great selection pressure in favor of the herbicide-resistant weed (red rice in this case) (Diggle and Neve, 2001). Likewise, repeated use of an herbicide in a commercial rice field that contains one or more naturally tolerant types of a weed will eventually select in favor of weed biotypes with greater tolerance to the herbicide, thus increasing their populations (Valverde and Itoh, 2001). To date, 4 to 10% of red rice accessions tested in the U.S. have been somewhat tolerant to imazethapyr, glufosinate, or glyphosate (herbicides used on herbicide-resistant rice cultivars under development) (Gealy, 2005; Gealy and Black, 1998; Noldin et al., 1999a).

Red rice contamination in harvested rice reduces its market value. Long-grain rough rice prices can be discounted more than 80% if red rice contamination levels exceed 15% (Gealy, 2005). The rice industry makes significant expenditures in order to remove red rice grains from rice and to remove the red seed coat from red rice. Rice mills can remove many of the red rice seeds from long-grain rough rice (hulls on) by exploiting differences in grain size and shape. Red rice in the U.S. typically is medium-grain with shorter and wider seeds compared to long-grain commercial rice. However, long-grain red rice types, which are more difficult to remove from long-grain rice, are occasionally found. Much of the red seed coat of red rice can be removed during milling, but the process often damages the quality and appearance of the milled grain.

Red rice in the southern U.S. is typically 'strawhulled' and awnless, or 'blackhulled' and awned (Diarra et al., 1985) and these populations are genetically distinguishable from each other and from commercial rice and rice-red rice crosses (Gealy et al., 2002; Vaughan et al., 2001). Recent surveys suggest that up to 80% of the red rice populations in Arkansas are strawhull awnless and 20% are awned or blackhull, and a small number of other types are also present (Gealy, 2005; Shivrain, 2005). Although substantial information on the identification, growth, and biology of southern red rice types is available (Diarra et al., 1985; Estorninos et al., 2005a,b; Noldin et al., 1999b; Shivrain, 2005), additional knowledge of the growth, development, and grain properties for a large number of diverse red rice types and red rice-commercial rice crosses can be helpful in the identification of specific red rice populations and their management in rice production systems, especially since new practices such as planting herbicide-resistant rice may alter the existing equilibrium of red rice populations in rice.

A large number of diverse red rice types from rice-producing areas in Arkansas and other southern states were collected and evaluated for their emergence, growth and development, physical characteristics, photosynthesis and transpiration, biomass and seed production, and seed dimensions under field conditions at Stuttgart, Ark.

PROCEDURES

In 1994 and 1995, seeds from diverse groups of mature red rice plants were collected from plants growing in rice fields in Arkansas or acquired from Louisiana, Mississippi, or Texas. Each seed stock was designated with the prefix AR, LA, MS, or TX according to its state of origin, and a unique identification number. There were 19 strawhull types and 8 blackhull types. Where possible, seeds were initially collected from individual panicles or plants and designated as a particular accession in order to minimize the genetic diversity among the seeds of that accession. The tropical japonica (Mackill, 1995), a traditional short-stature, short-season, high-yield, southern long-grain Kaybonnet, was included as a standard commercial cultivar.

Biological characteristics of the red rice types were evaluated in field experiments at Stuttgart, Ark., in 1995 and 1996 on a DeWitt silt loam (fine, montmorillonitic, thermic Typic Albaqualf). The field preparation, planting, fertilizer application, and water management generally were performed according to standard production practices for Arkansas (Helms, 1994). Immediately prior to planting, soil was tilled twice with a narrow-hoe chisel and a basket roller. Seeds of red rice types and several rice standards were drill-planted into moist soil in early June of 1995 and 21 May 1996. Seeds were planted approximately 2 cm deep in single rows that were 140 cm long and spaced 60 cm apart. Because the number of seeds was limited for many types, only 15 and 21 seeds per 140 cm row were planted in 1995 and 1996, respectively. Awns, when present, were removed from seeds before planting. Nitrogen fertilizer was applied at preflood only in early July of both years as urea at 110 kg N/ha to dry soil. Propanil, thiobencarb, and bensulfuron were applied uniformly to all plots at labeled use rates (Baldwin et al., 1995) as needed to kill unwanted vegetation.

Approximately 3 wk after planting (WAP), the numbers of emerged plants in each row were determined, as were heights and number of leaves per plant for five typical plants in each row. Relative chlorophyll content in the youngest fully-expanded leaves from eight plants was estimated using a hand-held silicon photodiode detector (Minolta SPAD 502; Spectrum Technologies Inc., Plainfield, Ill.). Thus, SPAD meters can provide a quantitative measurement of the 'lightness' or 'darkness' of green color in rice leaves and have been used previously to correlate leaf chlorophyll and leaf nitrogen content in rice plants (Peng et al., 1996; Takebe and Yoneyama, 1989). The number of days from emergence to 50% heading were recorded for each type.

At the heading stage after flag leaves were fully elongated (early Sept. 1995 and late Aug. 1996), net photosynthesis, transpiration, and diffusive resistance of flag leaves were measured in the field on regionally representative red rice types, AR-StgS, AR-StgB, LA-3, MS-4, and TX-4, and on Kaybonnet using a closed-system, infrared gas analyzer system equipped with leaf and air thermometers, a humidity meter, and a light meter (Model CI-301PS; CID, Inc., Vancouver, Wash.) (Gealy, 1998). Net photosynthesis, transpiration, and stomatal resistance are indirect indicators of plant productivity, water use, and the degree of stomatal opening, respectively. Temperatures of leaves in the leaf chamber (not temperature controlled) ranged from 38 to 40°C (100 to 104°F) and relative humidity ranged from 47 to 49%. Ambient light intensities ranged from 1930 to 2000 umol m^{-2} s^{-1} of photosynthetically active radiation (approximately full sun intensity). Ambient CO_2 concentrations in the air ranged from 280 to 300 uL L^{-1}. Maximum ambient air temperatures were 32 to 35°C (90 to 95°F).

At harvest, plant height, tiller, and panicle numbers (1996 only), stem dry weight, seed dry weight (seed yield), and total plant dry weight per meter of row were determined for all red rice types and rice standards. Tiller and panicle numbers, and dry weights were expressed per meter of row rather than per plant because plant densities sometimes varied between plots. A small sample of seed was taken from each type, dried at 50°C for three days, and the 100-seed weight determined to the nearest milligram.

Fifteen seeds were subsampled from each field plot for determination of seed dimension and awn length. Length, width, and thickness of each rough-rice seed (Adair et al., 1973) and awn length were measured with calipers (Plasti-cal digital calipers, model 30-412-1, Forestry Suppliers, Inc., Jackson, Miss.), which were accurate to 0.1 mm. Hulls were then removed by hand from these seeds and the resulting caryopses were measured.

The experimental design was a randomized complete block with three replications. The experiment was conducted in 1995 and 1996 with the year effects considered as blocks. Data were combined and subjected to analysis of variance. Means were separated using a Fisher's protected LSD test at the 0.05 level of probability.

RESULTS AND DISCUSSION

Emergence three WAP of 26 red rice accessions from Arkansas, Louisiana, Mississippi, and Texas ranged from 48% for AR-12B to 90% for AR-14C (Table 1). Except for AR-12B, all red rice accessions emerged at levels similar to Kaybonnet. Low emergence levels appeared to be correlated with late heading in some red rice accessions. Plant heights at three WAP ranged from 12.6 cm for AR-20E to 19.3 cm for AR-13A. The Kaybonnet standard was intermediate between the high and low at 16.2 cm. At this early stage, average height of blackhull types appeared to be slightly greater than that of strawhull types (17.3 vs 15.4 cm).

At three WAP, the number of leaves per plant ranged from 3.0 for AR-12B to 4.8 for AR-16E with an average of 3.8 (LSD 0.05=0.7; data not shown). At this stage, the number of leaves per plant for all red rice accessions was equal to or greater than that for Kaybonnet (3.7). The accessions with the fewest leaves at 3 WAP also tended to head latest.

Generally, strawhull-awned red rice headed latest, strawhull awnless types headed earliest, and Kaybonnet headed between the two groups (Table 1). Heading of blackhull awned types varied from early to late, but most were not different from Kaybonnet (Table 1). Days to heading ranged from 83 d for AR-14C, AR-16B and AR-StgS to 108 d for AR-12B and LA3. Kaybonnet headed at 96 d. The range of 'Days to anthesis' (comparable to 'emergence to 50% heading') for the 'red' entries in the U.S. rice collection was much greater than that of the southern red rice accessions with values from less than 60 d to more than 140 d (GRIN, 2000).

Leaves of Kaybonnet usually were darker green in color (greater SPAD values) than the red rice types (Table 1). This is consistent with field observations that red rice plants can usually be differentiated visually from the commercial cultivars they infest by their lighter green color and their greater height. SPAD values for red rice ranged from 29 for AR-11D to 37 for MS4. By comparison, the SPAD value for Kaybonnet was 39. The red rice types showing the lightest shades of green color included AR-11D, AR-3B, AR-12B, AR-7, AR-20E, AR-14F, AR-13A, and AR-StgS. The darkest green types included MS4, AR-16E, AR-9B, AR-14C, AR-5A, AR-4A, AR-16B, AR-10A, and TX4. A majority of the eight blackhull red rice types were among the darkest green of all types, suggesting that blackhull types may be slightly darker green as a group than strawhull types. Overall, SPAD values (chlorophyll content) of red rice seedlings averaged 15% less than for Kaybonnet. Shivrain (2005) has subsequently shown that the light green color trait is dominant over dark green. In addition to the light green coloration, leaves of mature red rice plants can be distinguished from commercial rice (glabrous) because of their rough, pubescent surface (Gealy et al., 2003b; Shivrain, 2005).

Net photosynthesis, transpiration and diffusive resistance values for flag leaves generally were similar among the red rice types tested (Table 2). AR-StgB had a slightly lower net photosynthesis and transpiration rate, and appeared to have a slightly elevated diffusive resistance compared with several of the other types. Generally, red rice leaf-transpiration and photosynthesis rates were similar among accessions, but as a group these were 12 to 13% less than for Kaybonnet. The relatively low leaf-gas exchange values for red rice were consistent with their relatively lower chlorophyll contents compared to Kaybonnet. However, red rice's low gas-exchange rates were more than compensated for by its greater production of tillers and total biomass. Net photosynthesis rates of medium-grain rice in California under similar conditions were approximately 15 to 45% higher (Bouhache and Bayer, 1993) than the value obtained for Kaybonnet in the current study (Table 2). The overall higher photosynthesis rates in the California study may have occurred because those plants were younger, were periodically treated with fertilizer, and were greenhouse-grown where environmental stresses can be less than in the field.

At harvest, the height of Kaybonnet was 101 cm, and red rice heights ranged from 118 cm for AR-18E to 161 cm for AR-13A (Table 1). As a group, strawhull-awned red rice types were the tallest, strawhull awnless types were the shortest, and blackhull-awned types were variable (Table 1). All red rice accessions except for the KatyRR cross were taller than Kaybonnet. The AR-StgS local type was one of the shortest of all red rice types. Many of the taller red rice types lodged late in the season. By comparison, heights of 'red' entries in the U.S. rice collection ranged from less than 80 cm to more than 160 cm (GRIN, 2000). About 60% of these were within the height range of the southern red rice accessions in the present study.

Tiller production (recorded in 1996 only) ranged from 205 per m row for AR-16 E to 345 per m row for AR-StgB (Table 1). Kaybonnet produced only 110 tillers/m of row. Most red rice types produced more than twice the number of tillers/m of row compared to commercial rice. A subset of these red rice types have produced similarly large numbers of tillers in other studies at Stuttgart (Estorninos et al., 2005 a,b).

Panicle production in 1996 ranged from 48/m of row for AR-13A to 204/m of row for LA3 (Table 1). Six of the ten types ranking lowest in panicles/m of row were also among the latest to head (Table 1). Cool, late-season weather in 1996, which induced new tiller formation in some types, may have contributed to the reduced number of panicles in those types.

Stem dry-weight production ranged from 490 g/m of row for AR-11D to 860 g/m of row for LA3 (Table 1). Kaybonnet stem dry weight was less than half of that of all red rice types at 210 g/m of row. Seed yield (rough rice) ranged from 56 g/m of row for AR-12B to 215 g/m of row for AR-16B (Table 1). Many red rice types lost a portion of their seeds to shattering before they could be harvested. Therefore, the red rice seed yields reported are probably lower than the true seed yields. The long-grain cross, KatyRR (Gealy et al., 2002), produced the greatest seed yield in 1996, largely because it does not shatter. Total biomass ranged from 540 g/m of row for AR-11D to 980 g/m of row for AR-StgB (Table 1). Total biomass of Kaybonnet was 290 g/m of row, about 50% of that for the least massive red rice type.

The 100-seed weight ranged from 1.4 g for MS4 to 2.1 g for AR-StgB and TX4 (Table 1). Several types produced proportionately lighter seeds in 1995 than in 1996 (AR-10A, AR-11D, AR-13A, and AR-12B; data not shown). The reduced 100-seed weight levels apparently occurred in these types in 1995 because their normally late maturity was delayed even more due to late-season cold weather which prevented optimal seed filling.

Considerable variation in growth characteristics among red rice types has been reported previously (Diarra et al., 1985). In these studies, tillering and straw production were greater and maturity dates were later for blackhull than for strawhull types. In the same study, a blackhull type from Arkansas emerged earlier, tillered 6 to 38% more, and produced 8 to 38% more panicles per plant than other red rice types. A blackhull type from Texas was 11 to 26% taller than the other types.

Dimensions of red rice seed with and without hulls present are shown in Table 3. For red rice seed with hulls present (rough rice), length ranged from 7.71 mm for AR-2B to 8.75 mm for AR-11D (Kaybonnet was highest at 8.80 mm); width ranged from 2.77 mm for AR-13A and AR-18E to 3.26 mm for AR-17A (Kaybonnet was second lowest at 2.33 mm); thickness ranged from 1.55 mm for MS4 to 1.99 mm for AR-14C (Kaybonnet was near the mean at 1.77 mm); and length:width ratio ranged from 2.56 for AR-StgS to 3.14 for AR-11D (the Kaybonnet was 3.87). Among all red rice accessions, the length:width ratios were generally greatest for awned strawhull types and lowest for awnless strawhull types. Lengths, widths, and length:width ratios of all red rice accessions with hulls present were within the ranges that are typical of conventional U.S. medium-grain rices grown in Uniform Performance Trials in the southern U.S.A. (Webb, 1991). Thickness of red rice seeds spanned the ranges for both medium-grain and long-grain conventional rices (Webb, 1991). Among the awned red rice entries, awn lengths ranged from 25.7 mm for MS4 to 44.6 mm for AR-17C.

For red rice seed with hulls removed (brown rice), seed lengths ranged from 5.26 mm for AR-2B to 5.95 mm for AR-StgB (Kaybonnet was 6.45 mm); widths ranged from 2.19 mm for AR-18E to 2.75 mm for AR-11B (Kaybonnet was 1.91 mm); thickness ranged from 1.22 mm for MS4 to 1.75 mm for AR-17A (Kaybonnet was 1.46 mm); and length:width ratios ranged from 2.02 for AR-StgS to 2.66 for AR-13A (Kaybonnet was 3.39). Ratios of seed widths with and without hulls ranged from 0.79 for AR-18E to 0.87 for AR-StgS (Kaybonnet was 0.87). The brown rice grading standards established by the USDA for medium-grain types have specified average kernel lengths of 5.51 mm to 6.60 mm and average kernel length:width ratios of 2.1 to 3.0 (Adair et al., 1973). Values for most of the dehulled red rice types (Table 3) are within these ranges. The dehulled seeds produced by the cross, KatyRR, were very long (6.76 mm) with a length:width ratio (2.88) near the upper range for a medium-grain type (Table 3). Thus, this accession is in a shape-size category intermediate between that for long-grain and medium-grain types. Subsequent DNA fingerprinting with microsatellite markers has shown that KatyRR (A.K.A. AR1996-1) is genetically similar to several other rice-red rice crosses (Gealy et al., 2002), suggesting that it was derived from a cross between a long-grain commercial rice and medium-grain red rice. The seed dimensions of some strawhull accessions were intermediate between those for medium-grain and short-grain rices (AR-StgS, AR-2B, AR-7, and AR-20E). The blackhull accessions AR-5A, AR-8, AR-17C, and AR-18E also fell into the intermediate category based on seed length only. Values for red rice grains with hulls present ('rough rice') (Table 3) generally fell within the same ranges as those reported previously for red rice types from Arkansas, Texas, and Louisiana (Diarra et al., 1985).

Diverse populations of shattering weedy rices (both red and non-red types) have developed in direct-seeded rice cultures of Asia and other parts of the world, and include both indica types (generally more tropical) and japonica types (generally more temperate) of *O. sativa* (Vaughan et al., 1999). Throughout the world, the most troublesome weedy rices generally are those possessing the AA genome (usually *O. sativa* or *O. glaberrima*) which are most similar to the rice crops that they infest. Other weedy *Oryza* species having the AA genome include *O. nivara*, *O. rufipogon*, *O. sativa* f. *spontanea*, *O. barthii*, *O. longistamminata*, *O. punctata*, and *O. latifolia* (Vaughan et al., 1999).

More than half of the foreign 'red' entries in the U.S. rice collection are medium-grain types, which comprise about three and five times the number of long-grain and short-grain types, respectively (GRIN, 2000). Additionally, more than 95% of these 'red' entries had partially or completely pubescent seed hulls. The general similarities between U.S. red rice accessions (Table 3) and 'red' entries in the U.S. rice collection (GRIN, 2000) leave open the possibility that U.S. red rice may be closely related to one or more of these foreign 'red' types. DNA studies addressing this question in detail are currently underway at Stuttgart (Gealy, unpublished data).

With a few exceptions, red rice accessions evaluated in the present studies were medium-grain types and generally could be grouped visually into strawhull awnless, strawhull awned, and blackhull awned types. The awned and awnless red rice types may have developed from different genetic backgrounds as indicated by DNA fingerprinting studies in which awned red rice, awnless red rice, rice-red rice crosses, and rice cultivars could generally be grouped into genetically distinct clusters (Gealy et al., 2002). In similar fingerprinting studies, awnless strawhull red rice, but not awned blackhull red rice, appeared to have a genetic background similar to that of indica rice (Vaughan et al., 2001). Growth, development, and seed characteristics varied widely among red rice accessions, but all were taller, lighter green in color, and produced more tillers than rice. The large difference in seedling emergence between certain red rice types may affect the overall weed pressure from these types early in the growing season when impacts from herbicides and competition often are most critical. Red rice types with low or delayed emergence may cause relatively little crop damage and be more easily controlled by herbicides compared to those with greater emergence. Variable flowering dates are likely to ensure partially synchronous flowering between some red rice types and herbicide-resistant rice, thus increasing the probability of gene flow between the two *Oryza* types. Minimizing this gene flow rate will be a key to managing herbicide-resistant cropping systems in rice.

SIGNIFICANCE OF FINDINGS

This research revealed key differences in several biological characteristics between and among awnless-strawhull, awned-strawhull, and awned-blackhull red rice types, a rice-red rice cross, and commercial Kaybonnet rice. For instance strawhull-awnless red rice types headed much earlier and were taller than strawhull-awned types. Relative chlorophyll content (used to estimate darkness of green coloration) and photosynthesis rates of red rice leaves averaged nearly 15% less than those of Kaybonnet. Although some red rice types were noticeably smaller (i.e. less competitive) than others, most red rice types more than compensated for these disadvantages in chlorophyll and photosynthesis levels by producing 2 to 3.5 times the tillers and biomass compared to Kaybonnet. Most red rice accessions were considered medium-grain types based on seed dimensions. Yet seed length:width ratios tended to be greatest for awned-strawhull types (more similar to long-grain commercial rice) and lowest for awnless-strawhull types (more similar to medium-grain or short-grain rice). The collective biological differences among red rice types in these studies may result in advantages for some types over other types. Strawhull-awned types may be particularly troublesome. Their large, late-maturing plants can be particularly competitive and their relatively high seed length:width ratios may reduce the efficiency of red rice seed separation from long-grain rice seeds based on size or shape differential. Long-grain red rice such as the KatyRR cross could be nearly inseparable from long-grain commercial rice using these methods.

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Table 1. Growth and biological characteristics

Accession/ description	Source	Date seed collected or acquired	SPAD value (relative chlorophyll 3 WAP[w]	Number seedlings 3 WAP[w]
			(relative units)	(% of planted)
Awnless strawhull types				
AR-StgS	Stuttgart,Ark.	8/94	32	77
AR-2B	Stuttgart, Ark.	8/94	32	74
AR-3B	Hazen, Ark.	8/94	30	88
AR-4A	Hazen, Ark.	8/94	34	83
AR-7	Hazen, Ark.	8/94	31	77
AR-9B	Stuttgart, Ark.	8/94	36	73
AR-11B	DeWitt, Ark.	8/94	33	76
AR-13G	DeWitt, Ark.	8/94	33	74
AR-14C	DeWitt, Ark.	8/94	35	90
AR-16B	DeWitt, Ark.	8/94	34	74
AR-16E	DeWitt, Ark.	8/94	36	65
AR-17A	DeWitt, Ark.	8/94	33	62
AR-20E	Stuttgart, Ark.	9/94	31	60
Awned strawhull types				
AR-11D	DeWitt, Ark.	8/94	29	54
AR-12B	DeWitt, Ark.	8/94	31	48
AR-13A	DeWitt, Ark.	8/94	32	60
LA3	Crowley, La.	1/95	32	77
MS4 (SH?)	Miss.	1/95	37	72
Awned blackhull types				
AR-StgB	Stuttgart, Ark.	8/94	34	67
AR-5A	Hazen, Ark.	8/94	35	66
AR-8	Hazen, Ark.	8/94	33	69
AR-10A	Stuttgart, Ark.	8/94	34	74
AR-14F	DeWitt, Ark.	8/94	32	82
AR-17C	DeWitt, Ark.	8/94	33	83
AR-18E	Stuttgart, Ark.	9/94	33	68
TX4	Katy, Texas	1/95	33	79
Standards				
Kaybonnet long-grain rice cultivar (SH awnless)	Stuttgart, Ark.	5/95	39	77
KatyRR (SH awnless; long-grain cross; 1996) only; not included in statistical analysis)	Stuttgart, Ark.	96	35	57
LSD (0.05)			5	19

[z] Values presented are means of 1995 and 1996 experiments. The SPAD value is a relative indication of chlorophyll content in leaves. Within a species, higher values generally indicate greater levels of leaf chlorophyll, and thus, a darker green color.

[y] The LSD (0.05) can be used to compare all means within a column.

[x] Stuttgart, Ark. and DeWitt, Ark. are located in Arkansas Co. Hazen, Ark. is located in Prairie Co. KatyRR is a non-shattering, long-grain type that was discovered in a foundation field of 'Katy' rice, and is an apparent cross between commercial rice and strawhull red rice (Gealy et al., 2002).

[w] WAP = weeks after planting.

of red rice accessions grown at Stuttgart, Ark.[z,y,x]

Plant height		Emergence to 50%	Tillers (1996 only)	Panicles (1996 only)	Stem dwt.	Seed dwt.	Total dwt.	seed wt.
3 WAP[w]	Maturity	heading	Maturity					
-------- (cm) ---------		(days)	----(no./m of row)---		---------(g/ m of row)--------			(g)
15	122	83	277	152	561	207	769	1.73
16	130	88	245	127	538	175	713	1.65
15	137	87	286	148	532	129	661	1.58
15	133	88	272	160	599	190	789	1.98
14	135	85	278	148	599	120	719	1.72
15	143	86	272	143	634	175	809	1.83
14	130	85	293	189	578	178	756	1.90
16	134	86	296	159	611	168	779	1.97
17	134	83	333	168	603	202	805	1.99
17	122	83	319	149	568	215	782	1.90
16	137	86	205	143	555	133	688	2.04
15	135	89	315	157	600	153	754	1.95
13	126	84	275	193	511	146	657	1.74
16	151	100	286	125	490	57	548	1.77
17	157	108	216	81	535	56	591	1.62
19	161	105	248	48	584	67	650	1.70
14	152	108	322	204	862	105	967	1.88
14	133	105	267	140	665	103	768	1.37
19	142	106	345	174	842	166	979	2.14
17	151	94	311	161	582	147	730	
18	142	97	305	86	499	64	563	1.59
16	142	104	300	171	714	127	821	2.01
17	139	97	338	186	691	148	838	1.90
17	123	89	219	179	517	135	652	1.76
16	118	102	239	154	497	91	588	1.65
18	142	103	283	136	784	103	899	2.12
16	101	96	110	---	212	151	286	1.72
-	114	93	138	112	261	242	739	–
3	14	9	107	78	142	57	166	0.18

Table 2. Flag leaf photosynthesis, transpiration, and diffusive resistance for selected red rice accessions in the field.[z,y,x]

Accession	Plant type	Net photosynthesis	Transpiration	Stomatal diffusive resistance
		(μmol $m^{-2}s^{-1}$)	(mmol $m^{-2}s^{-1}$)	(mol $m^{-2}s^{-1}$)
AR-StgS	awnless strawhull red rice	17.9	3.3	9.9
LA3	awned strawhull red rice	16.1	3.2	9.7
MS4	awned strawhull red rice	17.4	3.7	9.4
AR-StgB	awned blackhull red rice	15.8	2.9	12.3
TX4	awned blackhull red rice	16.1	3.7	8.6
Kaybonnet	awnless strawhull commercial long-grain rice	19.1	3.8	8.1
LSD (0.05)		3.0	0.5	NS (LSD=2.9 at P=0.11)

[z] Measurements taken 17 Aug. 1995 and 22 or 26 August 1996 on flag leaves of fully grown red rice and rice plants.

[y] Ambient light intensities ranged from 1930 to 2000 µmol m^{-2} s^{-1} (approximately maximum sun intensity). Leaf temperatures in the leaf chamber were 38 to 40°C (~100 to 104°F). Relative humidity in the leaf chamber ranged from 47 to 49%. Ambient air CO_2 concentration ranged from 280 to 300 µL L^{-1}.

[x] The LSD (0.05) can be used to compare all means within a column. Across all data points, photosynthesis was positively correlated with transpiration (R= 0.20 in 1995, 0.51 in 1996, and 0.55 combined over years) and negatively correlated with stomatal diffusive resistance (R= -0.21 in 1995, -0.26 in 1996, and -0.29 combined over years).

Table 3. Seed dimensions of red rice accessions with and without hulls grown in field plots in Stuttgart, Ark. in 1995 and 1996.

	With hulls					Without hulls			
	Length	Width	Thickness	L:W ratio	Awn length	Length	Width	Thickness	L:W ratio
	---- (mm) ----			(mm/mm)	----	---- (mm) ----			(mm/mm)
Awnless strawhull types									
AR-StgS	7.75	3.03	1.92	2.56	0	5.34	2.65	1.73	2.02
AR-2B	7.71	2.99	1.77	2.58	0	5.26	2.59	1.56	2.03
AR-3B	8.12	3.06	1.80	2.65	0	5.59	2.51	1.55	2.22
AR-4A	8.59	3.23	1.92	2.66	0	5.76	2.71	1.58	2.12
AR-7	7.94	3.08	1.86	2.58	0	5.40	2.64	1.63	2.04
AR-9B	8.63	3.25	1.88	2.65	0	5.91	2.72	1.56	2.17
AR-11B	8.37	3.17	1.95	2.64	0	5.77	2.75	1.67	2.10
AR-13G	8.42	3.18	1.91	2.65	0	5.73	2.72	1.65	2.11
AR-14C	8.48	3.20	1.99	2.65	0	5.82	2.71	1.72	2.15
AR-16B	8.24	3.04	1.91	2.71	0	5.61	2.64	1.69	2.12
AR-16E	8.51	3.17	1.92	2.68	0	5.79	2.67	1.64	2.17
AR-17A	8.47	3.26	1.96	2.60	0	5.69	2.67	1.75	2.13
AR-20E	7.97	3.06	1.92	2.60	0	5.37	2.56	1.64	2.10
Awned strawhull types									
AR-11D	8.75	2.79	1.78	3.14	37.0	5.95	2.24	1.53	2.66
AR-12B	8.60	2.78	1.73	3.09	37.4	5.90	2.23	1.49	2.64
AR-13A	8.60	2.77	1.74	3.10	37.2	5.90	2.22	1.49	2.66
LA3	8.74	3.11	1.89	2.81	40.2	5.82	2.47	1.48	2.35
MS4	8.47	2.85	1.55	2.98	25.7	5.83	2.28	1.22	2.56

continued

Table 3. Continued.

	With hulls					Without hulls			
	Length	Width	Thickness	L:W ratio	Awn length	Length	Width	Thickness	L:W ratio
	------------------- (mm) -------------------			(mm/mm)	-------------------------------(mm) -------------------------------				(mm/mm)
Awned blackhull types									
AR-StgB	8.66	2.93	1.85	2.96	42.5	5.95	2.37	1.54	2.51
AR-5A	8.03	2.82	1.73	2.85	37.4	5.37	2.38	1.53	2.26
AR-8	8.12	2.92	1.71	2.79	35.7	5.39	2.34	1.53	2.31
AR-10A	8.11	3.11	1.88	2.61	37.1	5.61	2.54	1.67	2.20
AR-14F	8.49	3.04	1.74	2.79	42.7	5.81	2.47	1.51	2.36
AR-17C	7.83	2.82	1.85	2.78	44.6	5.47	2.44	1.58	2.24
AR-18E	8.15	2.77	1.70	2.95	39.4	5.46	2.19	1.41	2.51
TX4	8.61	3.03	1.89	2.84	34.2	5.83	2.51	1.56	2.32
Standards									
Kaybonnet long-grain rice cultivar	8.80	2.33	1.77	3.87	0	6.45	1.91	1.46	3.39
KatyRR (long-grain cross; 1996 only; not included in statistical analysis)	9.69	2.63	1.93	3.68	0	6.76	2.34	1.69	2.88
LSD 0.05	0.27	0.14	0.13	0.20	6.04	0.18	0.085	0.13	0.103

Identifying Red Rice Crosses in Arkansas Rice Fields

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ABSTRACT

Interest in outcrossing between herbicide-resistant rice and red rice has increased since the introduction of imidazolinone (IMI)-resistant rice cultivars. Study leaders used phenotypic traits and 17 simple sequence repeat (SSR) markers to confirm outcrossing between rice and red rice on three Arkansas farms. A short red rice type from Prairie Co. in 2003 had uniform erect plants with awned seeds, rough leaves, and heights similar to semi-dwarf rice. The SSR technique detected few heterozygous alleles, suggesting that the plants had selfed several times since crossing. A tall red rice type from Prairie Co. was segregating for leaf texture, and stem and awn color. These plants were erect, much taller than rice cultivars, and produced awned seeds. The SSR technique detected many heterozygous alleles, suggesting that the plants had selfed relatively few times. Second-generation plants grown from long-grain (LG) red rice seeds found in 2001 in an Arkansas Co. field of ‘Cypress’ rice produced LG or medium-grain (MG) awnless seeds that were red or white in color, had purple lower stems, and were genetically similar to cultivated rice. Bushy, rough-leafed, IMI-resistant plants with delayed heading were obtained in 2004 from Jackson Co. The SSR technique confirmed that these were first generation crosses of IMI rice and awnless red rice, because alleles consistent with both IMI rice and awnless red rice standards were detected for all markers. Similarly, non-bushy, rough-leafed, early heading, IMI-resistant plants that produced pink-awned, MG seeds were apparently first-generation crosses of IMI rice and awned red rice. These studies show that visual observations and SSR analysis can be used in concert to identify specific red rice crosses found in farm fields.

INTRODUCTION

Interest in outcrossing between rice and red rice has increased since the introduction of imidazolinone (IMI)-resistant rice and the early observations that these cultivars can flower nearly synchronously with common red rice types. Red rice can outcross readily with rice because both require similar agro-ecosystems, have the same 12 pairs of chromosomes, and are diploids with the same "AA" genome (Gealy et al., 2003). However, outcrossing and gene flow may lead to increased genetic diversity in red rice especially when the IMI-resistance gene moves from rice into the weed. Recent developments with polymerase chain reaction (PCR)-based molecular markers, particularly the simple sequence repeats (SSR) or microsatellites (McCouch et al., 1997), have enabled the detection of genetic relationships and outcrossing frequencies between rice cultivars or between rice and red rice (Chen et al., 2004; Gealy et al., 2003; Messeguer et al., 2001; Messeguer et al., 2004; Vaughan et al., 2001). The objective of this study was to evaluate the post-crossing phenotypic and molecular evidence for outcrossing between rice and red rice on several farms in Arkansas using visual observations and rice SSR marker analysis.

PROCEDURES

Plant Materials

In Prairie County, samples were apparent rice-red rice (RR) crosses having long awned and blackhulled seeds collected from short or tall plants from a field in 2003. At least 30 seeds of each type were planted in the field in Stuttgart in 2004.

In Arkansas County, samples were collected from various areas of a Cypress field in 2001 and grown in the greenhouse in 2002. Original sample plants had rough green leaves, basal leaf sheath (stem) coloration ranging from light pink to wine red, green awns or were awnless, straw-colored hulls (strawhull), and red seeds. Offspring from these plants were grown in a greenhouse in 2004 and sampled for SSR analysis.

In Jackson County, plant samples were collected from about 800 acres of IMI rice. Typically, these were either late-heading "Bull" plants (indicative of F_1 crosses between strawhull red rice and LG rice), or pink-awned, blackhull plants (indicative of a cross derived from an awned RR parent). Samples from other fields were blackhull, with pink long awns, and had rough leaves. Some were blackhull, green-awned, medium short, had rough leaves, and were early to medium maturing (i.e. normal red rice). Some had short, smooth leaves and long-grain seeds (apparent IMI rice). Most crosses came from fields planted with 'CL161' IMI rice where they were not controlled by IMI applications, and were the only red rice survivors present. Apparently, these hybrids formed in the 2003 rice crop when IMI applications failed to control normal susceptible red rice, thus facilitating hybridization between IMI rice and red rice.

DNA Extraction and Analysis

Seedlings used for DNA isolation were grown from seeds planted in the greenhouse or in the field. DNA was extracted from leaves of 3- to 4-week old seedlings. Genomic DNA served as a template for application by PCR using the SSR rice markers RM167, RM19, RM206, RM215, RM219, RM235, RM241, RM251, RM258, RM26, RM212, RM220, RM230, RM234, RM261, RM253, RM 180, and RM53. This was carried out in 15-µl reaction volumes.

Amplified products were grouped and run using the robotic ABI 3700 DNA analyzer. SSR fragment sizing was done with GenScan 3.1.2 software, scored with Genotyper 2.5, and stored manually. Genetic distances were determined using the SAS IML program and displayed graphically using multidimensional scaling (MDS) (Gealy et al., 2002) to show groupings of genotypes in relation to their phenotypic characteristics.

RESULTS AND DISCUSSION

The short plants from Prairie Co. were uniform and erect with awned seeds, rough leaves, and heights similar to semi-dwarf rice (Table 1). They produced mostly homozygous alleles that were typical of either red rice or cultivated rice standards (data not presented). They were genetically similar to awned red rice standards (Fig. 1), suggesting that they were crosses of awned red rice and rice. The tall red rice type was segregating for leaf texture, basal leaf sheaths (stems), and awn color (Table 1). These plants were erect, much taller than rice cultivars, and produced awned seeds. SSR detected many heterozygous alleles (Table 2), suggesting that the plants had selfed relatively few times. The allele patterns in the tall-statured crosses were more variable than in the short crosses suggesting that this cross occurred more recently. Based on the MDS generated from nine SSR rice markers, these Prairie Co. crosses usually were genetically close to awned, but not awnless, red rice standards (Fig. 1), suggesting that awned red rice was a likely parent. Both types probably are products of crosses that have undergone multiple generations of self-fertilization.

Long-grain red rice seeds from Arkansas Co. produced plants with rough, green leaves, stem colors ranging from slight pink to wine red, green awns or were awnless, and had strawhull, red seeds (data not presented). Second-generation plants from original seeds were grown in the greenhouse in 2004. These plants were slightly taller than Cypress and produced leaves with intermediate roughness, purple lower stems, and LG or MG awnless seeds that were red or white in color (Table 1). SSR analysis produced homozygous alleles present in either red rice or rice plants, or produced alleles not present in the standards (data not presented). Thus, these plants appear to be several generations removed from the initial hybridization. They were genetically similar to rice although most had purple stems and red seeds (Fig. 1).

Most plants collected from Jackson Co. were Bull, bushy-type plants with rough green leaves, green stems, and awnless, MG, strawhull, and red seeds (Table 1). These plants did not flower until they were grown in a warm greenhouse for an additional month. The SSR markers produced heterozygous alleles consistent with red rice and cultivated rice (Table 3). Based on genetic distance, they grouped midway between strawhull red rice and cultivated rice standards (Fig. 1), and thus were probably F_1 hybrids derived from CL 161 and strawhull red rice. The other plants were non-bushy, rough-leafed, earlier heading, IMI-resistant plants that produced pink-awned, MG, and red seeds (Table 2). They produced heterozygous alleles consistent with awned red rice and cultivated rice standards (Table 3), and were grouped in the MDS plot between cultivated rice and awned red rice (Fig. 1), indicating that these were a first-generation cross between IMI rice and awned red rice. Earlier rice-red rice crosses obtained from Lawrence, Woodruff, and Arkansas counties were mostly genetically similar to awned red rice standards (Fig. 1). These studies demonstrate that visual observations and SSR analysis are both useful in the identification of red rice crosses. Additional plant standards and markers will further clarify these results.

SIGNIFICANCE OF FINDINGS

The present study's SSR analyses produced heterozygous alleles, which indicate that outcrossing had occurred between red rice and cultivated rice. The data suggest outcrossing products in the first generation or crosses that were several generations removed from the initial hybridization event that have undergone multiple generations of self-fertilization. The initial outcrossing that led to these plant types could have occurred before or after the development of the IMI herbicide-resistant rice, and potentially could have resulted from crossing between rice and red rice as well as between strawhull and blackhull or awnless and awned red rice. This work provides a sound basis for reliable diagnoses of the identities and recentness of red rice crosses on farms. Such knowledge will be useful in the management of red rice crossing in IMI rice systems.

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Table 1. Phenotypic characteristics of suspected rice-red rice crosses in Prairie, Arkansas, and Jackson counties, Ark.

Genotype	Leaf Texture	Leaf Color	Basal leaf sheath (stem)	Awn Present	Awn Color	Hull color	Seed/ pericarp
Prairie County (plants observed and tissues obtained in research fields in 2004)							
PC[z] Tall 25	Smooth	Green	Green	Yes	Green	Black	Red
PC Tall 19	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 3	Rough	Green	Green	Yes	Green	Straw	Red
PC Tall 2	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 14	Rough	Green	Green	Yes	Green	Black	Red
PC Tall red	NR[y]	NR	NR	Yes	Green	Black	Red
PC Tall 18	Rough(I)	Green	Green	Yes	Red	Black	Red
PC Tall 26	Rough	Green	Green	Yes	Red	Black	Red
PC Tall 5	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 17	Rough	Green	Green	Yes	Green	Black	White
PC Tall 11	Rough	Purple	Purple	Yes	Green	Straw	Red
PC Tall 13	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 1	Rough	Light purple	Purple	Yes	Pink	Black	Red
PC Tall 10	Smooth	Green	Green	Yes	Green	Straw	White
PC Tall 6	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 15	Rough	Light purple	Purple	Yes	Pink	Black	Red
PC Tall 12	Rough	Green	Green	Yes	Green	Black	Red
PC Tall 7	Rough	Purple	Purple	Yes	Green	Black	Red
PC short (all 30 entries)	Rough	Green	Green	Yes	Green	Black	Red
Arkansas County (plants observed and tissues obtained in the greenhouse in 2004)							
AC CPRS RR1	Intermed.	Green	Purple	No	---	Straw	Red
AC CPRS RR2	Intermed.	Green	Purple	No	---	Straw	White
AC CPRS RR3	Intermed.	Green	Purple	No	---	Straw	White
AC CPRS RR4	Intermed.	Green	Purple	No	---	Straw	Red
AC CPRS RR5	Intermed.	Green	Purple	No	---	Straw	Red
Jackson County (plants observed and tissues obtained in farm fields in 2004)							
Bull red (all)	Rough	Green	Green	No	---	Straw	Red
Pink awned (2)	Rough	Green	Purple	Yes	Pink	Black	Red

[z] PC - Prairie County; AC - Arkansas County; Intermed. = slightly rough, nearly smooth leaves; AC plants from previous generation had slightly pink to wine red stems and red seeds; Jackson County Bull reds were bushy and with delayed heading while pink awned plants were non-bushy and headed much earlier. Awnless and awned red rice standards had rough, green leaves, green basal leaf sheaths, and red seeds; awns when present were light green (not shown in table).

[y] NR = not recorded.

Table 2. Number of base pairs generated from selected markers used for suspected tall red rice crosses in Prairie County, Ark.

Genotype	RM 206[z] A/B[y]	RM 219 A/B	RM 241 A/B	RM 251 A/B
Suspected tall red rice crosses				
PC[x] Tall 25	132	195	145	123
PC Tall 19	0	195	100/145	123
PC Tall 3	131/132	195	145/151	123
PC Tall 2	0	195	145	123
PC Tall 14	131/135	195	100/145	123
PC Tall red	165/167	215	147	123
PC Tall 18	149	221	129/131	123
PC Tall 26	131	195	145/151	117/123
PC Tall 5	147/149	221	131/132	123
PC Tall 17	131	195	145	117/123
PC Tall 11	131	195	145/151	117
PC Tall 13	131/149	195	0	123
PC Tall 1	131	195	100/101	117/123
PC Tall 10	131	195	135/137	117/123
PC Tall 6	131	195	100/101	123
PC Tall 15	131	195	0	117/123
PC Tall 12	131	195	145	123
PC Tall 7	135	195	145	123
Red rice standards				
RRSI 2004 Stgblack	149	221	145	123
PC Stgstraw 6	131	205	145	124
Stgblack 10	131	205	100	123
Stgstraw 7	147	221	149	113
RRSI 2004 RR #8	132	205	100	123
Cultivated rice standards				
CL161 rice	132	190	131	117
Kaybonnet rice	131	195	151	117

[z] RM = rice marker.

[y] A and B represent the two parental alleles of a genotype from each marker.

[x] PC - Prairie County, Ark.

Table 3. Number of base pairs generated from selected markers used for suspected F_1 IMI-red rice hybrids in Jackson County, Ark.

Genotype	RM 19[z] A/B[y]	RM 219 A/B	RM 258 A/B	RM 26 A/B
Suspected F_1 IMI-red rice hybrids				
JC Bullred 3[x]	215/245	190/221	130/135	102/110
JC Bullred 4	215/245	190/221	130/135	102/110
JC Bullred 8	215/245	190	131/135	102/110
JC Bullred 6	215/222	191/219	131/135	102/110
JC Bullred 2	215/245	190	131/135	102/110
JC Bullred 1	215/245	191	130/135	102/110
JC Bullred 7	215/245	190/219	130/135	102/110
JC Bullred 5	215/245	190/221	131/135	102/110
JC awnless 11	215/245	190	130/135	102/110
JC WLS red 13	215/245	191/221	130/135	102/110
JC WLS red 16	215/245	191/219	130/135	102/110
JC WLS red 14	215/245	190/221	130/135	102/110
JC - FB awnless	215/221	190/219	130/135	102/110
JC - FB awned	215/217	190/205	131/147	102/110
JC - FB pink awned	215/226	190/205	130/147	102/110
Red rice standards				
JC - FB blackawned	226	205	147	110
Stgstraw #7	245	221	135	112
Stgstraw	222	221	135	112
LA-3-12 straw[w]	226	205	147	110
Stgblack 10	226	205	147	110
Cultivated rice standards				
CL161 rice	215	190	130	124
Cypress 4 rice	215	191	131	124

[z] RM = rice marker.
[y] A and B represent two parental alleles of a genotype from each marker.
[x] JC = Jackson County, Ark.
[w] LA = Louisiana.

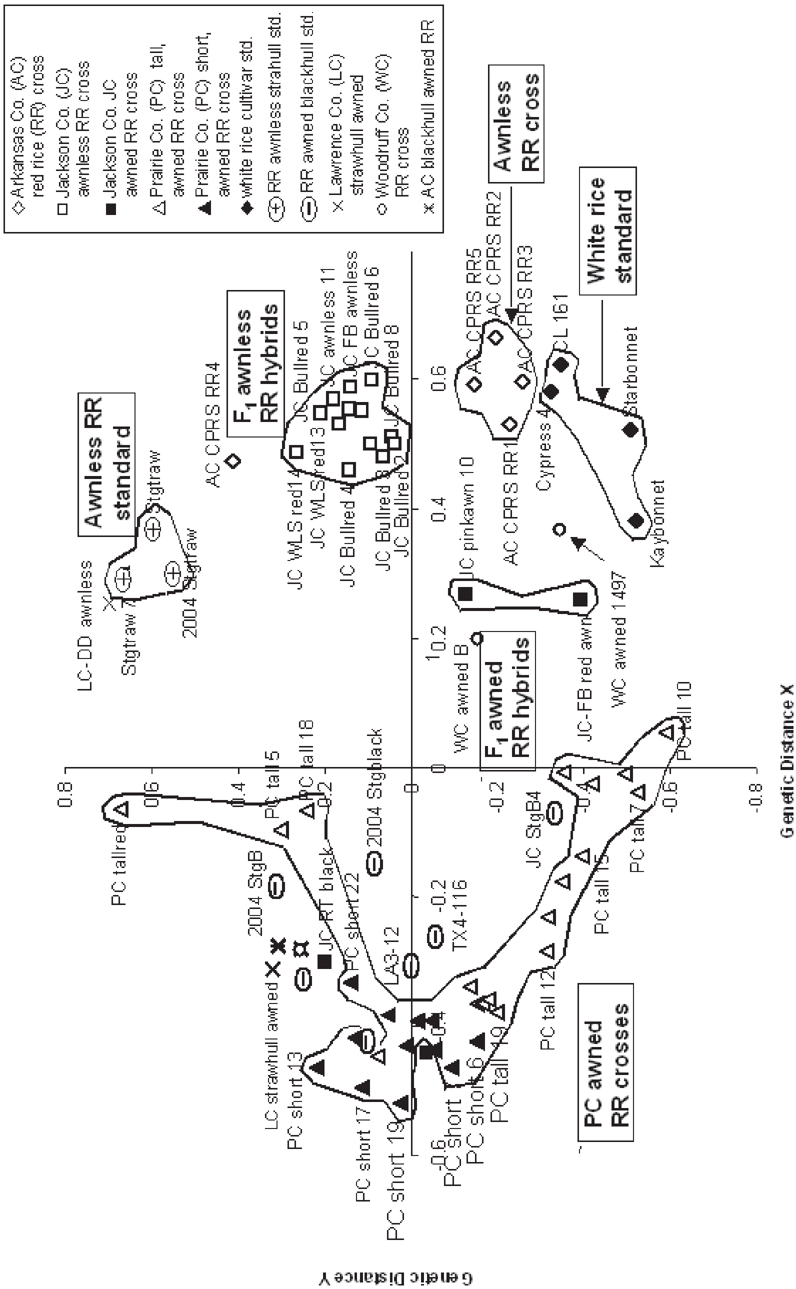

Fig. 1. Distribution of different Arkansas genotypes based on average genetic distances generated from nine selected SSR rice markers.

Environmental Implications of Pesticides in Rice Production

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

ABSTRACT

For the past five years study leaders 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 the study included four sites on Lagrue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt. In 2003 the study 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 (71-87%) of the detections that were over 2 ppb were less than 5 ppb, but until the past two years there had been between one and three detections of a compound in the 30-50 ppb range. For both of the past two years the highest detection was 13 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 two 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, and 5.4% in 2004).

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 scientists to detect a potential problem and address it before it becomes a major problem.

Small rivers in watersheds that are predominately in rice-growing country 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 the study 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 (Fig. 1). In 2002 the study added four sites on Lagrue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt, and in 2003 added four sites on the Cache River from the level of Jonesboro in the north to below I-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 and 2004. 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 (Fig. 1). 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 Highway 146 west of the Highway 33 junction, near the town of Lagrue at Highway 33 before the junction with Highway 153, and where the Lagrue crosses Highway 1 outside of DeWitt. In 2003 the study added four sites on the Cache River where it cross 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 I-40 (Fig. 1).

Sampling Procedure

Water samples were collected and extracted onto C18 Speedisks using a mobile field extractor which allows the samples to be extracted immediately after collecting them while en route 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 researchers to verify recovery and reproducibility. Sampling was performed at two-week intervals during the rice production season from May through August through 2003. In 2004 reseachers began collection in mid-April and stopped in mid-August.

Pesticides selected for monitoring were thiobencarb (Bolero), quinclorac (Facet), triclopyr (Garlon), methyl parathion, molinate (Ordram), clomazone (Command), acifluorfen (Blazer), imazethapyr (Pursuit), propanil (Stam), and 2,4-D.

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 this study can detect lower levels. The 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 looking at 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, and not drinking water, the 2 ppb level would be reasonable for making comparisons. All the detections from 2004 are listed in Table 1.

Table 2 lists the frequency of detections for each year from 2000-2004. 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 2000 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. 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 was repeated in 2004. If this occurs again in 2005 it may indicate a trend.

Table 4 shows the detection frequency of pesticides by site and 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 agriculture. This is also true of the upper Cache. The number of detections in the St. Francis has been variable over the four-year period with the number of detections in the first two years being much higher than the number of detections since then. Site E provided 11 detections in 2001, which tied with two other sites for the largest number of detections in the first two years. However, in 2002, 2003, and 2004 there were no detections over 2 ppb at this site. Site F at Marked Tree has consistently had the lowest, or next-to-lowest number of detections. A likely reason for this is that the St. Francis Sunken Lands Wildlife Management Area is approximately one mile upstream from the site and extends up to the Missouri border. This not only provides a buffer zone where there is no agriculture close to the river that could provide immediate runoff, but also because of the slow, meandering nature of the river here, there is ample opportunity for any pesticides that come in upstream to degrade before reaching the sampling site. The Cache River, while having 25% of the sampling sites, in 2003 had 46% of the detections and in 2004 had 43%.

Table 5 shows the number of samples each year that contained more than one compound. Most samples that contain a compound contain only one compound; however, 15 to 28% of the samples that contained a compound contained two compounds. There were several samples that contained more than two compounds, but the number was variable over years (3% in 2000 to 29% in 2001). In 2004 there were no samples that contained more than two compounds.

Detection of the same compound at the same site in 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 2004. Not surprisingly, the compounds that were detected most often were also most frequently detected on consecutive sampling dates. Also, the 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. Since then quinclorac (Facet) has been 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). The two most frequently detected compounds recently were quinclorac and clomazone (Command).

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 (Table 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 three, and quinclorac with four). In 2003 the concentrations were lower than for previous years (Table 3); the highest concentration was for molinate (12.8 ppb). In 2004 the highest concentration found was 13.4 ppb for quinclorac.

The EPA does not have guidelines on acceptable levels for most of these compounds in either the National Recommended Water Quality Criteria - Corrected (1999) or the 2002 Edition of the Drinking Water Standards and Health Advisories (2002). There was a listing of 70 ppb for the Maximum Contaminant Level (MCL) for 2,4-D in EPA drinking water standards. In this 2004 study, the highest level found in river water was 7.7 ppb.

The California Department of Pesticide Regulation has a performance goal of 10 ppb for molinate (3). The performance goal is a guide that is not enforceable, but is a level at which there can be toxic affects to some test species. In a personal call to the project leader in California, she likened it to a canary in a coal mine situation - a reason to be watchful. In the past five years this study had 11 detections of molinate above 10 ppb (two in 2000, eight in 2001, one each in 2002, 2003, and 2004); all but one were on the L'Anguille. These results are similar to those reported by the California Department of Pesticide Regulation (DPR) in their Rice Pesticides Program Monitoring Data-Final Update (2002). California has had periodic detections of molinate above the performance goal, and the concentrations were similar to what the present study found.

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

ACKNOWLEDGMENTS

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Fig. 1. Sampling sites for the 2004 water monitoring program.

Table 1. Results for the year 2004 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]	molin	clomaz	quinc	triclopyr	propanil	2,4-D	acifluor
			(ppb)						
4/13	Cache	Q		2.04					
5/4	L'Anguille	A		4.50					
	L'Anguille	B		6.21					
	L'Anguille	C		4.82					
	L'Anguille	D		2.45					
	Lagrue	L			2.20				
	Lagrue	N			3.00				
	Cache	Q		7.48					
	Cache	R		7.33					
	Cache	S		5.22					
	Cache	T		2.90	2.15				
5/18	L'Anguille	A		3.42					
	L'Anguille	B		4.92					
	L'Anguille	C		3.16			2.88		
	Lagrue	L			2.84				
	Cache	Q		5.21					
	Cache	R		3.09					
	Cache	S		2.17					
	Cache	T		3.27					
6/1	L'Anguille	B			2.73				
	L'Anguille	C			3.60				
	Cache	Q	2.32	2.48					
	Cache	R		2.19					
	Cache	S		2.39	2.09				
	Cache	T		2.72					
6/15	L'Anguille	A			5.60			5.00	
	L'Anguille	C			3.03				
	St. Francis	G			3.42			2.78	
	St. Francis	H						4.12	
	Lagrue	M			2.13				
	Lagrue	N			2.22				
	Cache	Q			5.80			3.25	
	Cache	R			5.19			3.21	
	Cache	S			3.71				
	Cache	T						4.80	
6/29	L'Anguille	A			13.38				
	L'Anguille	C			5.69	2.59			
	L'Anguille	D			2.26				
	St. Francis	G			2.38				
	St. Francis	H			3.67				
	Lagrue	K			2.16				
	Lagrue	L			3.41				
	Cache	Q			3.50			3.71	
	Cache	R			3.91				
	Cache	S			5.63				
	Cache	T			5.12				

continued

Table 1. Continued.

Date	River	Site[z]	Compounds and amounts detected[y]						
			molin	clomaz	quinc	triclopyr	propanil	2,4-D	acifluor
			----------	----------	----------	(ppb)	----------	----------	----------
7/13	L'Anguille	A			2.32	2.01			
	L'Anguille	B			2.98				
	L'Anguille	C			3.61				
	St. Francis	F				3.41			
	St. Francis	H				2.05			
	Lagrue	N				3.72			
	Cache	Q		2.08	2.77				
	Cache	R			3.45				
	Cache	S			2.78				
	Cache	T			2.42				
7/27	L'Anguille	A			2.79				2.68
	L'Anguille	B			3.05				
	L'Anguille	C			4.49				
	Cache	T			2.96				
	St. Francis	F					9.47	7.72	
	Lagrue	K					2.41		
	Lagrue	N					2.81		
TOTAL			1	21	37	5	4	8	1

[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] molin = molinate (Ordram); clomaz = clomazone (Command); quinc = quinclorac (Facet); triclopyr (Garlon); propanil (Stam); 2,4-D; and acifluor = acifluorfen (Blazer).

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

Year	2000	2001	2002	2003	2004
Number of rivers	2	2	3	4	4
Possible detections	576	565	958	1280	1440
Detections	53	68	49	79	77
Percent	9.2	12.0	5.1	6.2	5.4

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

ppb	2000	2001	2002	2003	2004
2-5	38 (72%)[z]	48 (71%)	38 (78%)	69 (87%)	63 (82%)
5-10	7 (13%)	13 (19%)	8 (16%)	9 (11%)	13 (17%)
10-20	3 (6%)	4 (6%)	1 (2%)	1 (1%)	1 (1%)
20-30	2 (4%)	2 (3%)	0 (0%)	0 (0%)	0 (0%)
30-40	1 (2%)	0 (0%)	2 (4%)	0 (0%)	0 (0%)
40-50	2 (4%)	1 (2%)	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 site.

L'Anguille						St. Francis						Lagrue				Cache		
Site[z]	2000	2001	2002	2003	2004	Site	2000	2001	2002	2003	2004	Site	2002	2003	2004	Site	2003	2004
A	8	9	14	8	9	E	5	11	0	0	0	K	0	5	2	Q	16	11
B	8	11	9	6	5	F	2	4	0	2	3	L	3	2	3	R	8	7
C	9	7	7	3	9	G	7	7	2	3	3	M	3	4	1	S	6	7
D	7	8	2	4	2	H	7	11	5	4	3	N	4	2	4	T	6	8
Total	32	35	32	21	25	Total	21	33	7	9	9	Total	10	13	10	Total	36	33

[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 water over 2 ppb per sample

Compound/ sample	2000	2001	2002	2003	2004
1	28 (70%)[z]	18 (51%)	23 (68%)	49 (80%)	63 (82%)
2	11 (28%)	7 (20%)	9 (26%)	9 (15%)	14 (18%)
3	1 (3%)	6 (17%)	1 (3%)	1 (2%)	0
4	0	2 (6%)	0	1 (2%)	0
5	0	2 (6%)	1 (3%)	1 (2%)	0

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

Table 6. Consecutive detections of a given pesticide by site - 2004.

Date	Clomazone							Quinclorac									2,4-D
4/13				Q													
5/4	A[z]	B	C	Q	R	S	T					L					
5/18	A	B	C	Q	R	S	T					L					
6/1				Q	R	S	T			C					S		
6/15								A		C	G		Q	R	S		Q
6/29								A		C	G		Q	R	S	T	Q
7/13								A	B	C			Q	R	S	T	
7/27								A	B	C						T	
8/10																	

[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.

Rice Tolerance and Weed Control with Penoxsulam Herbicide

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

ABSTRACT

Studies were conducted to evaluate crop tolerance and efficacy of penoxsulam herbicide in rice. Root pruning and crop stunting were observed with 2 oz/acre of penoxsulam applied to rice at various stages preflood. Postflood applications of 2 oz/acre did not result in stunting or root pruning. No application of penoxsulam caused a reduction in yield. Penoxsulam at 2 oz/acre was very effective at controlling both hemp sesbania and annual sedge when applied at the 3- to 4-leaf rice stage. Some barnyardgrass control (75%) was also observed from applications of penoxsulam. Penoxsulam could be an effective tool to control broadleaf weeds that are left behind after applications of clomazone.

INTRODUCTION

Many new herbicides have been introduced for use in rice over the last few years. Perhaps the most widely adopted and used of these is clomazone (Command). The widespread use of clomazone seems to have shifted the spectrum of problem weeds in rice to broadleaves such as hemp sesbania and annual sedge.

Penoxsulam is a new rice herbicide available from Dow AgroSciences under the trade name Grasp (Anonymous, 2004). Penoxsulam is a member of the sulfonylurea family of herbicides that has activity on hemp sesbania, annual sedge, and other broadleaves. Penoxsulam also has activity on barnyardgrass.

The objective of this study was to evaluate rice tolerance to penoxsulam and to evaluate penoxsulam in a clomazone-based weed control program.

PROCEDURES

Two studies were conducted in 2004 to evaluate crop tolerance and efficacy of penoxsulam in rice. These studies were conducted on the University of Arkansas at Pine Bluff Research Farm north of Lonoke, Ark.

Rice was drilled into 10 by 25ft plots using the variety 'Wells' at 90 lb/acre for the tolerance study and 'Cocodrie' at 90 lb/acre for the efficacy study. A naturally-occurring population of grass weeds, annual sedge, and hemp sesbania was present at the location chosen. Treatments were applied in a randomized complete block design with four replications. Standard farming practices for drilled, dry-seeded rice in Arkansas were followed. Treatments were applied with a MudMaster® spray rig calibrated to deliver 10 gal/acre using compressed air as a propellant.

Treatments in the tolerance study consisted of penoxsulam applied alone at 2 and 4 oz/acre at six different timings. The timings were 2- to 3-leaf rice, Preflood, 1 week after flood (WAF), panicle initiation (PI), 0.5-in. internode elongation, and boot. Bispyribac-sodium (Regiment) was also applied at 0.0198 lb ai/acre at the two latest timings for a comparison treatment. The entire test received 1.0 lb ai/acre pendimethalin (Prowl) plus 0.25 lb ai/acre quinclorac (Facet) applied delayed-preemergence in order to maintain the test area weed-free.

The efficacy study consisted of clomazone applied preemergence alone at 0.3 lb ai/acre followed by penoxsulam at 2 oz/acre applied on 3- to 4-leaf rice. Penoxsulam at 2 oz/acre applied alone on 3- to 4-leaf rice and tank-mixed with clomazone at 0.3 lb ai/acre was also applied. Penoxsulam at 2 oz/acre was applied postemergence in tank-mixes with triclopyr (Grandstand), halosulfuron (Permit), quinclorac, cyhalofop (Clincher), and propanil (Stam M-4).

Weed control was visually estimated using a scale of 0 to 100% where 0 equaled no control and 100 equaled complete control or desiccation of weeds. Crop response was visually estimated on the same scale with 0 equaling no injury and 100 equaling complete crop or root loss. Harvest was conducted and yield data were collected both years using a John Deere 4435 combine modified for plot harvesting.

Data were arranged and organized using Agriculture Research Manager (ARM) by Gylling Data Management (Brookings, S.D.). Data analysis was completed using the analysis of variance procedure (P=0.05), and treatment means were separated using the least significant difference (LSD) procedure in ARM.

RESULTS AND DISCUSSION

Crop injury in the form of root pruning and stunting was observed from both 2- to 3-leaf and preflood applications of penoxsulam. Penoxsulam at 2 and 4 oz/acre applied to 2- to 3-leaf rice had 5 and 8% stunting of rice and 18% root pruning, respectively (Fig. 1). Penoxsulam at 2 oz/acre applied preflood caused 8% stunting and 14% root pruning. Penoxsulam at 4 oz/acre applied preflood had 9% stunting and 38% root pruning. There was no stunting of the rice or root pruning observed on any treatment applied after the flood was established (data not shown). By 8 weeks after application of the preflood treatments, no stunting of shoots or roots was observed. An illustration of the root injury is shown in Figure 2. There were no yield differences between any treatment in the tolerance study (data not shown).

In the efficacy study, all treatments containing penoxsulam at 2 oz/acre applied on 3- to 4-leaf rice alone controlled hemp sesbania above 98% at two weeks after treatment (WAT) and above 91% by 14 WAT (Table 1). Annual sedge control with all penoxsulam treatments was above 96% at 2 WAT. Penoxsulam at 2 oz/acre tank-mixed with clomazone at 0.3 lb ai/acre controlled annual sedge 88%, while penoxsulam alone or following clomazone provided 100% control. This indicates a possible antagonism when the former is tank-mixed with clomazone. Barnyardgrass control with clomazone alone at 0.3 lb ai/acre applied PRE was 100% at 2 WAT and 91% at 14 WAT. Control of barnyardgrass with penoxsulam alone at 2 oz/acre applied to 3-leaf rice was 0% at 2 WAT and 75% by 14 WAT. This indicates that penoxsulam has some activity on barnyardgrass but is slow acting. Barnyardgrass control when clomazone at 0.3 lb ai/acre was tank-mixed with penoxsulam at 2 oz/acre applied to 3-leaf rice was 99% at 2 WAT and 95% by 14 WAT. Yield of rice was 146 bu/acre for penoxsulam applied alone and 167 bu/acre for clomazone applied alone. This is an indication of the competitive pressure of the weeds that each herbicide missed and the lack of residual grass control with penoxsulam. Yields increased to over 180 bu/acre when clomazone and penoxsulam were tank-mixed or when penoxsulam was applied following clomazone. Hemp sesbania control at 2 WAT and 14 WAT was above 94% with all tank-mixes of penoxsulam (data not shown). Annual sedge control 2 WAT and 14 WAT was above 96% with all tank-mixes (data not shown).

SIGNIFICANCE OF FINDINGS

Penoxsulam provides excellent control of hemp sesbania and annual sedge which have been selected for in many fields after the continued use of clomazone. Penoxsulam can cause stunting and pruning of roots in rice when applied preflood. Root injury did not affect rice yields.

More research is needed to evaluate rice tolerance to penoxsulam and to determine if the root pruning is an issue. Also, more studies evaluating rates and timings are needed to determine the best fit for penoxsulam in a weed control program. In addition, penoxsulam efficacy on other rice weeds, such as smartweed, aligatorweed, ducksalad, and northern jointvetch needs to be evaluated.

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Table 1. Weed control and rice yield with penoxsulam in a clomazone-based program.

Herbicides/ rates	Hemp sesbania 2 WAT[z]	Hemp sesbania 14 WAT	Annual sedge 2 WAT	Annual sedge 14 WAT	Barnyardgrass 2 WAT	Barnyardgrass 14 WAT	Yield
	(% control)						(bu/acre)
Clomazone 0.3 lb ai/acre[y]	0	0	0	0	100	91	167
Penoxsulam 2 oz/acre[x]	100	96	100	100	0	75	146
Clomazone 0.3 lb ai/acre[y] + penoxsulam 2 oz/acre[x]	98	91	100	88	99	95	181
Clomazone 0.3 lb ai/acre[y] fb penoxsulam 2 oz/acre[x]	100	91	99	100	99	94	184
LSD (P = 0.05)	4	7	4	10	6	9	13

[z] WAT = weeks after treatment.
[y] Applied preemergence.
[x] Applied to 3- to 4-leaf rice.

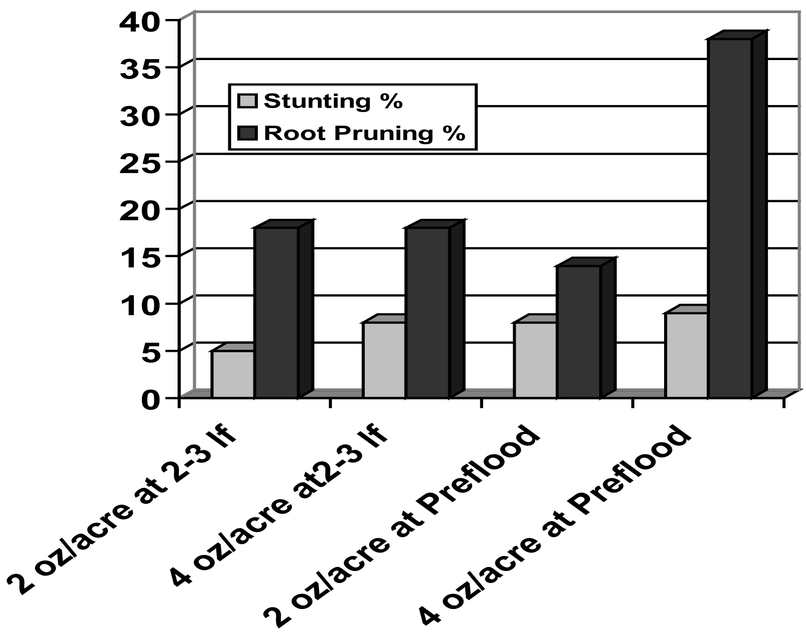

Fig. 1. Crop stunting and root pruning with 2 and 4 oz/acre of penoxsulam at 2 timings in rice. LSD (P=0.05).

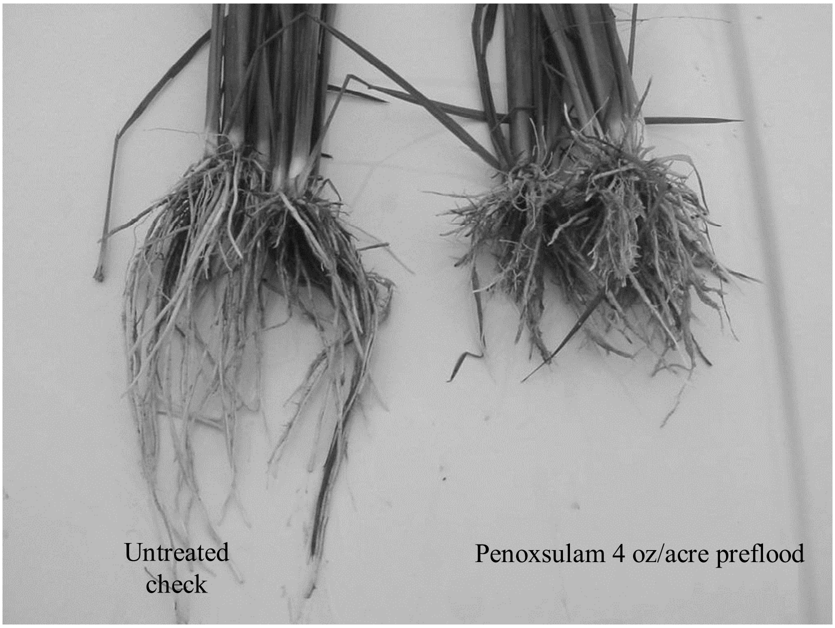

Fig. 2. Root pruning with a 2X rate of penoxsulam at two weeks after application.

Crop Tolerance and Efficacy of Imazamox in Clearfield® Rice

K.B. Meins, R.C. Scott, R.E. Talbert, and K.L. Smith

ABSTRACT

Field studies were conducted in 2003 and 2004 to evaluate imazamox efficacy and crop tolerance in Clearfield rice on non-red rice acres. No crop injury was observed with any treatment of imazamox in either year. Grass weeds were controlled 89% or better when imazamox was applied alone in a sequential postemergence program. When imazamox was tank-mixed with or applied following a residual herbicide, 94% or higher control of grass weeds was observed. These results show that imazamox can effectively control grass weeds on non-red rice acres.

INTRODUCTION

Since the introduction of imazethapyr (Newpath®) herbicide for Clearfield rice (*Oryza sativa*), growers across Arkansas have used the technology to successfully control red rice and other weeds. The success of this technology has led to widespread adoption and an increasing number of Clearfield rice acres (Wilson and Branson, 2004). As a result, many growers are faced with difficult situations because of the crop rotational restrictions placed on imazethapyr. The only acceptable crop rotations the first year after growing Clearfield rice are soybeans (*Glycine max*), another legume crop, corn (*Zea maize*), or to go back to Clearfield rice. Imazamox (Raptor, Beyond) has been used successfully to control red rice that may escape two imazethapyr applications. The physical properties of imazamox herbicide have been shown to pose little risk to rotational crops and the product is known to have a short half-life (Vencill, 2002). If imazamox were labeled for multiple applications in Clearfield rice, it would remove some of the crop rotational problems currently faced by some rice farmers. If crop rotational limits are removed then the introduction of high-yielding hybrid and conventional Clearfield rice types might result in their adoption on non-red rice acres. Single or sequential applications of imazamox could have a fit in these situations.

The objective of this study was to evaluate imazamox and imazamox programs for the control of common grass weeds in rice.

PROCEDURES

Studies were conducted in 2003 and 2004 to evaluate crop tolerance and efficacy of imazamox (Beyond) for Clearfield rice. These studies were conducted on the University of Arkansas Pine Bluff (UAPB) Farm north of Lonoke, Ark.

Rice was drilled into 10 by 25 ft plots using Clearfield 'CL 161' at 90 lb/acre for all studies in both years. Treatments were applied in a randomized complete block design with four replications. Standard farming practices for rice in Arkansas were followed. Treatments were applied with a MudMaster® spray rig calibrated to a spray volume of 10 gal/acre using compressed air as the propellant.

The tolerance study was conducted in both 2003 and 2004. Treatments consisted of imazamox applied alone at 4 and 8 oz/acre with four application timings. The timings were at panicle initiation (PI), 0.5-in. internode elongation, 2-in. internode elongation, and at the boot stage. Imazethapyr (Newpath) was also applied at 8 oz/acre at 0.5-in. internode elongation for a comparison treatment. The entire test received 8 oz/acre of imazethapyr at 3- to 4-tiller rice and 1 pt/acre of acifluorfen (Ultra Blazer) one week after flood (WAF) as a blanket treatment to keep the test area weed-free in both years.

The efficacy study was conducted in 2004 and consisted of imazamox alone at 3, 4, or 5 oz/acre applied to 1- to 2-leaf grass followed by imazamox at 3, 4, or 5 oz/acre applied preflood; clomazone (Command) at 0.3 lb ai/acre applied preemergence followed by imazamox at 5 oz/acre preflood or imazamox at 5 oz/acre postflood; pendimethalin (Prowl) applied preemergence at 1 lb ai/acre followed by imazamox applied at 5 oz/acre to 1- to 2-leaf grass; and imazamox at 5 oz/acre tank-mixed with propanil (Super Wham) at 4 qt/ or pendimethalin at 1 lb ai/acre applied to 1- to 2-leaf grass.

Weed control was visually estimated using a scale of 0 to 100% where 0 equaled no control and 100 equaled complete control or desiccation of weeds. Crop response was visually estimated on the same scale with 0 equaling no injury and 100 equaling complete crop loss. Harvest was conducted and yield data were collected both years using a John Deere 4435 combine modified for plot harvesting.

Data were arranged and organized using Agriculture Research Manager (ARM) by Gylling Data Management (Brookings, S.D.). Data analysis was completed using the analysis of variance procedure (P=0.05), and treatment means were separated using the least significant difference (LSD) procedure in ARM.

RESULTS AND DISCUSSION

There was no crop injury with any treatment or any timing in the injury studies (Data not shown). There were also no yield differences in the tolerance study in either year (data not shown).

Grass weed control was above 89% for all species when imazamox was applied posteemergence in sequential application (Table 1). Barnyardgrass control was above 96% for all three rates at 2 and 14 weeks after treatment (WAT). Broadleaf signalgrass was controlled above 91% at 2 WAT and 89% by 14 WAT for all three rates evaluated. Control of large crabgrass was 100% at 14 WAT for all three rates. These numbers show the excellent postemergence activity of imazamox on grass weeds and the potential that imazamox has as a conventional weed-control herbicide.

Control of grass weeds with tank-mixes of imazamox and other grass herbicides is shown in Table 2. Clomazone at 0.3 lb ai/acre applied preemergence followed by imazamox at 5 oz/acre to 1- to 2-leaf grass controlled barnyardgrass, broadleaf signalgrass, and large crabgrass above 98% up to 14 WAT. Imazamox applied at 5 oz/acre tank-mixed with propanil at 4 qt/acre controlled barnyardgrass 95% at 14 WAT. Broadleaf signalgrass control was 100% at 2 WAT, but dropped to 83% by 14 WAT with imazamox tank-mixed with propanil. Pendimethalin at 1 lb ai/acre applied delayed-preemergence followed by or tank-mixed with imazamox at 5 oz/acre to 1- to 2-leaf grass provided 100% control of all three grass weeds evaluated, and clomazone applied preemergence followed by imazamox postflood provided above 94% control of grasses through 14 WAT.

SIGNIFICANCE OF FINDINGS

Tolerance of CL 161 to imazamox herbicide was excellent up through the boot growth stage. Imazamox was effective for control of barnyardgrass, broadleaf signalgrass, and large crabgrass on non-red rice acres with Clearfield rice. Program approaches with Command and Prowl were also effective. These data suggests that imazamox herbicide would be a valuable tool in rice production regardless of the presence or absence of red rice.

More research is needed to evaluate imazamox herbicide on other grass weeds of rice. Tank-mix partners and efficacy of imazamox on a full range of rice broadleaf weeds are also needed. In addition, at this time it is the authors' understanding that several more years of crop residue and aquatic dissipation work would be required before BASF Corporation could pursue a section-3 label for Beyond on Clearfield rice (S. Asher, personal communication).

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Table 1. Grass weed control with sequential applications of imazamox.

	Barnyardgrass		Broadleaf signalgrass		Large crabgrass	
Imazamox[z]	2 WAT[y]	14 WAT	2 WAT	14 WAT	2 WAT	14 WAT
	(% control)					
3 oz/acre[x] fb 3 oz/acre[w]	96	100	91	89	---	100
4 oz/acre[x] fb 4 oz/acre[w]	100	100	100	95	---	100
5 oz/acre[x] fb 5 oz/acre[w]	100	100	100	100	---	100
LDS (p=0.05)	2	5	4	7	---	2

[z] All treatments received 1% v/v crop oil concentrate.
[y] WAT = Weeks after first treatment.
[x] Application made to 1- to 2-leaf grass.
[w] Application made preflood.

Table 2. Grass weed control and rice yield with imazamox tank-mixes and herbicide programs.

	Barnyardgrass		Broadleaf signalgrass		Large crabgrass		
Herbicides[z]	2 WAT[y]	14 WAT	2 WAT	14 WAT	2 WAT	14 WAT	Yield
	(% control)						(bu/acre)
Clomazone 0.3 lb ai/acre fb imazamox 5 oz/acre[x]	100	100	100	98	—	100	154
Imazamox 5 oz/acre + propanil 4 qt/acre	100	95	100	83	---	100	147
Pendimethalin 1 lb ai/acre fb imazamox 5 oz/acre[w]	100	100	100	100	---	100	161
Clomazone 0.3 lb ai/acre fb imazamox 5 oz/acre[v]	94	100	96	98	---	100	150
Pendimethalin 1 lb ai/acre + imazamox 5 oz/acre	100	100	100	100	---	100	162
LDS (p=0.05)	2	5	4	7	---	2	11

[z] All postemergence imazamox treatments received 1% v/v crop oil concentrate.
[y] WAT = Weeks after treatment.
[x] Applications made preemergence fb preflood.
[w] Applications made preemergence fb 1- to 2-leaf grass.
[v] Applications made preemergence fb postflood.

Reducing Seeding Rates with Modern Rice Cultivars as a Function of Barnyardgrass Control[1]

B.V. Ottis, R.E. Talbert, and A.T. Ellis

ABSTRACT

New rice cultivars have been released that have yield potential greater than 11,000 lb/acre. However, in order to achieve high yields it is important to have the proper fertility, seeding rates, and weed control. It is not well understood how these new, high-yielding cultivars respond to various weed control levels or seeding rates. Studies were established in 2002 through 2004 at the Rice Research and Extension Center, Stuttgart, Ark., to evaluate yield of three modern rice cultivars at four seeding rates under various barnyardgrass control levels. Representatives from each of the three classes of long-grain rice were selected: 'Wells' represented conventional long-grain rice, 'CL161' represented semi-dwarf, imidazolinone-tolerant rice, and 'XL8' represented hybrid long-grain rice. Weed control was managed with timely herbicide applications in an effort to achieve the desired barnyardgrass control levels. Rice plant populations were determined by taking stand counts 2 wk after emergence. Rice plant densities ranging between 6.8 and 34.6 plants/ft^2 did not affect yield. For each 1% increase in barnyardgrass control, rice yield increased 67 lb/acre for all cultivars. The main effect of seeding rate was not significant for rice biomass, panicle density, harvest index, or rice yield in a weed-free environment, regardless of cultivar. Wells produced higher panicle weights and had a higher harvest index than CL161 across the four seeding rates. XL8 and Wells produced similar yields, and were higher than CL161 across the four seeding rates. Results from this study indicate that recommended seeding rates for CL161, Wells, and XL8 can be reduced by 50% under optimal conditions while still maintaining optimal yield.

[1] This is a completed study.

INTRODUCTION

Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] is the principal weed in rice (*Oryza sativa* L.) production (Holm et al., 1977) and is a problem weed in 42 countries (Holm et al., 1979). It is found in 36 crops around the world (Holm et al., 1977) and in all rice-production fields across the state of Arkansas (Carey et al., 1995). Young barnyardgrass plants look similar to rice plants and can be hard to differentiate. Barrett (1983) believes that many thousands of years of hand removal of barnyardgrass in Asia may have selected for this mimicry trait.

With the exception of red rice (*Oryza sativa* L.), barnyardgrass is the most competitive weed in rice production (Smith, 1974), resulting in 70% yield loss as a result of season-long interference with 'Newbonnet' rice (Smith, 1988). Stauber et al. (1991) found that one barnyardgrass plant spaced 16 in. from a rice plant reduced rice yields 27%. Some infestations of barnyardgrass have been shown to remove 60 to 80% of available nitrogen from the soil (Holm et al., 1977).

Research has been conducted over the years to develop weed population-threshold levels in rice production. These levels are affected by rice cultivar, soil fertility, and seeding rate (Hill et al., 1985). Stauber et al. (1991) showed that semi-dwarf cultivars compete less than conventional cultivars against full-season barnyardgrass competition. Barnyardgrass populations of 0.5 plants/ft^2 are threshold levels for control measures in rice production (Smith, 1988). Therefore, it is important to maintain barnyardgrass control in order to maximize yield potential.

Several new rice cultivars and hybrids have become available for production in recent years. Many of these new cultivars have exceptional yield potential (Moldenhauer et al., 2001). A lack of information exists concerning the effect of rice plant density on yield components with these new rice cultivars. The objective of this study was to determine if new, high-yielding rice cultivars differ among their competitive abilities and to quantify these differences based on yield parameters.

PROCEDURES

A field study was established during the summers of 2002 through 2004 at the Rice Research and Extension Center, Stuttgart, Ark. The experiment was designed as a randomized complete block with four replications. A factorial treatment arrangement was used with factors consisting of three rice cultivars (CL161, Wells, and XL8), four target seeding rates (5, 10, 20, and 40 seeds/ft^2), and four levels of barnyardgrass control (25, 50, 75, and 100%).

The three rice cultivars used in the experiment represented the three major types of long-grain rice grown in the U.S. CL161 represented imidazolinone-tolerant, semi-dwarf rice, Wells represented conventional-height rice, and XL8 represented hybrid rice. Rice was sown on 14 May in 2002, 13 June in 2003, and 22 May in 2004. The late planting date in 2003 was the result of poor seed germination among CL161 plots from the original planting on 20 May; therefore, the study was abandoned and replanted 13 June. Seeding rates were established by counting and weighing 1000 seeds, then adding the amount of seed to the planter to achieve the aforementioned seed densities based on seed weight and the germination percentage for each cultivar. Minimum germination for CL161 and Wells was 80% while minimum germination for XL8 was 90%. Rice was drill-seeded with a nine-row cone planter set on 7.5-in. row spacings. Four barnyardgrass control levels were attempted with four different herbicide programs in an effort to establish a range of barnyardgrass control levels that might be encountered in a typical rice field. The 25% barnyardgrass control level (treatment 1) was established with a preflood application of propanil at 3 lb ai/acre to 4- to 5-leaf barnyardgrass. The 50% weed-control level (treatment 2) was maintained with an application of propanil at 3 lb/acre + thiobencarb at 3 lb/acre to 3- to 4-leaf barnyardgrass. The 75% barnyardgrass-control level (treatment 3) was maintained with an application of propanil at 4 lb/acre + quinclorac at 0.25 lb/acre to 2- to 3-leaf barnyardgrass. The 100% barnyardgrass-control (weed-free; treatment 4) level was maintained with a preemergence application of clomazone at 0.3 lb/acre + quinclorac at 0.25 lb/acre followed by (fb) quinclorac at 0.25 lb/acre to 4- to 5-leaf barnyardgrass. Broadleaf weed and sedge control was maintained in the study area with applications of triclopyr at 0.25 lb/acre + halosulfuron at 0.05 lb/acre + crop oil concentrate at 1% V/V applied 1 wk following establishment of the flood.

Nitrogen fertilizer was applied as urea preflood at a rate of 90 lb N/acre followed by a mid-season application of urea at 67 lb N/acre to CL161 and Wells. Cultivar XL8 did not receive a mid-season N application, but was fertilized instead with an additional 67 lb N/acre at 5% heading.

Barnyardgrass control evaluations were taken 1 wk following flood on a scale of 0 to 100 where 0 = no control and 100 = complete control. Rice stand counts were taken 2 wk after emergence by counting the number of plants in 3 ft of row in the center of each plot. Resulting stand counts were converted to rice density in plants/ft^2. Flags were placed at the front and back of the counted area. Once rice matured, rice plants from the 3-ft section of row were removed from the field, placed in paper bags, and dried. Then, the plants from the sample area were weighed and total biomass was recorded. Panicles were counted and threshed to separate seed. Harvest index, which is the ratio of economical yield (seed weight) to total biological yield (biomass), was determined. Grain yield was collected by harvesting the center four rows with a small-plot combine (Wintersteiger Classic, Wintersteiger Ag, Upper Austria). Yield from the 3-ft row samples was added to the plot weights for yield calculations. In 2002, severe lodging occurred due to high wind and rain as a result of tropical storms Isidore and Lili, which impacted the study in late September and early October, respectively. Therefore, yield data in 2002 were calculated from seed collected from the 3-ft row samples. Yield samples in all three years were weighed and adjusted to 12% moisture.

Data were analyzed using PROC GLM in SAS (SAS, Version 8.02, SAS Institute, Inc. N.C.) as a factorial using ANOVA, and means were separated using Fisher's protected LSD at the 5% level of significance. Regression analysis was done on rice densities and barnyardgrass control resulting from the four seeding rates and herbicide treatments one through three to predict their combined effect on rice yield. Regression coefficients were compared using single-degree-of-freedom contrasts. Using ANOVA, the fixed effects of cultivar and seeding rate were analyzed for their effects on rice density, yield, and yield components of rice in a weed-free environment (treatment 4). Means were separated using Fishers protected LSD at the 5% level of significance.

RESULTS AND DISCUSSION

Rice Yield as Affected by Plant Density and Barnyardgrass Control

Rice density did not affect yield; therefore, data were averaged across rice densities to evaluate the effect of barnyardgrass control. Rice yield increased linearly 67 lb/acre for each percentage increase in barnyardgrass control over the 3 years of the experiment (Fig. 1). Cultivar XL8 produced the highest average yield over the range of barnyardgrass control (5750 lb/acre), with CL161 producing the lowest (4160 lb/acre) (data not shown). Rice density did not affect yield probably because of the compensatory nature of rice whereby it fills voids in the canopy by producing more reproductive tillers. Furthermore, panicle density was unaffected by rice density (data not shown), and has been shown to be highly correlated with rice yield (Gravois and Helms, 1992).

Yield Components in a Weed-free Environment

Analysis of the effects of cultivar and rice density on yield and yield components among weed-free plots indicated no significant cultivar-by-seeding-rate interactions over the 3 years of the study (Table 1). Rice densities resulting from the 5 seeds/ft^2 seeding rate were 40% higher than expected from the actual seeding rate; however, densities resulting from the 40 seeds/ft^2 seeding rate were 12% lower than expected from the actual seeding rate. A late planting date combined with less intraspecific competition at low seeding rates most likely caused higher seed germination than expected based on minimum germination percentages (80% for CL161 and Wells; 90% for XL8) indicated by the seed labels. However, at the 40 seeds/ft^2 seeding rate, intraspecific competition likely resulted in lower-than-expected rice densities. Seeding rates equal to or greater than 40 seeds/ft^2 appeared to reduce rice emergence and early plant-establishment efficiency.

Rice biomass tended to decrease numerically as rice density increased, providing evidence for the compensatory nature of rice to fill voids in the canopy by producing larger amounts of tillers and biomass. For all cultivars, a decreasing trend in panicles/plant was observed as seeding rate increased, indicating that each of these cultivars responded to low densities by producing reproductive tillers. Similarly, panicle weight decreased as seeding rate increased for all cultivars. Harvest index remained constant across the four seeding rates. The University of Arkansas recommends final plant densities ranging from 15 to 20 plants/ft^2 for optimal yield (Wilson et al., 2005). Results indicated that the 10 seeds/ft^2 seeding rate produced the highest numerical yields for each cultivar; however, there was no cultivar-by-seeding-rate interaction for yield, indicating that there was no reduction in rice yield even at the lowest rice density of 6.8 plants/ft^2.

SIGNIFICANCE OF FINDINGS

Results from this study indicate that barnyardgrass is still a major yield-limiting factor in rice production, and with good barnyardgrass control, seeding rates can be reduced while still attaining optimal yield. Cultivars XL8 and Wells produced similar yields at later-than-optimal planting dates, and seeding rates ranging from 5 to 40 seeds/ft^2 did not affect yield for any cultivar. With the recent privatization of the rice-seed industry, seed costs have risen in respect to herbicide-tolerant and hybrid rice. Reductions in currently recommended seeding rates are suggested.

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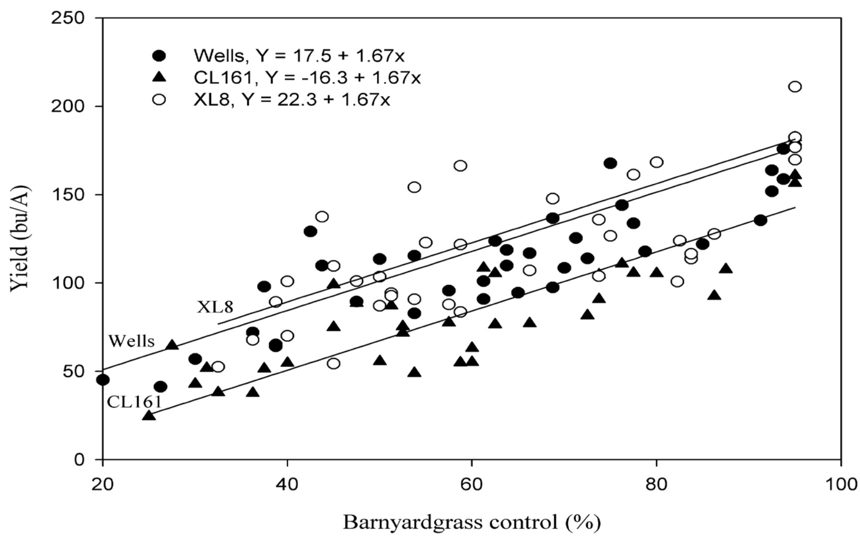

Fig. 1. Main effect of barnyardgrass control on rice yield for three cultivars near Stuttgart, Ark., 2002 to 2004.

Table 1. Main effects of cultivar and seeding rate on rice density, biomass production, panicle density, panicle weight, harvest index, and yield in a weed-free environment near Stuttgart, Ark., 2002 to 2004.

Effect	Rice density	Rice biomass	Panicle density	Panicles/plant	Panicle weight	Harvest index	Yield
	(plants/ft^2)	(lb/ft^2)	(no./ft^2)	(no./plant)	(g seed/panicle)		(lb/acre)
Target seeding rate (seeds/ft^2)							
5	6.8	0.45	34	5.3	1.9	0.32	6110
10	9.7	0.43	38	3.5	1.7	0.32	6630
20	19.9	0.40	37	1.9	1.6	0.31	6100
40	34.6	0.39	39	1.2	1.5	0.31	5880
LSD (0.05)	2	NS	NS	0.5	0.25	NS	NS
Cultivar							
CL161	18	0.39	36	3.1	1.5	0.29	5130
Wells	20	0.43	37	2.7	1.8	0.33	6620
XL8	17	0.43	38	3.1	1.7	0.32	6650
LSD (0.05)	2	NS	NS	NS	0.2	0.03	902

Performance of Residual Rice (*Oryza sativa*) Herbicides as Affected by Soybean (*Glycine max*) Crop Residue

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

ABSTRACT

A field study was conducted to evaluate the impact of soybean residue on grass weed control from soil-applied herbicides for rice. Clomazone, pendimethalin, quinclorac, and imazethapyr were applied to both a no-till area and a conventional-till area. Soybean residue did not appear to have any effect on grass control with imazethapyr or quinclorac, but grass control with clomazone or pendimethalin was reduced to under 85% in the no-till plots, while remaining above 90% in the tilled plots. The results of this study show that higher rates of clomazone may be needed to effectively control grass weeds in no-till rice fields compared to conventional tillage.

INTRODUCTION

Since its introduction into the rice herbicide market, clomazone (Command/Commit) herbicide has become the standard for grass weed control in Arkansas rice production (Smith et al., 2002). Over the past few years more and more rice in Arkansas is being grown under a reduced tillage system of some kind (Wilson and Branson, 2004). Because clomazone rates are based on soil type, the presence of crop residue may reduce its herbicidal activity. This may also be true for other residual rice herbicides such as imazethapyr (Newpath), quinclorac (Facet), and pendimethalin (Prowl). The effects of crop residue on herbicide activity have been studied extensively in crops like corn (*Zea mays*) and soybeans (*Glycine max*), but to a lesser degree in reduced or no-till rice production (Koskinen and McWhorter, 1986; Nowak, 1983; Swanton and Weise, 1991).

The objective of this study was to compare grass weed control with commonly used residual rice herbicides in two tillage systems.

PROCEDURES

A field study was conducted in 2004 to evaluate grass weed control from soil-applied herbicides in rice (*Oryza* sativa) grown under conventional tillage and a reduced tillage system. The study was conducted on a silt loam soil with a pH of 6.5 at the University of Arkansas at Pine Bluff Research Farm north of Lonoke, Ark.

Rice was planted into 10 by 25 ft plots. The variety used was 'CL161' seeded at 90 lb/acre. Naturally occurring populations of barnyardgrass (*Echinochloa crus-galli*) and broadleaf signalgrass (*Brachiaria platyphylla*) were present at the location. The study was conducted as a split-block design with tillage as the main blocks. Treatments were randomly applied within each block. Treatments were replicated four times. All treatments were applied using hand-held booms with a spray volume of 10 gal/acre using CO_2 as a propellant.

Treatments consisted of clomazone at 0.4 or 0.5 lb ai/acre applied preemergence (PRE), pendimethalin at 1.0 lb ai/acre delayed-PRE, quinclorac at 0.25 or 0.375 lb ai/acre PRE, and imazethapyr at 4.0 oz/acre PRE followed by imazethapyr at 4.0 oz/acre on 4-leaf rice. These treatments were applied to both the conventional-till rice and no-till rice blocks.

The conventional tillage system consisted of four passes with a disk, two passes with a land plane, and two passes with a field cultivator. The no-till block received a burndown application of glyphosate at 1.0 lb ai/acre 18 d prior to planting in an area that produced 35 bu/acre of soybeans the previous year. The tillage blocks were established side by side.

Weed control was visually estimated using a scale of 0 to 100%, where 0 equaled no control and 100 equaled complete control or desiccation of weeds. Crop response was visually estimated on the same scale with 0 equaling no injury and 100 equaling complete crop loss. Harvest was conducted and yield data collected at both locations using a John Deere 4435 combine modified for plot harvesting.

Data were arranged and organized using Agriculture Research Manager (ARM) by Gylling Data Management (Brookings, S.D.). Data analysis was completed using the analysis of variance procedure (P=0.05), and treatment means were separated using the least significant difference (LSD) procedure.

RESULTS AND DISCUSSION

At 2 weeks after planting (WAP), barnyardgrass control was 94% or more for all treatments evaluated with the exception of pendimethalin applied alone (Table 1). This was true for both conventional and no-till tillage systems. As the season progressed, pendimethalin controlled barnyardgrass over 80% in the conventional tillage system and failed to control barnyardgrass in the no-tillage system. Barnyardgrass control with pendimethalin was affected by tillage system more than all other herbicides evaluated (Table 1). Barnyardgrass control with both the sequential imazethapyr treatment and quinclorac at either rate evaluated was not affected by tillage. At 8 and 16 WAP, barnyardgrass control with both 0.4 And 0.5 lb ai/acre of clomazone was around 15% higher in the tilled system versus the no-till system. Also, late in the season, the higher rate of clomazone was needed to achieve 85% barnyardgrass control in the no-till system, while the lower rate of clomazone controlled barnyardgrass 96% in the conventional tillage system at 16 WAP (Table 1).

At 2 WAP, all treatments except pendimethalin were controlling broadleaf signalgrass 85% or more in both tillage systems (Table 2). By 16 WAP, pendimethalin was providing only 63% control of broadleaf signalgrass in the conventional tillage plots and no control in the no-till plots. Crop residue in the no-till treatments affected the efficacy of pendimethalin on broadleaf signalgrass more than that of any other herbicide evaluated. By comparison, imazethapyr and quinclorac activity were not consistently affected by tillage system in terms of broadleaf signalgrass control at the various rating intervals. However, clomazone activity was affected by tillage system (Table 1). General trends in broadleaf signalgrass control followed that of barnyardgrass control with clomazone. At 4, 8 and 16 WAP, clomazone at either evaluated rate controlled broadleaf signalgrass 15 to 20% less on average in the no-till systems versus the conventional tillage system. In terms of broadleaf signalgrass control, there was no difference between 0.4 and 0.5 lb ai/acre rates of clomazone within the no-till block.

SIGNIFICANCE OF FINDINGS

Both imazethapyr and quinclorac did not appear to be affected by crop residue (tillage system) in this study. However, clomazone and pendimethalin were affected. Pendimethalin activity was severely reduced under no-till cropping systems; this reduction makes it unlikely to be a good choice for grass control in no-till rice production. Barnyardgrass and broadleaf signalgrass were controlled only 85 and 75%, respectively, by clomazone at the end of the season in the no-till system. This was with a higher rate (0.5 lb ai/acre) than is currently recommended on silt loam soils such as the one on which this study was conducted. By comparison, the lower rate of clomazone (0.4 lb ai/acre) controlled both barnyardgrass and broadleaf signalgrass over 93% in the conventional tillage system. The data from this study strongly support changing the rate structure of clomazone when it is being applied in a no-till system. Crop injury was not significant in the no-till study at the higher-than-labeled rates (data not shown). More research is needed to refine the clomazone rate based not only on soil type, but also the amount of crop residue remaining in various no-till or reduced tillage systems to maximize weed-control efficacy.

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Table 1. Barnyardgrass control at 2, 4, 8, and 16 weeks after planting (WAP).

	2 WAP		4 WAP		8 WAP		16 WAP	
Herbicides/rates	No-till	Tilled	No-till	Tilled	No-till	Tilled	No-till	Tilled
	(% control)							
Clomazone 0.4 lb ai/acre[z]	95	100	90	98	74	91	74	96
Clomazone 0.5 lb ai/acre[z]	95	100	94	100	85	99	85	98
Pendimethalin 1.0 lb ai/acre[y]	0	0	65	93	0	80	0	88
Quinclorac 0.25 lb ai/acre[z]	94	100	93	99	94	89	89	95
Quinclorac 0.375 lb ai/acre[z]	99	100	99	100	91	89	88	100
Imazethapyr 4 oz/acre fb imazethapyr 4 oz/acre[x]	100	95	100	100	100	100	100	100
LSD (p=0.05)	7		4		9		7	

[z] Application made preemergence.
[y] Application made delayed-preemergence.
[x] Application made preemergence followed by early-postemergence.

Table 2. Broadleaf signalgrass control at 2, 4, 8, and 16 weeks after planting (WAP).

	2 WAP		4 WAP		8 WAP		16 WAP	
Herbicides/rates	No-till	Tilled	No-till	Tilled	No-till	Tilled	No-till	Tilled
	(% control)							
Clomazone 0.4 lb ai/acre[z]	95	100	90	98	74	91	74	96
Clomazone 0.4 lb ai/acre[z]	97	100	74	99	78	90	71	93
Clomazone 0.5 lb ai/acre[z]	97	100	81	100	70	93	75	94
Pendimethalin 1.0 lb ai/acre[y]	0	0	45	78	0	45	0	63
Quinclorac 0.25 lb ai/acre[z]	85	95	88	100	92	96	88	94
Quinclorac 0.375 lb ai/acre[z]	95	98	95	100	93	99	88	95
Imazethapyr 4 oz/acre fb100 imazethapyr 4 oz/acre[x]	94	100	100	100	100	100	100	
LSD (p=0.05)	8		9		9		8	

[z] Application made preemergence.
[y] Application made delayed-preemergence.
[x] Application made preemergence followed by early-postemergence.

Planting Time and Cultivar Effects on Outcrossing in Clearfield^{TM} Rice

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

ABSTRACT

Experiments were conducted at the Rice Research and Extension Center (RREC), Stuttgart, Ark., from 2002 to 2004 to determine the effect of planting date on the synchronization of flowering between Clearfield^{TM} cultivars, 'CL121' and 'CL161', and Stuttgart strawhull red rice. Seeds were drill-planted in 10-ft long, 3-row plots starting from mid-April to the third week of May at weekly intervals. Each Clearfield cultivar was replicated four times at each planting date. Data on flowering were collected twice a week. At maturity, plant height was measured and seed samples were collected for planting and subsequent screening of hybrids. Plots were sprayed with Newpath® (0.063 lb ai/acre) in the following year to observe the number of hybrids resulting from the shattering of red rice in the preceding year. Seed samples collected were planted and sprayed with Newpath (0.063 lb ai/acre) at the Vegetable Substation, Kibler, Ark., in 2004 to observe the number of hybrids. Red rice, CL121, and CL161 planted in mid-April (first planting) started flowering 90, 95, and 97 days after planting (DAP), respectively. In the second planting, flowering started 85, 90 and 95 DAP for red rice, CL121, and CL161, respectively. In subsequent plantings, flowering time decreased by 5 to 7 days for the Clearfield cultivars as well as for the red rice. Synchronization in flowering was highest between CL121 and red rice compared to CL161 and red rice in all planting timings. Survivors of screening from seedlings were confirmed as hybrids by DNA fingerprinting with the single sequence repeat (SSR) primer RM 180. The six planting dates in 2003 produced 48, 8, 25, 18, 8, and 9 hybrids, respectively, for both cultivars. The highest synchronization in flowering between red rice and Clearfield rice at first planting produced the highest number of survivors. Despite less synchronous flowering, CL161 produced a higher number of hybrids with red rice than did CL121.

INTRODUCTION

Red rice has many morphological, biochemical, and physiological characteristics similar to cultivated rice. Due to these similarities, red rice is hard to control with traditional herbicides in a rice-production system (Smith et al., 1977). Imidazolinone-resistant Clearfield rice is a valuable tool for red rice control, but transfer of the imi-resistant gene from Clearfield rice to red rice is a concomitant trade-off. Gene transfer occurs because cultivated rice and red rice are sexually compatible (Clegg et al., 1993).

Hybridization between cultivated rice and its weedy and wild relatives, red rice and *O. rufipogon,* has been reported in many studies (Chen et al., 2004; Messeguer et al., 2004; Song et al., 2003). Outcrossing between Clearfield cultivars (CL121 and CL161) and Stuttgart strawhull red rice has been documented in experiments at the Rice Research and Extension Center, Stuttgart, Ark., (Shivrain et al., 2005). Cultivated rice and red rice are both autogamous plants, but cross-pollination may take place depending on the planting time, cultivars grown, environmental conditions at a particular location, and distance from pollen source. Due to increasing acreage of Clearfield rice and the expected release of more herbicide-resistant cultivars in the near future, it is important to determine the effects of planting date and cultivars on outcrossing rate. The objectives of this study were to evaluate the effect of planting date on the synchronization of flowering between Clearfield rice cultivars and red rice, and to determine the outcrossing rate between Clearfield rice and red rice, depending on planting date.

PROCEDURES

Experiments were conducted at the RREC, Stuttgart, Ark., in 2002 and 2004. The soil at the experimental site is a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) with 1% organic matter and a pH of 6.0. The experiments were planted in a split-plot design with planting date as main plot and cultivar as subplot, with four replications. There were six planting dates at weekly intervals starting from mid-April to the third week of May (Table 1). Clearfield cultivars CL121 and CL161 and Stuttgart strawhull red rice were drill-planted in 10-ft long, 3-row plots, with rows 7 inches apart. The outer two rows were planted with one Clearfield cultivar and the middle row with red rice. The other Clearfield cultivar was planted in the adjacent plot. Distance between plots was 21 inches. Propanil and halosulfuron were applied at 3 and 0.063 lb ai/acre, respectively, at 5 weeks after planting (WAP) to control other rice weeds. The herbicide treatments were applied with a hand-held sprayer delivering 15 gal/acre through flat-fan spray tips. Urea (46% N) was applied at 100 lb/acre. Permanent flood was established when plants were at 4- to 5-leaf stage. Other standard agronomic and pest-management practices were implemented throughout the growing season.

Data on flowering were collected twice a week. At maturity, plant height was measured and approximately 200 red rice panicles were collected from each plot to screen for outcrossing. Harvested panicles were threshed by hand, and the seeds were cleaned and stored for planting in the field. The Clearfield rice was harvested by hand while red rice was allowed to shatter in the plots. The following year, natural populations of red rice in the plots were sprayed thrice with Newpath at 0.063 lb ai/acre at weekly intervals starting from the 1- to 2-leaf stage. Survivors of these three applications were suspected F_1 hybrids between Clearfield and red rice.

Seeds from the hand-harvested panicles were planted in the field at the Vegetable Research Substation, Kibler, Ark., in 2003 and 2004 to detect hybrids. Red rice seedlings starting at 2- to 3-leaf stage were sprayed with Newpath at 0.063 lb ai/acre for three consecutive weeks. Survivors from plots at the RREC and the Vegetable Substation were confirmed as F_1 hybrids using simple sequence repeat (SSR) DNA fingerprinting technique (Rajguru et al., 2002).

Data on the number of F_1s detected were analyzed using the GLM procedure in SAS (SAS, 2004). Data on the number of hybrids from the RREC plots and the hand-collected samples were combined to get a better estimate of outcrossing. Complete data from the 2003 experiment are reported here, whereas only data on flowering time is presented from the 2004 experiment.

RESULTS AND DISCUSSION

Synchronization in Flowering

In all plantings dates, red rice emerged first, followed by CL121 and CL161. Flowering in red rice, CL121, and CL161 at first planting started 90, 95, and 97 days after planting (DAP), respectively, in 2003 (Fig. 1). Synchronization in flowering was higher between CL121 and red rice than between CL161 and red rice. In 2003, flowering in red rice and both Clearfield cultivars was earlier by 5 to 7 days at the second planting compared to first the planting (Fig. 2), but the flowering synchronization pattern remained the same. In 2004, flowering was delayed by 5 days. As the planting time was delayed, synchronization in flowering between Clearfield cultivars and red rice decreased. Moreover, days to flowering also decreased (Figs. 3 and 4). Flowering in 2004 at all planting dates was delayed by 5 to 7 days compared to flowering in 2003. Regardless of planting time, CL121 had more synchronous flowering with red rice compared to CL161. Flowering was very early in red rice compared to the Clearfield cultivars at the fifth and sixth planting, resulting in very low flowering synchronization between both Clearfield cultivars and red rice (data no shown).

There was a significant difference in the number of hybrids produced based on planting date (Fig. 5). The highest number of hybrids was found at the first planting with 28 and 15 hybrids in the CL161 and CL121 plots, respectively. At the second planting, there were eight and four hybrids in the CL161 and CL121 plots, respectively. The third planting had 22 and seven hybrids in the CL161 and CL121 plots, respectively. At the fourth planting, the number of hybrids was not significantly different from the first three plantings, but was numerically lower. At the fifth and sixth planting, the hybrids were less than five, regardless of cultivar. In general, the number of hybrids decreased with delayed planting date in both Clearfield cultivars. Cultivar CL121 flowered earlier than CL161 and was therefore more synchronized in flowering with red rice for all planting dates. The earliest planting date resulted in the most synchronous flowering between either Clearfield cultivar and red rice. The highest number of survivors was from first planting, as expected, due to the synchronized flowering between red rice and Clearfield rice. Seeds collected in 2004 will be evaluated for hybrids next year in the field. Gene-specific primers will also be used to identify the Clearfield parent of each hybrid. The number of hybrids was higher in CL161 than in CL121 plots but the trend of decreasing number of hybrids as planting date was delayed was similar in both cultivars. Most of the hybrids were late in flowering and their seeds did not mature in the field due to the onset of cold weather.

Difference in synchronization rate was detected between Clearfield rice cultivars. Despite higher synchronization between CL121 and red rice, higher outcrossing was observed between CL 161 and red rice, suggesting that factors other than synchronized flowering contributed to differences in outcrossing rates between the two cultivars. This could be the height difference between pollen donor and pollen acceptor. The CL161 cultivar (93 cm) is taller than CL121 (84 cm) and thus, more similar in height to red rice (108 cm). Chances of pollen exchange are higher between plants with less height differential and this could explain the higher outcrossing between CL 161 and red rice.

Differences in the flower morphology of CL161 and CL121 could be another reason. Although the length of anthers, stigma, style, and other floral parts was not recorded in this study, these characteristics influence outcrossing rate. In general, wild rices have longer anthers and a higher proportion of exserted stigma than the cultivated varieties (Virmani and Athwal, 1973). Higher outcrossing rates between wild rice *(O. rufipogon*) and cultivated rice compared to red rice and most cultivated rice may have been a result of these morphological differences (Song et al., 2003). Other factors to consider include pollen production and longevity.

SIGNIFICANCE OF FINDINGS

Results of this study suggest that planting time affects the outcrossing rate between Clearfield rice cultivars and red rice. The Clearfield cultivar CL161, currently the major cultivar being planted, has higher chances of outcrossing than CL121. Given enough warm days, and without further intervention after rice harvest, hybrid plants resulting from outcrossing can produce viable seeds that replenish the seed bank with imi-resistant seed. Planting time and cultivar should be carefully considered in planning for management of outcrossing between Clearfield rice and red rice to keep the Clearfield rice technology sustainable.

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Table 1. Planting dates of CL121, CL161, and red rice at the Rice Research and Extension Center, Stuttgart, Ark., from 2002 to 2004.

	Year		
Planting	2002	2003	2004
First	18 April	15 April	16 April
Second	24 April	22 April	20 April
Third	30 April	29 April	29 April
Fourth	8 May	6 May	7 May
Fifth	16 May	13 May	13 May
Sixth	21 May	19 May	18 May

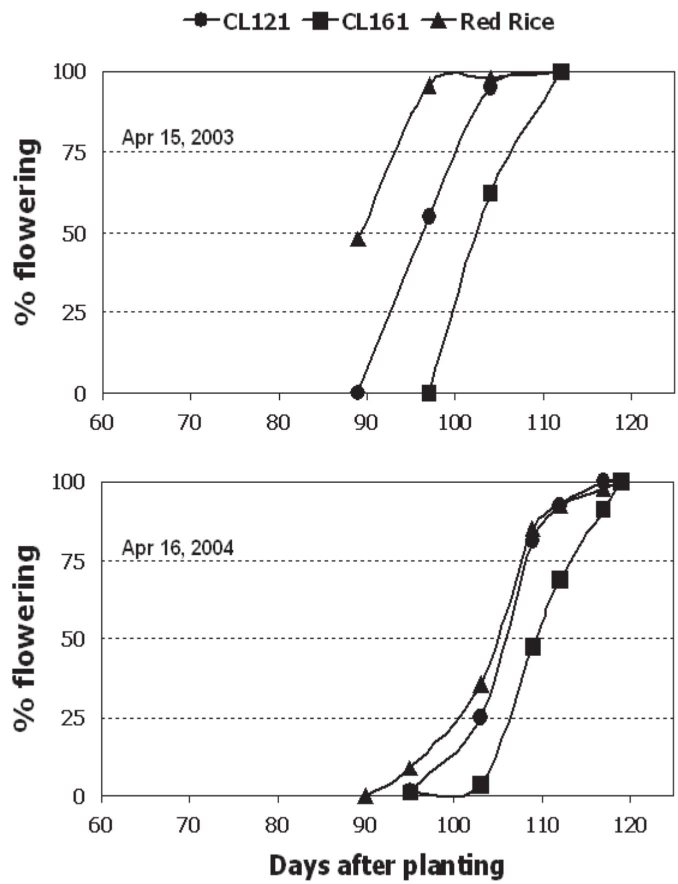

Fig. 1. Flowering for the 1st planting in red rice, CL121, and CL161 at the RREC, Stuttgart, Ark., in 2003 and 2004.

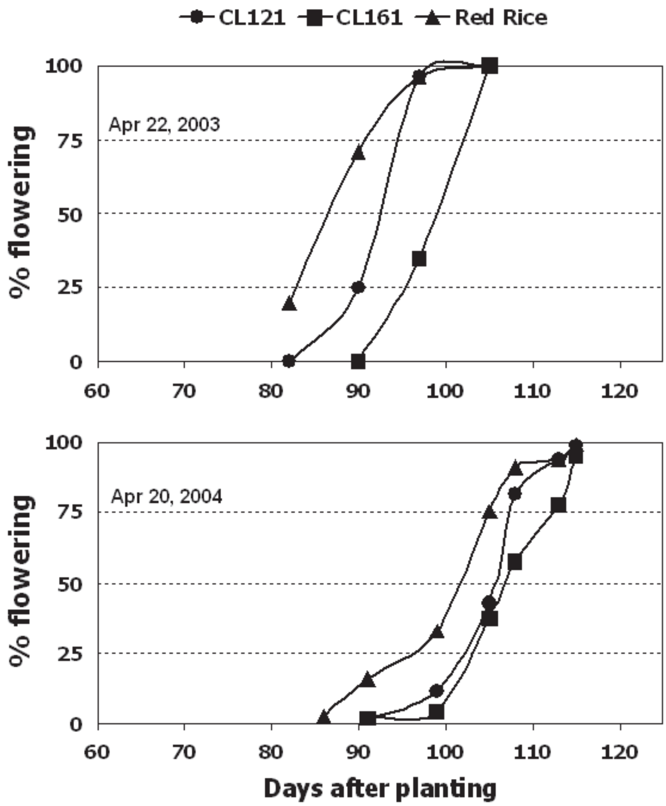

Fig. 2. Flowering for the 2nd planting in red rice, CL121, and CL161 at the RREC, Stuttgart, Ark., in 2003 and 2004. 0

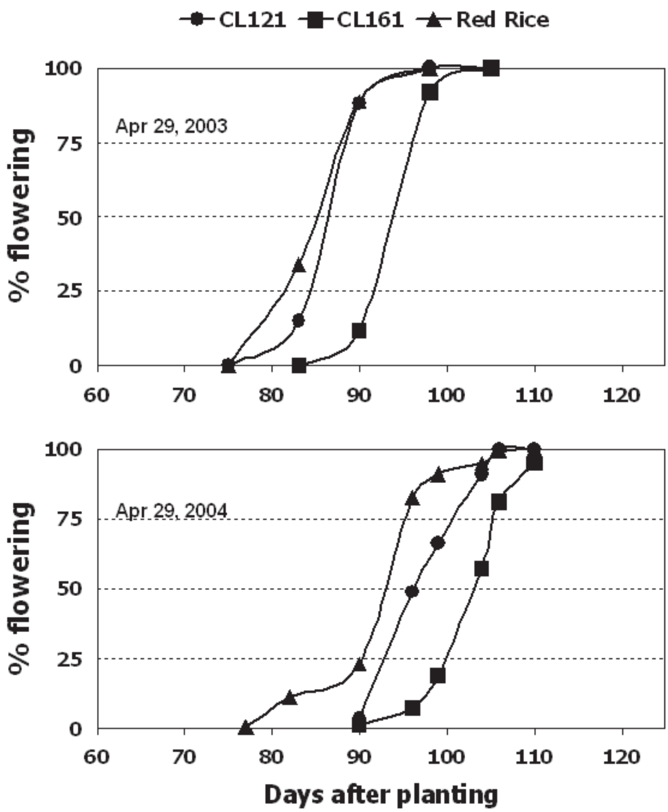

Fig. 3. Flowering for the 3rd planting in red rice, CL121, and CL161 at the RREC, Stuttgart, Ark., in 2003 and 2004.

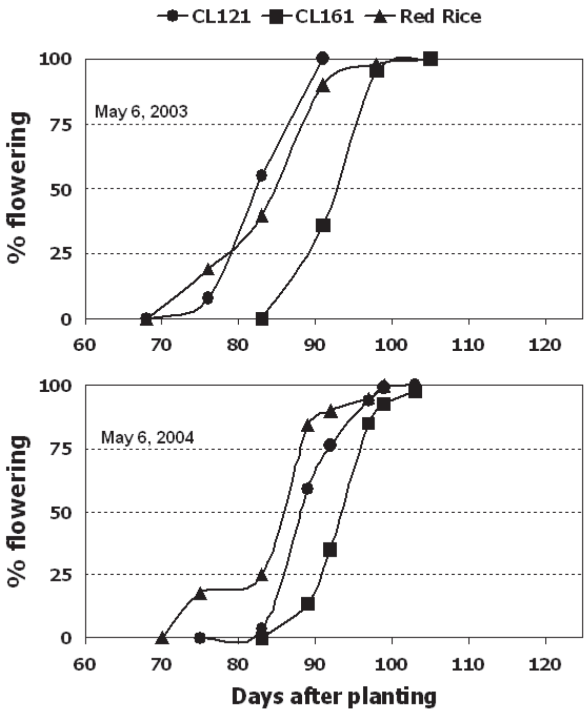

Fig. 4. Flowering for the 4th planting in red rice, CL121, and CL161 at the RREC, Stuttgart, Ark., in 2003 and 2004.

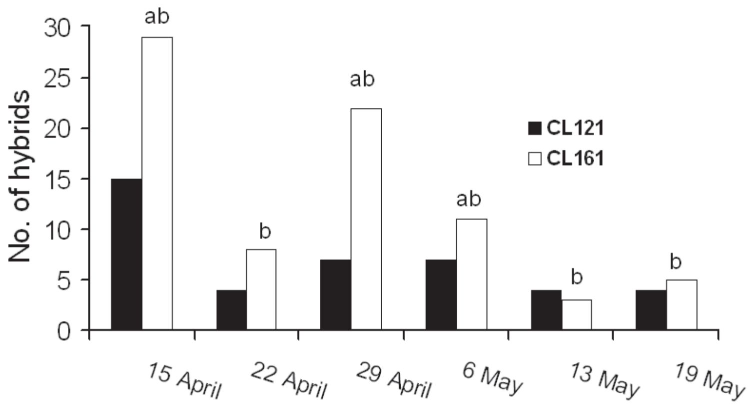

Fig. 5. Number of hybrids detected between Clearfield cultivars and red rice for six planting dates at the RREC, Stuttgart, Ark., in 2003.

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

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ABSTRACT

Average rough rice yields in 2004 for the systems rotation studies were 170 bu/acre; the second highest mean grain yield since the study began in 1999. Differences in rough rice yields were significant for the main effects of tillage, rotation, and variety, but not for fertility. In 2004, the lowest rough rice yield (156 bu/acre) was in the continuous rice rotation. This was the first year that continuous rice yielded less than rice planted after wheat. Grain yields were highest in the rice-soybean and rice-corn rotations. For the variety 'Cybonnet', grain yields in the two rotations where rice was planted following wheat were not significantly different than those obtained in standard rice-soybean and rice-corn rotations. Consistently, equal or higher grain yields from the 'standard' fertility treatment compared to the 'enhanced' fertility treatment support current recommendations and suggest that higher N, P, and K rates may not result in increased grain yields. Fertilizer-N uptake at the higher-N rate (150 lb/acre) was lower in the continuous rice rotation when compared to the rice-soybean rotation. No-till further decreased fertilizer-N uptake in the continuous rice rotation; a result not found in the rice-soybean rotation. No-till resulted in equal or increased soil-N uptake for both rotations indicating a potential nutrient benefit from no-till production. Total N uptake was lower in the continuous rice rotation compared to the rice-soybean rotation. Lower N uptake in the continuous rice rotation may have contributed to reduced grain yields in that rotation. Increasing phosphorus and potassium levels resulted in increased soil P and K levels but were not associated with increased grain yields. There were no significant differences in soil P and K levels in the no-till plots compared to the conventional-till plots.

INTRODUCTION

Rice production has changed considerably in the past 10 years, partially due to the availability of high-yielding varieties and improved production techniques. Farm legislation has also influenced production by removing acreage restrictions. Concurrent with these developments is an increasing concern that rice production is detrimental to land and water quality. One way farmers can directly address these concerns is the use of minimum or no-till rice production. This project was established with the following objectives: 1) provide a set of management guidelines that farmers can use to assist them in maintaining their profitability should they change their rotations, 2) explore the potential of using short-duration rice, soybean, wheat, and corn varieties in a range of crop rotations, 3) measure the effects of fertility levels and crop sequences on pest and disease incidence in existing and new rotations, 4) explore the use of conservation tillage in a range of rotations, 5) determine the feasibility of using corn in rice-based cropping systems, and 6) test existing cropping systems models that include the crop species used in this study.

PROCEDURES

Field #8 at the University of Arkansas Rice Research and Extension Center was selected for this study and cut to a 0.15% slope in February 1999. This site had not been regularly used for rice research because irrigation water was not readily available. Soil at the site is referred to as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaquultic Hapludalfs. Initial soil samples showed a pH range of 5.6 to 6.2 with a carbon content averaging 0.84% and nitrogen 0.08%. Main rotation plots measuring 250 ft. x 40 ft. were laid out in a north-south direction. These plots were then divided (strip across each replication) in half east-west with each side randomized as conventional or no-till treatments. Each tillage treatment was then split (strip across each replication) into a standard and high-fertility treatment. For rice, 'standard' fertility consisted of a single pre-flood N application of 100 lb urea/acre plus 40 lb/acre P_2O_5 and 60 lb/acre K_2O applied prior to planting. Rates increased to 150 lb/acre N, 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. This design has not changed except when a specific variety was either not available or was not resistant to a particular disease. The rice varieties used in 2004 were 'Wells' and Cybonnet for the full-season rotations and 'XL7' and 'Spring' for the rice planted after wheat. In March, soil samples were collected for fertility evaluations along with soil-strength measurements from selected plots. Irrigation water applied to each rotation (conventional-till and no-till) was measured in one replication with commercial flow meters. 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-corn (wheat)-soybeans. Those rotations containing standard full-season rice varieties are 1, 2, 3, 9, and 10. Short-season rice varieties are used in rotations 6, 7, and 8.

All full-season rice plots were sown on 20 April 2004. 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 with Icon applied as a seed treatment. Phosphorus and K were applied prior to sowing with a single pre-flood N application made prior to flooding. P and K were incorporated in the conventional-till treatment and not in the no-till treatment. Short-season plots were sown on 8 June 2004. An analysis of variance was performed for each individual year and a Duncan means test used to test differences within each year.

Collaboration was initiated in 2002 with the National Soil Tilth Laboratory, Ames, Iowa, to study N uptake using ^{15}N. This work continued through the 2004 season. Nitrogen uptake comparisons were made using ^{15}N enriched urea (5 atomic percent ^{15}N) fertilizer in 'enhanced' fertility plots planted into Wells in the continuous rice and rice-soybean rotations. Four metal rings 2 ft. in diameter were inserted into the appropriate larger plots. When the rice plants had reached the 4- to 5-leaf growth stage, labeled N was applied inside each ring at a rate of 150 lb N/acre (same rate that was used in the larger plots) at the same time the larger plots were fertilized. Each ring was flooded to a depth of 2 to 3 in. water and maintained at this depth for a period of two weeks. At that time, rubber stoppers were removed from the ring and flood water from the larger plot allowed to maintain water depth inside the ring. No additional fertilizer was applied to the larger plots after they were flooded. Plant and soil samples for ^{15}N determination were collected from rings throughout the growing season at 2 weeks following N application, green ring, heading, and harvest. Soil bulk density samples were collected two weeks after N application and flowering. The ^{15}N atom percentages of the plant and soil samples were determined by continuous flow isotope ratio mass spectromety, using a Fisons NA 1500 NC elemental analyzer coupled to a Finnigan Delta S mass spectrometer. Plant Y leaf samples were collected from the larger treatment plots weekly beginning at 2 weeks following N application and continuing to 50% heading. Nitrogen content was measured in these samples. Plant samples collected at harvest were divided into grain, leaf, and stem components for N analysis.

RESULTS AND DISCUSSION

Rice Grain Yields - 2004

Mean grain yield for all rotations was 170 bu/acre (Table 1). Grain yields were significantly different for rotation main-effect comparisons with lowest yields (156 bu/acre) in the continuous rice rotation. These results are consistent with previous years (Table 1). There was a significant (16 bu/acre) increase in grain yield in the conventional-till when compared to the no-till treatments (Table 1). Tillage treatments have been significantly and consistently different in every year except 2003 when the Roundup problems occurred.

Rotation differences were significant when comparing the continuous rice rotation with the other rotation treatments. Grain yields were the second highest recorded to date for the continuous rice rotation (156 bu/acre) yet remained significantly lower than the other rotations. For the first time, grain yields for rice sown after wheat were similar to rotations using a full-season rice. This change is attributed to the selection of short-duration rice varieties and a relatively cool summer. Unfortunately, the variety used in these rotations (XL7) is no longer available. As more short-duration varieties become available these rotations will be more attractive.

The full-season variety LaGrue was replaced with Cybonnet in 2004. This change was made because LaGrue's popularity had declined. Cybonnet was selected as a replacement because of its dwarf character and high grain quality. Mean grain yield over all treatments for Cybonnet was 144 bu/acre, approximately 23 bu/acre less than Wells. Weather conditions were conducive for high grain quality in 2004, thus, there were no differences in the milling quality of these varieties.

There were no differences in grain yields when comparing fertility treatments. These results are much the same as in previous years and indicate that there is no gain in increasing P and K fertility levels over those recommended ('standard' treatment). There is some evidence that rotation differences are closely associated with N uptake, suggesting that different approaches to N-fertility management might be needed for different rotations.

Plant Nutrient Uptake and Soil Nutrient Levels

Data on N uptake were collected in 2002, 2003, and 2004 using ^{15}N as described earlier. For purposes of this report, study leaders will present data collected at maturity in 2002. Roundup damage in 2003 resulted in confusing mid-season results, but 2004 data are similar. Results for fertilizer-N uptake (Fig. 1) show a reduction in fertilizer-N uptake in the continuous rice rotation regardless of tillage treatment. For the continuous rice rotation, there was a reduction in plant-N uptake in the no-till plots when compared to the conventional till plots. Plant leaf-N concentration (results not presented) showed a trend of increased decline in the Y leaf-N concentration in the continuous rice rotation compared to the rice-soybean rotation.

Soil-N uptake showed the same trend as fertilizer-N uptake where N uptake was lower in the continuous rice rotation when compared to the rice-soybean rotation (Fig. 2). Soil-N uptake for the continuous rice rotation was higher in the no-till treatment; opposite that of the fertilizer-N uptake trend. Both rotations had a non-significant trend of higher soil-N uptake in the no-till treatment when compared to conventional tillage. These results suggest a possible benefit from no-till through additional N being supplied in the no-till system; a result that could lead to decreased N-fertilizer use.

Total plant- N uptake was lower in the continuous rice rotation when compared to the rice-soybean rotation and there were no differences between tillage treatments within each rotation (Fig. 3). Increased N uptake in the no-till treatment did not result in higher grain yields. Researchers believe decreased fertilizer-N uptake in the continuous rice rotation when compared to the rice-soybean rotation contributes to lower grain yields and that increases in soil-N uptake in the no-till plots do not impact yields because that uptake occurs later in the growing season.

Soil nutrient data collected in 1999, 2000, 2001, and 2002 show a trend of increasing P and K levels in the 'enhanced' fertility plots when compared to 'standard' fertility plots (Figs. 4 and 5). This increase has not resulted in increased grain yield. A consistent lack of yield increases using elevated or 'enhanced' fertility supports current fertilizer recommendations, which are the 'standard' treatment.

SIGNIFICANCE OF FINDINGS

Results summarized in this paper indicate that, over a five-year period, there was no significant increase in rice yields when N, P, and K fertilizer levels were increased at approximately 25% over recommended levels. Rice grain yields were highest when rice was rotated with soybeans or corn. No-till resulted in overall reduced grain yields in all rotations. The amount yields are reduced by no-till varies with rotation, fertility, and variety. Highest no-till grain yields were obtained in the rice-soybean rotation, using standard fertility and the variety Wells. Rotation and tillage greatly influence fertilizer- and soil-nitrogen uptake. Total N uptake was lower in the continuous rice rotation when compared to the rice-soybean rotation. No-till increased soil-N uptake in both rotations thus indicating a potential to reduce N applications in no-till rice production.

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The authors would like to thank the Arkansas Rice Research and Promotion Board, Arkansas Soybean Promotion Board, Arkansas Wheat Promotion Board, and Arkansas Corn and Sorghum Promotion Board, the Potash and Phosphate Institute, and the University of Arkansas for their support of this project. The authors would also like to thank Asgrow, Pioneer, and Monsanto for providing seed and chemicals for this study.

Table 1. Summary of full-season rice mean grain yield (bu/acre) for treatment main effects in 1999, 2000, 2001, 2002, 2003, and 2004 in the long-term cropping systems study at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

	Year					
Treatment	1999	2000	2001	2002	2003[z]	2004
All						
All	195	140	137	159	166	170
Tillage						
Conventional	NA	149 a[y]	143 a	168 a	153	178 a
No-till	NA	131 b	131 b	151 b	153	162 b
Rotation						
Continuous rice	NA	159 b	145 b	132 d	138	156 b
Rice-soybeans	NA	198 ab	164 a	174 ab	173	187 a
Rice-corn	NA	205 a	165 a	165 bc	176	177 a
Rice-corn-soybeans	NA	NA	NA	180 a	NA	NA
Rice-corn (wheat)-soybeans	NA	NA	NA	177 ab	NA	NA
Rice (wheat)-rice (wheat)	NA	68 c	130 b	134 d	146	156 b
Rice (wheat)-soybeans(wheat)	NA	69 c	131 b	154 c	132	162 b
Fertility						
Standard	198 a	138 a	135 a	156 a	159	168 a
Enhanced	191 b	142 a	138 a	163 a	147	171 a
Variety						
Wells	198 a	187 a	159 a	168 a	153	182 a
LaGrue	191 a	178 a	157 a	164 a	157	NA
Cybonnet	NA	NA	NA	NA	NA	164 b
STG95L-28-045	NA	75 b	92 b	NA	NA	NA
Early Lagrue	NA	62 b	NA	NA	NA	NA
XL6	NA	NA	68 c	NA	NA	NA
XL7	NA	NA	NA	150 b	148	158 b
Spring	NA	NA	NA	138 c	155	NA

[z] Roundup damage resulted in 2 replications being dropped thus there were not sufficient replications to result in significant differences.

[y] Means within a “Year and Treatment Factor” followed by different letters are significantly different at the P=0.05 level of confidence.

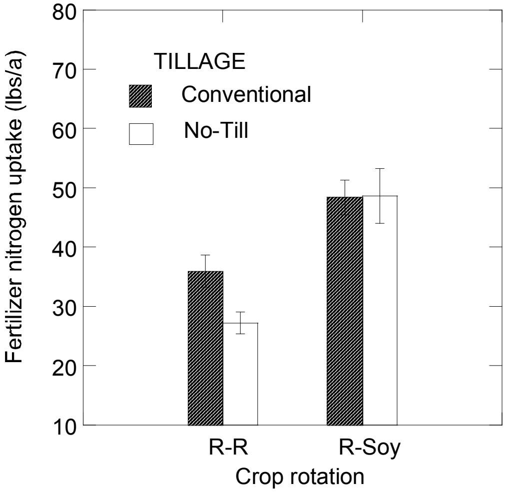

Fig. 1. Fertilizer nitrogen (N) uptake at harvest maturity measured using ^{15}N for conventional- and no-till rice grown in a continuous rice (RR) or rice-soybean rotation (R-Soy) at the University of Arkansas Rice Research and Extension Center in 2003 (bars indicate standard error).

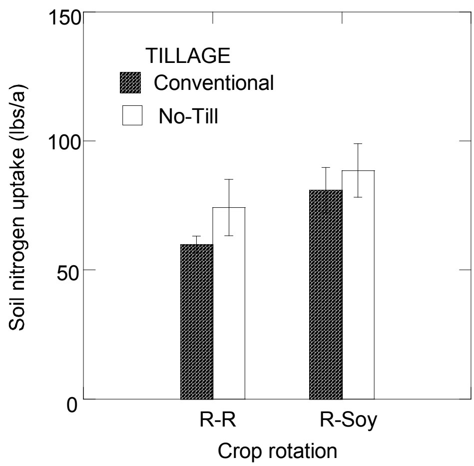

Fig. 2. Soil nitrogen (N) uptake at harvest maturity measured using ^{15}N for conventional- and no-till rice grown in a continuous rice (RR) or rice-soybean rotation (R-Soy) at the University of Arkansas Rice Research and Extension Center in 2003 (bars indicate standard error).

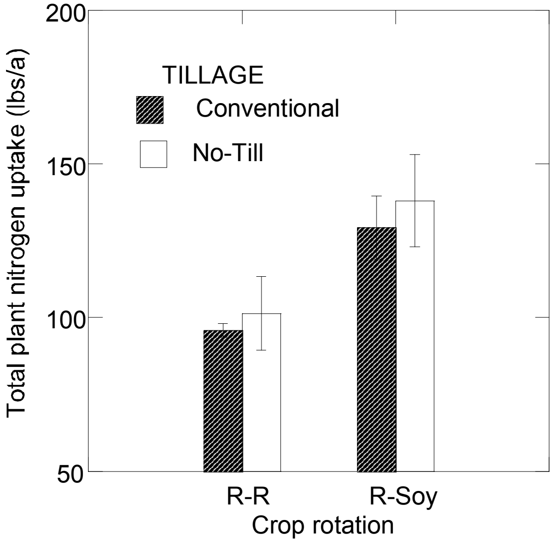

Fig. 3. Total plant nitrogen (N) uptake at maturity measured using [15]N for conventional- and no-till rice grown in a continuous rice (RR) or rice-soybean rotation (R-Soy) at the University of Arkansas Rice Research and Extension Center in 2003 (bars indicate standard error).

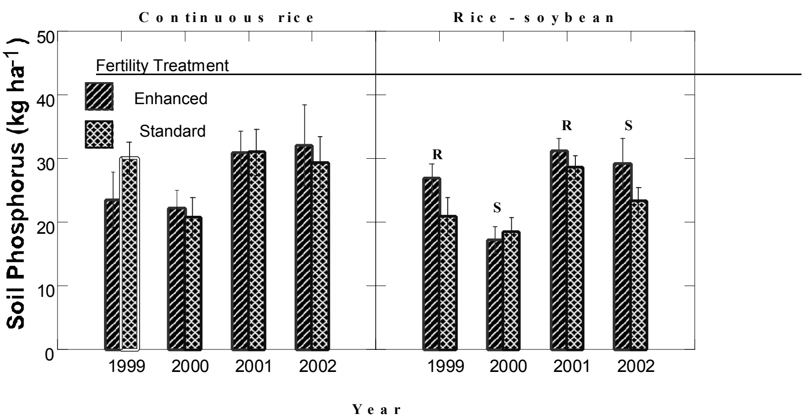

Fig. 4. Soil phosphorus levels (kg/ha) for the continuous rice and rice-soybean (R=rice, S=soybeans) rotations in conventional and no-till plots in 1999, 2000, 2001, and 2002.

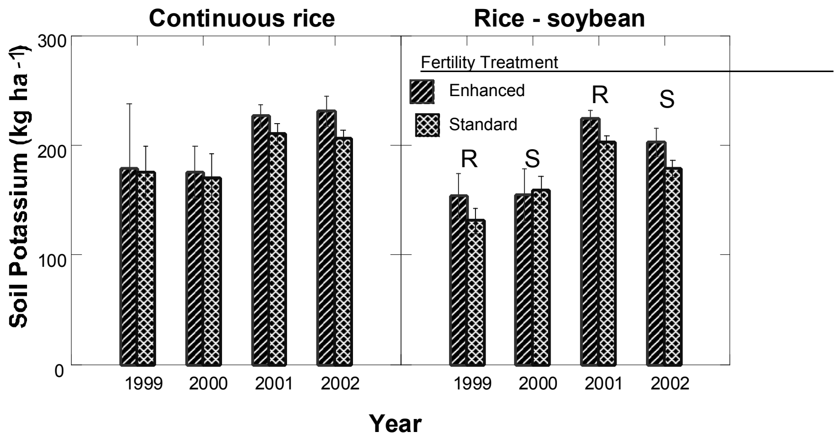

Fig. 5. Soil potassium levels (kg/ha) for the continuous rice and rice-soybean rotations in conventional- and no-till plots in 1999, 2000, 2001, and 2002.

2004 Rice Research Verification Program

J.W. Branson, C.E. Wilson, Jr., T.E. Windham, and J. Marshall

ABSTRACT

The 2004 Rice Research Verification Program (RRVP) was conducted on eleven commercial rice fields across the state. Counties participating in the program during 2004 included Arkansas, Craighead, Chicot, Desha, Independence, Lawrence, Lincoln, Jackson, Mississippi, and Poinsett for a total of 608 acres. Grain yield in the 2004 RRVP averaged 171 bu/acre with a range of 142 to 192 bu/acre. All fields were planted in April and emerged without flushing. The 2004 RRVP average yield was 17 bu/acre greater than the estimated Arkansas state average of 154 bu/acre. The highest-yielding field was in Mississippi County with a grain yield of 192 bu/acre. The lowest-yielding field was in Independence County and produced 142 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 63/71.

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) is to verify the profitability of University of Arkansas recommendations in fields with less than optimal yields or returns.

The goals of the RRVP are: (1) to educate producers on the benefits of utilizing University of Arkansas recommendations to improve yields and/or net returns; (2) to conduct on-farm field trials to verify research-based recommendations; (3) to aid researchers in identifying areas of production that require further study; (4) to improve or refine existing recommendations which contribute to more profitable production; and

(5) to incorporate data from RRVP into extension educational programs at the county and state level. Since 1983, the RRVP has been conducted on 221 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged about 20 bu/acre better than the state average. In 2004, the RRVP recorded an average yield of 171 bu/acre (Table 1). This increase in yields 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. Management decisions are made utilizing integrated pest management philosophy based on current University of Arkansas recommendations. An advisory committee, consisting of extension specialists and university researchers with rice responsibility, assists in decision-making, development of recommendations, and program direction.

Counties participating in the program during 2004 included Arkansas, Craighead, Chicot, Desha, Independence, Lawrence, Lincoln, Jackson, Mississippi, and Poinsett, with a total of 608 acres enrolled in the program. Five varieties were seeded ('Wells', 'Cocodrie', 'Francis', 'CL161', and 'Cheniere') in the eleven fields. University of Arkansas recommendations were used to manage the RRVP fields. Management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. 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 AND DISCUSSION

Yield

The average RRVP yield was 171 bu/acre with a range of 142 to 192 bu/acre (Table 1). The RRVP average yield was 17 bu/acre more than the estimated state yield of 154 bu/acre. The 2004 RRVP average was 1 bu/acre less than the program's highest yield of 172 bu/acre set in 2003 (Table 1). The highest-yielding field was seeded with Wells in Mississippi County and yielded 192 bu/acre. Two fields, Mississippi and Craighead counties, exceeded 190 bu/acre. The lowest-yielding field was also seeded with Wells in Independence County. A significant amount of the preflood nitrogen in Independence County was lost due to inadequate flood conditions. Field size, soil type, and irrigation capacity resulted in parts of the field losing the flood and nitrogen escaping the soil. Plant analysis at 0.5-in. internode elongation showed that parts of the field were significantly deficient in nitrogen. Rice panicle blast was also present in this field and contributed to the low yield.

Milling data were recorded on all of the RRVP fields. The average milling yield for the eleven fields was 63/71 (i.e., head rice / total white rice) with the highest milling yield of 68/74 occurring in Chicot County (Table 1). All fields milled greater than 55/70, which is considered the standard used by the rice milling industry. The lowest-milling field was seeded with Wells in Independence County and milled 56/68 (Table 1). Part of the reason for low head-rice yield in Independence County was rice panicle blast. The average milling in 2004 was 6% higher than the 2003 average of 57/70. The increase of head rice in 2004 may be attributed to the mild temperatures experienced during grain fill.

Planting and Emergence

Dry weather in March and April allowed all RRVP fields to be planted in the optimal time frame. All of the fields were planted from 6 April through 5 May (Table 2). Eighty percent of the Poinsett County location had to be replanted due to a poor stand following an 8-in. rain received four days after planting. An average of 101 lb/acre was seeded in the RRVP fields (Table 2). Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. Rainfall in late April and early May allowed all of the fields to emerge without flushing for germination or herbicide activation. An average of 12 days was required for emergence. Stand density ranged from 9 to 26 plants/ft^2, with an average of 19 plants/ft^2.

Irrigation

Well water was used to irrigate nine of the eleven fields in the 2004 RRVP. Chicot and Independence counties were irrigated with surface water. Four of the eleven fields used multiple inlet (MI) irrigation (Arkansas, Independence, Mississippi, and Poinsett). Flow meters were used in all of the fields (except Lawrence County) to record water usage throughout the growing season and compare MI to conventional flooding. An average of 24.4 acre-in. of water was used across both irrigation methods (Table 2). The fields with MI irrigation averaged 21.2 acre-in. of water compared to 26.5 acre-in. for fields using conventional flooding. Research suggests MI reduces water usage by approximately 25%; however, in 2004 only a 20% reduction was observed. The average water usage from the conventional method was less in 2004 compared to RRVP records over the last few years. This reduction in irrigation may be attributed to the above-average rainfall received from May through July. Chicot, Desha, and Jackson counties received an average of 18 in. of rainfall during this period and Mississippi County received more than 24 in. of rain (Table 2).

Fertilization

Nitrogen recommendations were based on a combination of factors including soil texture and variety requirements. Mid-season nitrogen was applied at 100 lb of urea/acre across all varieties with the exception of Poinsett County (Table 3). Poinsett County received an additional 75 lb/acre of urea at mid-season due to varying plant growth stages following replanting.

Phosphorus (P) was applied in all of the RRVP fields based on soil test results (Table 3). Diammonium phosphate (DAP; 18-46-0) was blended with the preflood nitrogen in Desha, Jackson, and Lincoln counties. The DAP was applied preflood rather than preplant to minimize P being tied up by the soil to allow as much P uptake as possible from the DAP. Potassium and P were blended and applied in Arkansas, Craighead, Independence, and Lawrence counties as a preplant application. In Mississippi County, DAP was inadvertently applied even though the soil test results did not recommend a P application.

Zinc (Zn) was applied in Arkansas, Craighead, and Lawrence counties. The soil test in Craighead County did not call for a Zn treatment; however, the Zn levels were marginal and the field did have a history of Zn problems. A seed treatment was applied and no Zn deficiency was observed during the growing season. Granular Zn was applied to the four fields and no Zn deficiency was observed during the year (Table 3). The average cost of fertilizer across all fields was $57.49 which does not include application costs (Table 4).

Weed Control

In 2004, the average herbicide cost was $48.09 (Table 4). All fields utilized Command for early-season grass control with the exception of Chicot County (Table 5). Heavy rain immediately following planting in Chicot County delayed the Command application and resulted in Stam and Facet being applied postemergence. Two fields (Desha and Jackson counties) did not require a postemergence herbicide application for grass weed control. In both fields, weed pressure was light and Command was activated in a timely manner resulting in excellent and very inexpensive grass weed control.

Jackson County had the most inexpensive weed control program at $23.77/acre (Table 4). Command was applied preemergence and provided excellent control of grass species. The main broadleaf weed was yellow nutsedge and was controlled using Permit at 1 oz/acre applied preflood.

Lincoln and Mississippi counties had the most expensive weed control programs at $63.18 and $55.59, respectively (Table 4). Command at 1.5 pt/acre was applied to both fields, but failed to provide season-long control of grass. Clincher was applied at 15 oz/acre in both fields for the control of grass weed species (Table 5). Permit was applied in Mississippi County for the control of yellow nutsedge, which in part explains the higher-than-average herbicide cost. Storm was applied at 1.5 pt/acre in Lincoln County for the control of hemp sesbania and morningglory species. Aim controls these weeds equally as well as Storm for less money per acre, but windy conditions and adjacent soybean fields prevented an Aim application.

Disease Control

Summers in Arkansas are usually defined by hot and dry weather. This was not the case in most of the RRVP fields in 2004. A prolonged wet and cool June and July in many areas resulted in seven of the eleven fields being treated for sheath blight (Table 6). In some cases sheath blight was a problem late when the rice was starting to head. Quadris was used in Craighead and Lawrence counties due to the problem occurring so late in the season and a reduced rate of 6.4 oz/acre was used and provided excellent control of the disease. Stratego was used in Lincoln County due to sheath blight and a field history of kernel smut. The field was seeded with Francis rice, which is susceptible to kernel smut. In Mississippi County, the full label rate of Stratego (19 oz/acre) was used because the treatment had to be applied early in the season due to the aggressive movement of the disease. In both cases Stratego provided excellent control of both diseases. Disease monitoring studies were established in five of the RRVP fields to evaluate various varieties across the state.

Insect Control

One of the RRVP fields was treated for rice water weevil in 2004 (Desha County; Table 6). Weevil traps were placed in the RRVP in cooperation with Dr. John Bernhardt and Tony Richards. The traps and thresholds are being developed as a more accurate way of scouting for weevils as compared to the leaf-scarring method. Most of the varieties being grown in Arkansas today would require an average of 40 weevils/trap to require treatment. Desha County was treated with Karate at 1.8 oz/acre 7 days following flood establishment. Weevil numbers were as high as 150/trap. Karate provided excellent weevil control and no root damage was observed during the year. Rice stinkbug levels never reached treatment thresholds in any of the RRVP fields. This is in contrast to at least 50% of the RRVP being treated for stinkbugs in 2002 and 2003.

Economic Analysis

This section provides information on the development of estimated production costs for the 2004 RRVP. Records of operations on each field provided the basis for estimating these costs. The field records were compiled by participating county extension faculty, the coordinator of the RRVP, and the producers for each field. Presented in this analysis are specified operating costs, specified ownership costs, and total specified costs for each field (Table 7). Break-even prices for the various cost components and returns above specified expenses at the average 2004 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 (Tables 4 and 7). Actual quantities of all operating inputs were used in this analysis. The average of the actual per-unit prices paid by cooperating producers was used to calculate costs.

Fuel and repair costs for both machinery and irrigation equipment were calculated by Extension models based on averages. Therefore, the producers' actual machinery costs may vary from the machinery cost estimates that are presented in this report. However, the producer's actual field operations were used as a basis for calculations and his equipment size and type were matched as closely as possible. Specified operating costs for the eleven RRVP fields ranged from $186.63/acre for Jackson County to $347.69/acre for Poinsett County with an overall average of $260.41/acre (Table 7).

Land costs incurred by producers participating in the RRVP would likely vary from land ownership, cash rent, or some form of crop-share arrangement. Therefore, a comparison of these divergent cost structures would contribute little to this analysis. For this reason, a 25% crop-share rent was assumed to provide a consistent standard for comparison. This is not meant to imply that this arrangement is normal or that it should be used in place of existing arrangements. It is simply a consistent measure to be used across all RRVP fields. The average break-even price needed to cover total specified costs including an assumed 25% crop share was $1.83/bu (Table 7).

Table 7 includes estimated returns per acre above Total Specified Operating Costs and Total Specified Costs. Costs for risk, overhead, and management are not included. Since land agreements are so variable, it is difficult to figure land costs. However, a break-even price that takes land in consideration is included and ranged from $70.54/acre in Poinsett County to $315.08/acre in Jackson County with an average of $237.70/acre.

On-Farm Research

Research was conducted in many of the verification fields in 2004. Disease-monitoring tests were planted in five fields across the state. This provides researchers with information on how varieties perform under various environmental conditions and different soil types. Hybrid yields ranged from 177 to 243 bu/acre. Wells and Francis also performed well with yields ranging from 168 to 207 bu/acre. Seeding-rate studies were also planted in one of the verification fields. These studies are established to determine the optimal seeding rate for various varieties. Data from this study suggest that seeding rates may be reduced to as little as 67.5 lb/acre without sacrificing yield. Wells was reduced when the seeding rate was dropped to 45 lb/acre. Zinc studies were conducted in 3 RRVP fields to determine the need for Zn on clay soils. No responses were observed in 2004.

Infrared Photography

Infrared photographs were taken during the growing season of each field in the program. 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-truth" 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 possible. However, there may be potential uses for this new technology in the future.

SIGNIFICANCE OF FINDINGS

Data collected from the 2004 RRVP reflect the general trend of increasing rice yields and above-average returns in the 2004 growing season. Analysis of this data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs. The average net returns were enough to cover land and all production costs.

Table 1. Variety, soil series, previous crop, acreage, yield, and milling yield for 2004 RRVP.

County	Variety	Soil series	Previous crop	Acres	Yield	Milling yield[z]
					(bu/acre)	
Arkansas	Wells	Dewitt silt loam	Soybean	90	180	68/73
Chicot	Cocodrie	Perry clay	Corn	53	176	68/74
Craighead 1	Francis	Fountain silt loam	Soybean	14	191	56/71
Craighead 2	Cheniere	Fountain silt loam	Soybean	14	178	63/72
Desha	Wells	Sharkey clay	Soybean	45	177	65/72
Independence	Wells	Dundee silt loam	Corn	67	142	56/68
Jackson	Wells	Dundee silt loam	Soybean	33	175	61/70
Lawrence	Wells	Hillemann silt loam	Soybean	156	167	65/73
Lincoln	Francis	Sharkey clay	Soybean	32	172	62/71
Mississippi	Wells	Sharkey clay	Soybean	68	192	64/75
Poinsett	CL161	Sharkey clay	Soybean	36	150	60/67
Average				58	171	63/71

[z] Head rice / total white rice.

Table 2. Stand density, irrigation, seeding rate, and important dates during the 2004 season.

County	Stand density	Rainfall	Irrigation	Total Rain + Irr	Seeding rate	Planting date	Emergence date	Harvest date
	(plants/ft^2)	(in.)	(acre-in.)	(lb/acre)				
Arkansas	13	11.7	25.2	36.9	103	4-14	4-28	9-10
Chicot	18	18.0	22.3	40.3	78	5-1	5-12	9-12
Craighead 1	17	14.0	35.0	49.0	100	4-6	4-21	9-15
Craighead 2	9	14.0	35.0	49.0	100	4-6	4-20	9-17
Desha	20	20.0	21.0	41.0	112	4-20	5-10	9-16
Independence	23	18.0	22.0	40.0	104	4-15	4-23	8-24
Jackson	26	16.0	21.4	37.4	103	4-15	4-24	8-24
Lawrence	21	21.0	NA	NA	99	4-8	4-23	9-6
Lincoln	21	13.5	25.2	38.7	110	4-23	5-3	9-17
Mississippi	15	24.5	18.1	42.6	112	4-16	4-25	9-2
Poinsett	21	17.2	19.2	36.4	95	5-5	5-20	9-21
Average	19	17.1	24.4	41.1	101	-------	-------	-------

Table 3. Soil test results from RRVP fields and fertility recommendations.

County	pH	P	K	Zn	Nitrogen rate Urea (45%)[z]	Total N Rate	Fertilizer P-K-Zn[y]
		-------(lb/acre) ------			(lb/acre)		
Arkansas	7.5	27	99	1.4	23-230-100	158	60-90-20
Chicot	6.1	20	605	4.4	300-100	180	60-0-0
Craighead 1	7.2	49	199	5.6	23-230-100	158	40-60-5
Craighead 2	6.8	44	221	5.3	23-230-100	158	40-60-5
Desha	7.4	18	358	4.8	300-100	180	46-0-0
Independence	5.3	72	204	4.9	260-100	162	74-111-0
Jackson	6.0	20	266	17.2	230-100	149	23-0-0
Lawrence	5.7	16	124	3.6	230-100	149	20-90-5
Lincoln	7.1	20	452	4.9	300-100	180	46-0-0
Mississippi	5.8	67	322	7.2	27-300-100	192	69-0-0
Poinsett	6.6	39	293	6.5	300-150	202	60-0-0

[z] Flushed at 2 leaf, preflood, and midseason.
[y] P_2O_5-K_2O-Zn includes seed treatments.

Table 4. Selected variable input expense from 2004 RRVP fields.[z]

County	Variety/ hybrid	Input				
		Fertilizer[y]	Herbicides	Fungicides	Insecticides	Irrigation
		($/acre)				
Arkansas	Wells	60.80	33.53	1.50	0	40.57
Chicot	Cocodrie	59.80	45.12	13.07	0	35.90
Craighead 1	Francis	57.42	54.13	12.28	0	56.35
Craighead 2	Cheniere	57.42	54.13	17.28	0	56.35
Desha	Wells	55.20	43.54	0.00	6.08	33.81
Independence	Wells	59.38	53.59	0.00	0	35.42
Jackson	Wells	44.40	23.77	0.00	0	34.45
Lawrence	Wells	51.4	51.15	12.28	0	57.96
Lincoln	Francis	55.20	63.18	19.00	0	40.57
Mississippi	Wells	66.00	55.59	20.90	0	29.14
Poinsett	CL161	65.00	51.34	29.56	0	30.91
Average		57.45	48.09	11.44	0.55	41.33

[z] Does not include all variable costs, such as drying, hauling, equipment repair, etc.
[y] Includes cost for material and application costs for each variable.

Table 5. Herbicide rate and timings for 2004 RRVP fields.[z]

Arkansas	**PRE:** Command (0.8 pt) **POST:** Facet (0.38 lb) Aim (1.6 oz)
Chicot	**POST:** Facet (0.5 lb) Stam (4 qt)
Craighead 1	**PRE:** Glyphosate (1 qt) Command (0.8 pt) **POST:** Facet (0.5 lb) Permit (1 oz)
Craighead 2	**PRE:** Glyphosate (1 qt) Command (0.8 pt) **POST:** Facet (0.5 lb) Permit (1 oz)
Desha	**PRE:** Command (1.5 pt) **POST:** Aim (1.6 oz) Permit (1 oz)
Independence	**PRE:** Command (0.8 pt) **POST:** Facet (0.5 LB) Stam (4 qt)
Jackson	**PRE:** Command (0.8 pt) **POST:** Permit (1 oz)
Lawrence	**PRE:** Command (0.8 pt) **POST:** Aim (1.6 oz) Stam (4 qt) Permit (1 oz)
Lincoln	**PRE:** Command (1.5 pt) **POST:** Clincher (15 oz) Storm (1.5 pt)
Mississippi	**PRE:** Command (1.5 pt) **POST:** Clincher (15 oz) Permit (1 oz)
Poinsett	**PRE:** Command (0.8 pt) Newpath (4 oz) **POST:** Newpath (4 oz) Blazer (0.5 pt)

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

Table 6. Fungicide and insecticide applications in 2004 RRVP fields.

County	Fungicide	Rice water weevil	Rice stink bug
Arkansas	------	------	------
Chicot	4 oz/acre Tilt	------	------
Craighead 1	6.4 oz/acre Quadris	------	------
Craighead 2	9 oz/acre Quadris	------	------
Desha	------	1.85 oz/acre Karate	------
Independence	------	------	------
Jackson	------	------	------
Lawrence	6.4 oz/acre Quadris	------	------
Lincoln	16 oz/acre Stratego	------	------
Mississippi	19 oz/acre Stratego	------	------
Poinsett	34 oz/acre Quilt	------	------

Table 7. Selected economic information from 2004 RRVP.

County	Specified operating costs[z]	Specified ownership costs	Land costs[y]	Total specified costs	Return above specified operating cost[x]	Returns above total specified cost	Breakeven price w/land[w]
	($/acre)						($/bu)
Arkansas	241.66	58.06	144.00	299.72	334.34	276.33	1.66
Chicot	241.69	46.38	140.00	288.07	321.51	275.13	1.64
Craighead 1	288.24	58.19	152.80	346.43	322.96	264.77	1.81
Craighead 2	291.88	58.19	142.40	350.07	277.72	219.53	1.97
Desha	240.69	58.92	141.60	299.61	352.71	266.79	1.69
Independence	233.91	54.15	133.60	288.06	220.49	166.34	2.03
Jackson	186.63	58.29	140.00	244.92	373.37	315.08	1.40
Lawrence	245.93	47.56	133.60	293.49	288.47	240.91	1.76
Lincoln	277.56	52.79	137.60	330.35	272.84	220.05	1.92
Mississippi	268.69	46.42	153.60	315.11	345.71	299.29	1.64
Poinsett	347.69	61.77	120.00	409.46	132.31	70.54	2.72
Average	260.41	54.61	138.18	315.02	292.31	237.70	1.83

[z] Specified variable costs of production (See Table 4 for details).
[y] 25% crop-share rent was assumed.
[x] $3.20/bu settlement price for rough rice.
[w] Price/bu required by producer to equal total costs.

Short-term Impacts of Land Leveling on Soil Physical and Biological Properties In a Clayey Aquert

K.R. Brye

ABSTRACT

Land leveling is considered a water-conservation practice, but is also a severe soil disturbance. The objective of this study was to determine the short-term effects of deep-cut land leveling on physical and biological properties of a clayey soil in northeast Arkansas. Relatively deep-cut land leveling resulted in significantly lower sand and silt contents and significantly higher clay contents and soil bulk densities in the top 4 in. (10 cm). Land leveling also resulted in significantly lower soil fungal biomass concentrations and fungal-to-bacterial biomass ratios, but significantly higher soil bacterial biomass concentrations in the top 4 in. The results of this study demonstrate the significant, potentially negative impacts relatively deep-cut land leveling can have on soil physical and biological properties in a clayey soil. Further, the time required for restoration and/or re-equilibration of soil properties to ranges that do not adversely affect crop production is yet unknown.

INTRODUCTION

In the recent Farm Bill, the United States Congress re-authorized substantial financial assistance in the form of government subsidies to farmers willing to adopt water-conservation practices (USDA, 2002). Land leveling, a relatively common agricultural practice in the south-central United States currently and in recent decades, is considered a water-conservation practice. Land leveling creates a slight, but uniform, slope gradient to facilitate more even distribution of irrigation water and is routinely performed in fields where crops such as rice (*Oryza sativa* L.) and soybean [*Glycine max* (L.) Merr.] are grown.

Though recognized and subsidized as a water-conservation practice, land leveling is a severe soil disturbance. Nearly the entire equilibrium among soil physical, chemical, and biological properties is disrupted during the process of land leveling. For example, land leveling can expose highly acidic subsoil, which becomes the primary rooting medium for subsequent crops, with the likely possibility for development of nutrient deficiencies as well as toxicities (Brye et al., 2004a,b,c). Land leveling can also result in hard-pan migration towards the soil surface that can decrease the volume of soil a subsequent crop is grown in by as much as 25% (Brye et al., 2005). Ascertaining the degree to which soil properties change, both in magnitude and spatially, and how a subsequent crop will respond to altered and potentially more variable soil properties will improve management capabilities to ensure maximal or near-maximal production from graded fields. Therefore, the objective of this study was to determine the short-term effects of deep-cut land leveling on physical and biological properties of a clayey soil in northeast Arkansas.

PROCEDURES

Site Description and Experimental Design

A 12-acre (4.9-ha) field, previously cropped to soybean, on Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquert) at the Northeast Research and Extension Center (NEREC), Keiser, Ark., that was scheduled to be land-leveled in spring 2004 was chosen as the study site. 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 approximately one-half of the field to be land-leveled. Each study area contained a 50-point grid system with sampling points spaced evenly 10 m apart.

Study Site Manipulations

Land-leveling activities began on 18 April and were completed on 20 April 2004. Following initial land-leveling activities, the entire field was disked and land-planed numerous times to reduce soil clod size to an approximate diameter of <2 cm.

Measurements and Sample Collection

Immediately prior to (17 April) and following land leveling (29 and 30 April), relative elevation was measured and soil samples were collected from the top 4 in. (10 cm) at each of the 50 grid points in each study area to characterize elevational and soil physical and biological property changes as a result of land leveling. Elevational changes were measured using a laser level and stadia rod. A single 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 bulk-density determination. 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 hydrometer method (Arshad et al., 1996). A second set of samples consisting of 10, 0.8-in. (2-cm)-diameter soil cores was collected and composited from the 0- to 4-in. depth from within an 8-in. radius surrounding each grid point. Samples were kept cool and sent to the Soil Foodweb (Soil Foodweb, Inc., Corvallis, Ore.) for total fungal (Ingham and Klein, 1984) and bacterial (Babiuk and Paul, 1970) biomass determinations.

Statistical Analyses

Paired *t*-tests were performed to determine the effect of land leveling on soil bulk density, particle-size fractions, bacterial and fungal biomass concentrations, and fungal-to-bacterial biomass ratios (Minitab Version 13.31, Minitab Inc., State College, Pa.). Linear correlations were performed between pre- and post-leveling soil properties. Homogeneity of variance was also evaluated using Levene's test (Minitab).

RESULTS AND DISCUSSION

Soil Physical Properties

Land leveling, whether shallow or deep, represents a significant and severe form of soil disturbance (Brye et al., 2004a). The immediate disruption of a previous quasi-equilibrium that land-leveling activities impart on the soil can have lasting negative effects on soil properties (Brye et al., 2003, 2004a, 2005) and crop production, particularly for rice and soybean (Brye et al., 2004b,c), that are not easily reversed with additional fertilizers.

In this study, land leveling resulted in an average elevational change of -0.35 ft, ranging from +0.19 (i.e., a fill) to -0.95 ft (i.e., a cut), across the two study areas. Consequently, land leveling significantly affected the magnitude and spatial variability of selected soil physical and biological properties.

On average, land leveling resulted in significantly less ($P < 0.05$) sand and silt, and significantly more ($P < 0.001$) clay, in the top 4 in. of both study areas (Table 1). However, the surface soil texture did not change dramatically. Increasing the soil surface clay content will likely decrease the soil surface hydraulic conductivity and infiltration capacity, which will not be an issue for rice production, but would likely be a major water-management issue for soybean if grown in rotation with rice since soybean is a crop that is relatively sensitive to water-logging and prolonged soil wetness (Griffin and Saxton, 1988; Scott et al., 1989; Oosterhuis et al., 1990; Scott et al., 1990; Linkemer et al., 1998). Depending on the study area, land leveling also resulted in significantly greater variability in sand, silt, and clay percentages (Table 1).

In addition to altering soil-particle size distributions, land leveling resulted in significantly higher ($P < 0.001$) average soil bulk densities in the top 4 in. in both study areas (Table 1). Increased soil bulk density occurs as a result of soil compaction and compaction has been shown to negatively affect seedling emergence capability, soil water storage, crop water-use efficiency, crop growth characteristics, yield, nutrient uptake, and root development and distribution (Brye et al., 2005). In this study, the resulting higher soil bulk densities following land leveling did not exceed what would be considered root-limiting (i.e., 1.6 g cm^{-3}). Similar to soil particle-size distributions, land leveling resulted in significantly greater variability in soil bulk density in one study area, but not the other (Table 1).

Pre-leveling soil bulk density, sand, silt, and clay percentages, bacterial biomass concentration, and fungal-to-bacterial biomass ratio in one study area or both were significantly positively correlated ($P < 0.05$; $0.31 < r < 0.66$) with their post-leveling values. This result indicates that a soil property in a given location that was particularly high in magnitude prior to land leveling retained a relatively high magnitude and that a soil property in a given location that was particularly low in magnitude prior to land leveling retained a relatively low magnitude following land leveling. This result also indicates that the immediate effects of land leveling may be predictable. Pre-leveling fungal bacterial biomass concentration was not correlated with post-leveling values in either study area indicating that the changes in fungal biomass induced by land leveling are unpredictable.

Soil Biological Properties

Soil microorganisms are important for maintaining good soil tilth due to their role in decomposition of organic matter and nutrient cycling and storage, and potentially represent a very sensitive biological marker (Turco et al., 1994). Since the combined populations of fungi and bacteria represent a large fraction of the total soil microbial biomass, changes in land management or disturbance of the soil profile from land leveling should be reflected in the population ratio of soil fungi and bacteria (Bardgett et al., 1996).

Similar to soil physical properties, land leveling significantly altered the magnitudes and variability of selected soil biological properties. In this study, land leveling resulted in significantly lower ($P < 0.001$) fungal biomass concentrations and lower fungal-to-bacterial biomass concentration ratios in both study areas (Table 1). In addition, bacterial biomass concentrations were significantly higher ($P < 0.001$) following land leveling in one study area, but not the other (Table 1). Similar to soil physical properties, land leveling resulted in significantly greater variability in soil biological properties following land leveling, with the exception of the fungal-to-bacterial biomass concentration ratio at one location, in which land leveling resulted in significantly lower variability (Table 1).

SIGNIFICANCE OF FINDINGS

Soil physical, chemical, and biological properties collectively affect crop productivity. The results of this study demonstrate the significant potentially negative impacts relatively deep-cut land leveling can have on soil physical and biological properties in a clayey soil. The time required for restoration and/or re-equilibration of soil properties to ranges that do not adversely affect crop production is yet unknown. Further research is necessary to ascertain potential long-lasting effects of land leveling and their impacts on subsequent crop production. In addition, further research is necessary to evaluate potential soil-management practices, such as deep-tillage and poultry litter, that may facilitate expeditious recovery of soil properties following land leveling.

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Table 1. Effect of land-leveling on soil physical and biological properties in the top 4 in. of a clayey Aquert. Mean values are reported with standard errors in parentheses. The change in coefficient of variation (CV) is also reported.

	Study area 1				Study area 2			
Soil parameter	Homogeneity of variance	Pre-leveling	Post-leveling[z]	ΔCV^y	Homogeneity of variance	Pre-leveling	Post-leveling[z]	ΔCV^y
	(P-value)			(%)	(P-value)			(%)
Physical property								
Bulk density (g cm^{-3})	0.278	1.12 (0.01)	1.25 (0.01)**	-15.8	<0.001	1.18 (0.01)	1.44 (0.02)**	82.9
Sand (%)	0.416	21.2 (0.5)	18.2 (0.5)**	23.0	0.009	32.0 (0.7)	28.4 (1.1)**	73.9
Silt (%)	0.004	23.6 (0.1)	21.2 (0.2)**	102	0.093	22.6 (0.2)	21.9 (0.3)*	42.8
Clay (%)	0.918	55.2 (0.5)	60.6 (0.6)**	7.4	0.002	45.4 (0.6)	49.7 (1)**	67.
Biological property								
Bacterial biomass (μg g^{-1})	0.181	828 (51)	732 (71)	56.2	< 0.001	797 (38)	1985 (145)**	54.2
Fungal biomass (μg g^{-1})	< 0.001	53.1 (3.4)	21.0 (1.7)**	24.5	0.05	70.9 (6)	33.2 (4)**	32.3
Fungal-to-bacterial-biomass ratio	0.013	0.09 (0.01)	0.04 (<0.01)**	-13.4	< 0.001	0.10 (0.01)	0.02 (<0.01)**	59.7

[z] Asterisks next to post-leveling means represent significant differences (* 0.05 $P > 0.01$; ** P 0.001) between pre- and post-leveling measurements caused by land leveling.

[y] Calculated from ($[CV_{post}-CV_{pre}]/CV_{pre}$ x100).

Evaluation of Several Indices of Potentially Mineralizable Soil Nitrogen on Arkansas Silt Loam Rice Soils

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

ABSTRACT

A nitrogen (N) soil test that predicts N mineralization in rice soils has long eluded researchers. Over the years numerous methods have been proposed, but no one method has been widely accepted. Incubation indices have been shown to be the most reliable methods for predicting N mineralization and are often used as standards in mineralization studies. The objective of this study was to compare proposed analytical methods for predicting N mineralization with the NH_4^+-N mineralized after a 14 d anaerobic incubation on Arkansas silt loam rice soils. The proposed methods were: i.) acid oxidation, ii.) ultraviolet absorbance of NO_3^- reduced and unreduced soil extracts, and iii.) diffusion of amino sugar-N using the Illinois Soil N Test. Linear regression models revealed that the acid oxidation procedure, the ultraviolet absorbance of NO_3^- unreduced soil extracts, and the diffusion of amino sugar-N using the Illinois Soil N Test all accurately predicted the NH_4^+-N mineralized after a 14 d anaerobic incubation. In conclusion, if the 14 d anaerobic incubation procedure is a reliable indicator of N uptake in rice, then it can be assumed the aforementioned methods should accurately predict N mineralization in the field.

INTRODUCTION

A reliable N soil test that accurately predicts N mineralization in rice soils has long been sought. Currently, N fertilizer recommendations are based upon crop/cultivar need, soil texture, and/or previous crop and do not take into account the N mineralized from the soil organic fraction. Not taking into account the N mineralization of the soil organic fraction can lead to over- and under-N fertilization. It is known that under-fertilizing with N can decrease rice grain yields, however, over-fertilizing with N can decrease yields due to increases in disease, mutual shading, and lodging. In addition, over-fertilizing with N increases fertilizer and application costs and could potentially contaminate nearby surfacewater and groundwater.

Over the years, numerous methods have been proposed, but no one method has been widely accepted. Biological or incubation studies have been shown to have the highest correlation with N uptake in field studies, however, the time needed for incubation does not lend them to be practical for soil testing use. Wilson et al. (1994a) observed that a 14 d anaerobic incubation accurately predicted N uptake in greenhouse-grown rice. Other researchers have evaluated quick analytical procedures that utilize some form of a chemical reaction to predict N mineralization. Procedures of interest are acid oxidation (Stanford and Smith,1978; Wilson et al., 1994a,b), ultraviolet (UV) absorption of soils extracted with a mild salt (Fox and Piekielek 1978; Hong et al., 1990), and diffusion of amino sugar-N (Mulvaney et al., 2001; Khan et al., 2001).

The objective of this study was to compare the aforementioned analytical methods for predicting N mineralization with the NH_4^+-N mineralized after a 14 d anaerobic incubation utilizing Arkansas silt loam rice soils.

PROCEDURES

Sixteen silt-loam soil samples were collected from the rice-growing region of Arkansas (Table 1). Samples were initially oven-dried and crushed to pass a 2-mm sieve. The anaerobic-incubation (AI) procedure, which acted as the standard in this study, was carried out by incubating the soils anaerobically for 14 d at 40°C. After incubation, the NH_4^+-N concentration was determined using steam distillation techniques. The acid oxidation (ACOX) was conducted according to the modified method of Stanford and Smith (1978) proposed by Wilson et al. (1994a,b). The diffusion of amino sugar-N method was conducted according to the Illinois Soil N Test (ISNT) proposed by Khan et al. (2001). The UV methods were conducted by extracting the soil with 1 *M* KCl. Absorbance values of NO_3^- unreduced extractions were then measured at 260 nm (NU260). Absorbance values of NO_3^- reduced extractions, which were reduced according to Norman and Stucki (1981), were also measured at 210 nm (NR210) and 260 nm (NR260). Simple linear regressions were utilized to determine which method most accurately predicted the NH_4^+-N mineralized after a 14 d anaerobic incubation.

RESULTS AND DISCUSSION

For all analytical methods evaluated, significant relationships were observed with the anaerobic incubation procedure (Table 2). However, some methods performed better than others. The ACOX method performed the best of all methods evaluated, by displaying a coefficient of determination of 0.83 (Fig. 1). The NU260 method performed fairly well with a coefficient of determination of 0.63 (Fig. 2). However, the NR210 and the NR260 methods displayed unacceptably low coefficients of determination (R^2 = 0.48 and 0.38, respectively). This may be attributed to the reducing agent not giving a consistent blank. It was observed that the ISNT method also accurately predicted anaerobic incubation values with a coefficient of determination of 0.71 (Fig. 3).

SIGNIFICANCE OF FINDINGS

If the concentration of NH_4^+-N mineralized after a 14 d anaerobic incubation is a reliable indicator of N uptake in field-grown rice, then it can be assumed that the ACOX, NU260, and the ISNT methods for predicting N mineralization should accurately predict N mineralization in the field.

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Table 1. Characterization of 16 soils utilized.

Soil	Series	pH	Organic C	Total N	NH_4^+-N	NO_3^-N
			---------- (g/kg) ----------		--------- (mg/kg) --------	
1	Dewitt	6.2	12.2	0.9	3.38	0.35
2	Dewitt	6.1	11.2	0.8	2.29	0.23
3	Dewitt	6.2	11.0	0.9	1.79	0.16
4	Dewitt	6.3	10.7	0.9	0.98	0.16
5	Tichnor	5.9	13.0	1.2	3.28	0.61
6	Tichnor	5.5	13.5	1.2	3.46	1.09
7	Calhoun	6.2	15.8	1.0	2.42	0.84
8	Calloway	7.5	13.2	0.9	3.82	0.98
9	Muskogee	6.8	11.7	0.8	4.86	0.16
10	Commerce	6.3	14.4	1.2	6.55	0.75
11	Commerce	6.8	12.2	1.0	3.64	0.18
12	Henry	6.0	12.3	1.4	8.66	0.50
13	Calhoun	6.9	5.0	0.8	5.67	0.24
14	Dewitt	7.5	6.0	0.9	7.98	0.31
15	Dewitt	7.1	2.7	0.7	1.82	2.99
16	Pembroke	6.2	14.8	1.5	13.88	0.21

Table 2. Linear regression equations for 5 analytical methods compared to NH_4^+-N mineralized after a 14 d anaerobic incubation.

Model[z]	*P* value	R^2	Slope	Intercept
AI vs. ACOX	<0.0001	0.83	2.00	-46.05
AI vs. NU260	0.0002	0.63	317.46	44.29
AI vs. NR210	0.0030	0.48	613.86	41.51
AI vs. NR260	0.0109	0.38	1371.94	49.00
AI vs. ISNT	<0.0001	0.71	0.64	-16.56

[z] AI = anaerobic incubation; ACOX = acid oxidation method; NU260 = unreduced soil extracts measured at 260 nm; NR210 = reduced soil extracts measured at 210 nm; NR260 = reduced soil extracts measured at 260 nm; and ISNT = Illinois Soil N Test.

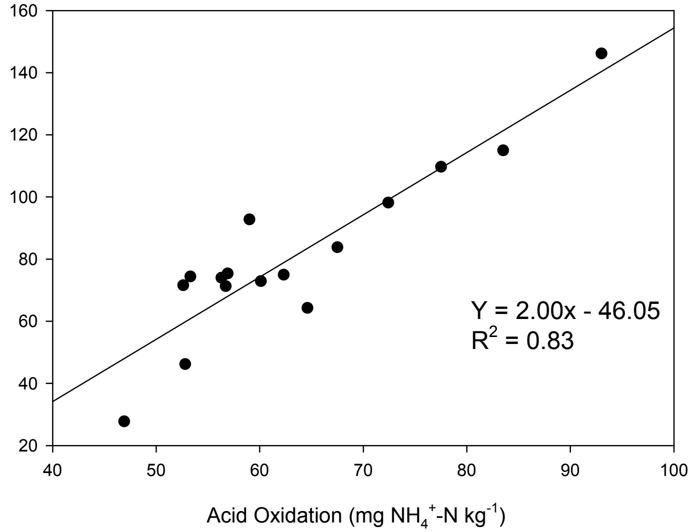

Fig. 1. Comparison of acid oxidation procedure and anaerobic incubation procedures.

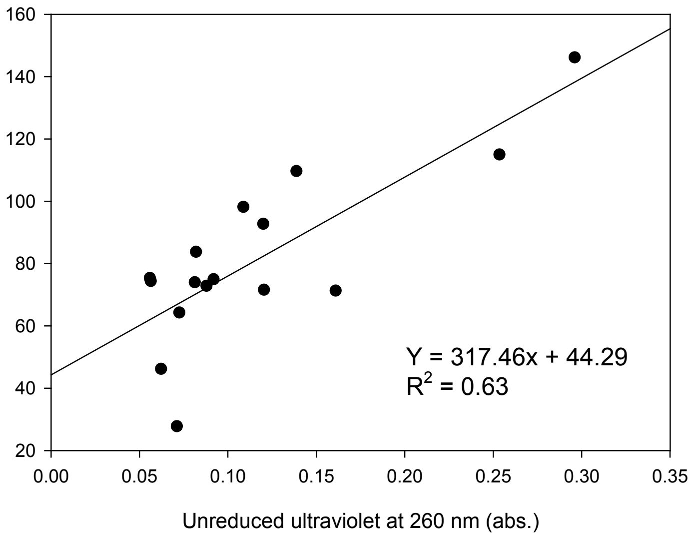

Fig. 2. Comparison of ultraviolet absorbance of NO_3, unreduced soil extracts, and anaerobic incubation procedures.

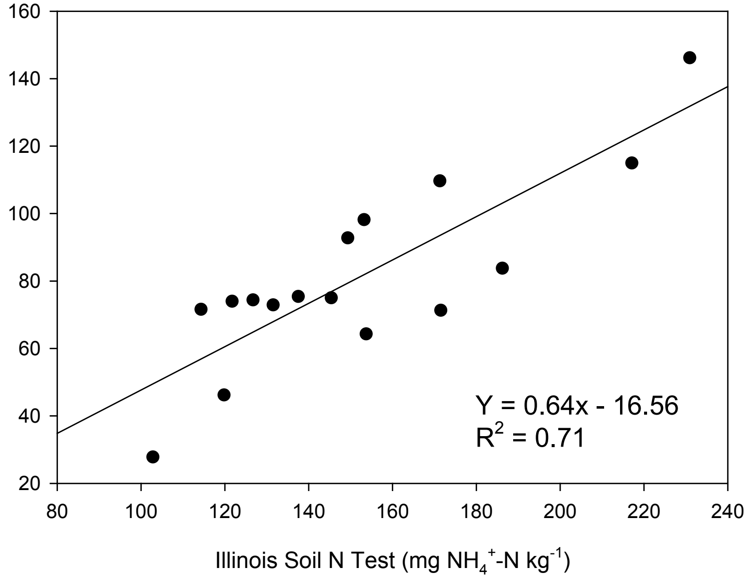

Fig. 3. Comparison of the Illinois soil-N test method and anaerobic incubation procedures.

Ammonia Volatilization and Grain Yield by Delayed Flood Rice Utilizing Conventional and Conservation Tillage Practices

B.R. Griggs, R.J. Norman, C.E. Wilson, Jr., and N.A. Slaton

ABSTRACT

Conservation tillage has become increasingly popular among Arkansas rice growers, and no research has been conducted to determine the influence this tillage practice has on ammonia (NH_3) volatilization loss, especially when the permanent flood is not achieved in a timely manner. Field studies were conducted in 2000 and 2001 on a clay and silt loam soil utilizing both stale-seedbed and conventional tillage practices. Urea and ammonium sulfate (2 atom % ^{15}N) were applied 14 days preflood and urea 1 day preflood at four rates. Ammonia volatilization was measured for 21 days and plant and soil samples were collected for total dry matter, fertilizer and total N uptake at 50% heading, and grain yield at physiological maturity. During 2000, NH_3 volatilization was greatest on the silt loam soil (22%) compared to the clay soil (14%) when urea was applied 14 days preflood with no significant differences between tillage practices. In 2001, NH_3 volatilization of urea-N applied to stale-seedbed rice (32%) was significantly greater compared to conventional-till rice (24%) on the silt loam soil. During both years and at both locations, losses via NH_3 volatilization from ammonium sulfate were <7%. When urea-N was applied 14 days preflood, grain yields were significantly lower compared to urea applied 1 day preflood or ammonium sulfate applied 14 days preflood.

INTRODUCTION

Conservation tillage practices have become increasingly popular in southern U.S. rice culture due to the cost savings and flexibility in planting that they afford growers. However, little research has been conducted to assess nitrogen (N) efficiency or ammonia

(NH_3) volatilization losses in conservation-till rice. Nitrogen fertilizer is typically applied to delayed flood rice in two applications with 75 to 150 lb N/acre applied preflood at the 4- to 5-leaf stage, followed by 30 to 60 lb N/acre applied between panicle initiation and differentiation, depending on variety, soil, and previous crop. When rice is grown utilizing a stale-seedbed tillage system where a substantial amount of weedy residue is present, an additional 10 lb N/acre of fertilizer is currently recommended in Arkansas to compensate for N lost via NH_3 volatilization and to accommodate decomposition of the residue (Slaton, 2001). Urea is the N-fertilizer source generally preferred by growers compared to ammonium sulfate because urea is less expensive and application costs are lower due to the higher N analysis of urea. However, urea-N is more susceptible to losses via NH_3 volatilization than ammonium sulfate (Mikkelsen, 1987). Commercial rice fields require from a few days to a few weeks to achieve a permanent flood, depending upon the pumping capacity and size of the field (Slaton, 2001). In situations where a permanent flood cannot be achieved in a timely manner, urea-N may remain at or near the soil surface where significant N losses via ammonia volatilization can occur. The objectives of this study were to determine the influence of tillage, N source, N rate, and application time on NH_3 volatilization losses, and subsequent differences in grain yields of rice grown on a silt loam and clay soil.

PROCEDURES

The field experiment was conducted at two locations, the Southeast Research Extension Center (SEREC), Rohwer, Ark., on a Perry clay (very fine, smectitic, thermic Chromic Epiaquerts), and at the University of Arkansas Rice Research Extension Center (RREC), Stuttgart Ark., on a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualf), during the 2000 and 2001 growing seasons. Weeds were controlled in the stale-seedbed rice with a single application of Roundup® at a rate of 1.0 lb ai/acre a few weeks prior to planting. 'Cocodrie' rice was drill-seeded into both conventional-tilled and stale-seedbed soils on 1 May 2000 at the SEREC and on 17 May 2000 and 6 June 2001 at the RREC, at a rate of 110 lb/acre with 7-in. row spacing. Micro-plots containing four rows of rice were established by driving galvanized steel collars approximately 6 in. into the soil just prior to fertilizer-N application to prohibit lateral movement of fertilizer-N with the flood water. Urea and ammonium sulfate were broadcast by hand at rates of 0 (control), 75, 150, and 225 lb N/acre 14 days prior to flooding and urea 1 day prior to flooding. The 14-day preflood applications were made on 16 May in 2000 at the SEREC and 6 June 2000 and 26 June 2001 at the RREC. The N-fertilizer sources were ^{15}N-labeled urea (46% N, 2.365 atom % ^{15}N in 2000 and 2.67 atom % ^{15}N in 2001) and ammonium sulfate (21% N, 2.413 atom% ^{15}N in 2000 and 2.32 atom ^{15}N% in 2001).

Ammonia volatilization was measured for 21 days following the 14-day preflood N-fertilizer application for the 150 lb N/acre rate at both the RREC and the SEREC. Two rows of rice were hand-harvested at physiological maturity on 14 August 2000 at SEREC and on 24 August 2000 and 11 September 2001 at RREC for grain yields.

In 2001, research plots at the SEREC received in excess of 5.2 in. of rainfall during a single rainfall event 6 days after the 14-day preflood N-fertilizer application. Consequently, the plots were essentially flooded at that time and ammonia volatilization ceased. This also negated the 1-day preflood application of urea onto dry soil. Because of the aforementioned, the site was abandoned and no data were collected from the SEREC location in 2001.

The experimental design was a randomized complete block with a split-plot 3 (application time / N source) by 4 (N rates) factorial arrangement with four replications. The main plot consisted of two tillage practices (conventional and stale-seedbed). Differences among means were compared by using the Fisher's protected least significant difference (LSD) procedure at the 0.05 probability level.

RESULTS AND DISCUSSION

Ammonia Volatilization

Losses via NH_3 volatilization on the clay soil at the SEREC were greatest when urea was applied 14 days preflood to the stale-seedbed rice, but were not significantly different from conventional till (Fig. 1A). Cumulative NH_3 volatilization losses from urea-N showed significant gradual increases with time for both stale-seedbed and conventional-tilled rice until the permanent flood was applied on 30 May. Approximately 11% of the applied urea-N was lost via NH_3 volatilization during the first 14 days after fertilizer application. Unlike the silt loam soil at the RREC, NH_3 volatilization did not cease on the clay soil after the flood was applied (Fig. 1A and 1B). This most likely indicates that on the clay soil the flood water does not incorporate the N fertilizer as readily or as deeply as on a silt loam soil. Total NH_3 volatilization losses from urea-N at the end of the 21 days averaged 14% regardless of tillage practice utilized. When ammonium sulfate was applied 14 days preflood, losses via NH_3 volatilization followed the same trend as those for urea, but to a lesser degree. Losses of ammonium sulfate-N from stale seedbed rice were not significantly greater than those from conventional-tilled rice and averaged >4% of the applied N when the flood was applied and 7% 1 week later.

In 2000 at the RREC, urea-N lost via NH_3 volatilization was greatest during the first 7 days, accounting for over 17% of the applied N regardless of tillage practice utilized (Fig. 1B). When the flood was established 7 days later, 19% of the urea-N had been lost via NH_3 volatilization with little additional loss afterwards. When compared to N losses via NH_3 volatilization at the SEREC (Fig. 1A), 5% more of the applied urea-N was lost at the RREC due at least in part to the higher buffer capacity of the clay soil and warmer temperatures when measurements were taken at the RREC. Total losses of ammonium sulfate-N via NH_3 volatilization averaged 1.4% of the applied N regardless of whether applied to stale-seedbed or conventional-tilled rice and had essentially ceased between 3 and 7 days after application. When compared to losses of ammonium sulfate-N from the clay soil at the SEREC (7% of applied N), NH_3 volatilization losses at the RREC (1.4% of applied N) were much less and can most likely be attributed to the lower soil pH at the RREC (4.9) compared to the pH at the SEREC (6.6) as well as continued NH_3 volatilization after flood application at the SEREC.

In 2001 at the RREC, continuous late spring rains resulted in a later planting date (6 June) and greater daily high temperatures, which resulted in greater urea-N losses during the first 3 days after fertilizer application (Fig. 1C). After day 7, losses of urea-N via NH_3 volatilization from stale-seedbed rice increased significantly until the permanent flood was applied, while volatilization losses from conventional-tilled rice showed no further significant increases after day 7. This may indicate that some of the applied urea landed on weedy residue where it would not be in contact with the soil, be buffered by the soil CEC after hydrolysis, or be incorporated into the soil with the floodwater. Total NH_3 volatilization losses from urea-N applied to the stale-seedbed (31% of applied N) were significantly greater compared to when urea was applied to a conventional-tilled soil (25% of applied N). The majority of N loss from ammonium sulfate in 2001 via NH_3 volatilization occurred by day 3, after which there were no further significant increases. Total N losses from ammonium sulfate accounted for 5% of the applied N regardless of whether applied to stale-seedbed or conventional-tilled rice

Grain Yields

Differences in grain yield between stale-seedbed and conventional-tilled rice were not statistically significant (data not shown). However, the N rate × N source/application time interaction was statistically significant at the SEREC in 2000 and at the RREC in 2000 and 2001 (Table 1). Grain yields reflected trends observed from fertilizer and total N uptake influenced by NH_3 volatilization with the greatest grain yields at the SEREC and RREC in 2000 measured when urea was applied 1 day preflood and ammonium sulfate was applied 14 days preflood, which were not statistically different. When urea was applied 1 day preflood and ammonium sulfate 14 days preflood, grain yields increased significantly with additional N up to the 150 lb N/acre rate, after which continued increases were not statistically significant. Grain yields were significantly lower when urea was applied 14 days preflood compared to urea applied 1 day preflood and ammonium sulfate applied 14 days preflood. This lower yield is a result of greater NH_3 volatilization and subsequent lower fertilizer and total N uptake when urea was applied 14 days preflood. As a result, significant increases in grain yield with increased N were recorded up to the 225 lb N/acre rate when urea was applied 14 days preflood, indicating that yield potentials had not yet been maximized. When the N rate was increased to 150 and 225 lb N/acre, grain yields from urea applied 14 days preflood were not significantly different from grain yields for ammonium sulfate applied 14 days preflood or urea applied 1 day preflood at the 75 and 150 lb N/acre rates, respectively. This signifies that the application of higher rates of urea-N was compensating to a limited degree for the N losses attributed to NH_3 volatilization when urea was applied 14 days preflood.

Greater losses via NH_3 volatilization in 2001 compared to 2000 for urea and ammonium sulfate applied 14 days preflood (Fig. 1B and 1C) resulted in lower N uptake (data not shown) and thus, overall lower grain yields in 2001 for these treatments at the 75 and 150 lb N/acre rates (Table 1). Otherwise, the grain yields at the RREC in 2001 exhibited similar trends to what was observed in 2000. Grain yields from urea applied 1 day preflood tended to not be significantly greater compared to ammonium sulfate applied 14 days preflood. In addition, grain yields from both urea applied 1 day preflood and ammonium sulfate 14 days preflood increased significantly with additional N up to the 150 lb N/acre rate, after which there was no continued response to additional N. Similar to at the RREC and SEREC in 2000, grain yields from urea applied 14 days preflood were significantly lower than those for both urea applied 1 day preflood and ammonium sulfate applied 14 days preflood and continued to increase significantly up to the 225 lb N/acre rate. This indicates that the effect of N losses via NH_3 volatilization that resulted in the lower N uptake and ultimately lower yield when urea was applied 14 days preflood can be compensated for with additional urea-N application, but large amounts of N may need to be applied. The most prudent compensation would be to use ammonium sulfate or Agrotain if a permanent flood cannot be attained in a timely manner (Norman et al., 2004).

SIGNIFICANCE OF FINDINGS

Ammonia volatilization was greatest on the silt loam soil compared to the clay soil and the majority of N losses occurred within the first 7 to 10 days after urea application. In order to minimize NH_3 volatilization losses, it is critical that the permanent flood be applied within 3 days after urea application. If a silt loam field cannot be flooded in less than 3 days, then additional urea-N will be necessary to compensate for NH_3 volatilization losses or an alternative N source less susceptible to NH_3 volatilization, such as ammonium sulfate or Agrotain, should be utilized. When urea was applied to a clay soil, NH_3 volatilization was slower and this should allow the grower 7 to 10 days to establish the permanent flood before losses exceed 10% of the applied N. However, as evidenced in this study, NH_3 volatilization did not appear to necessarily cease when the permanent flood was applied to the clay soil, indicating that the fertilizer N may not be incorporated deeply enough. Further research is necessary to determine the depth to which fertilizer N is incorporated with the floodwater on clay soils. If a substantial amount of the fertilizer N remains within the top 0.5 in. or so of the soil, it may diffuse into the floodwater or into the oxidized zone at the soil-water interface where it would be subject to NH_3 volatilization or nitrification/denitrification, respectively.

ACKNOWLEDGMENTS

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Table 1. Influence of fertilizer-N rate and N source (urea and ammonium sulfate (AS) /application time (averaged across tillage treatments) on rice grain yield on a silt loam soil at the Rice Research Extension Center (RREC) and a clay soil at the Southeast Research Extension Center (SEREC).

	Grain yield								
	SEREC			RREC					
	2000			2000			2001		
N rate	AS 14 d[z] preflood	Urea 14 d preflood	Urea 1 d preflood	AS 14 d preflood	Urea 14 d preflood	Urea 1 d preflood	AS 14 d preflood	Urea 14 d preflood	Urea 1 d preflood
(lb N/acre)	(lb/acre)								
0		3491			3618			3258	
75	5750	4911	5761	6808	5879	6981	5181	4627	5796
150	7660	6068	8038	8181	6732	8387	7716	6268	8002
225	8278	7258	8447	8024	7414	8149	7929	7046	7987
LSD(0.05)[y]		845			575			651	

[z] d = days.

[y] LSD(0.05) = least significant difference for the N rate × N source/application time treatment interaction for grain yield at the 0.05 probability level.

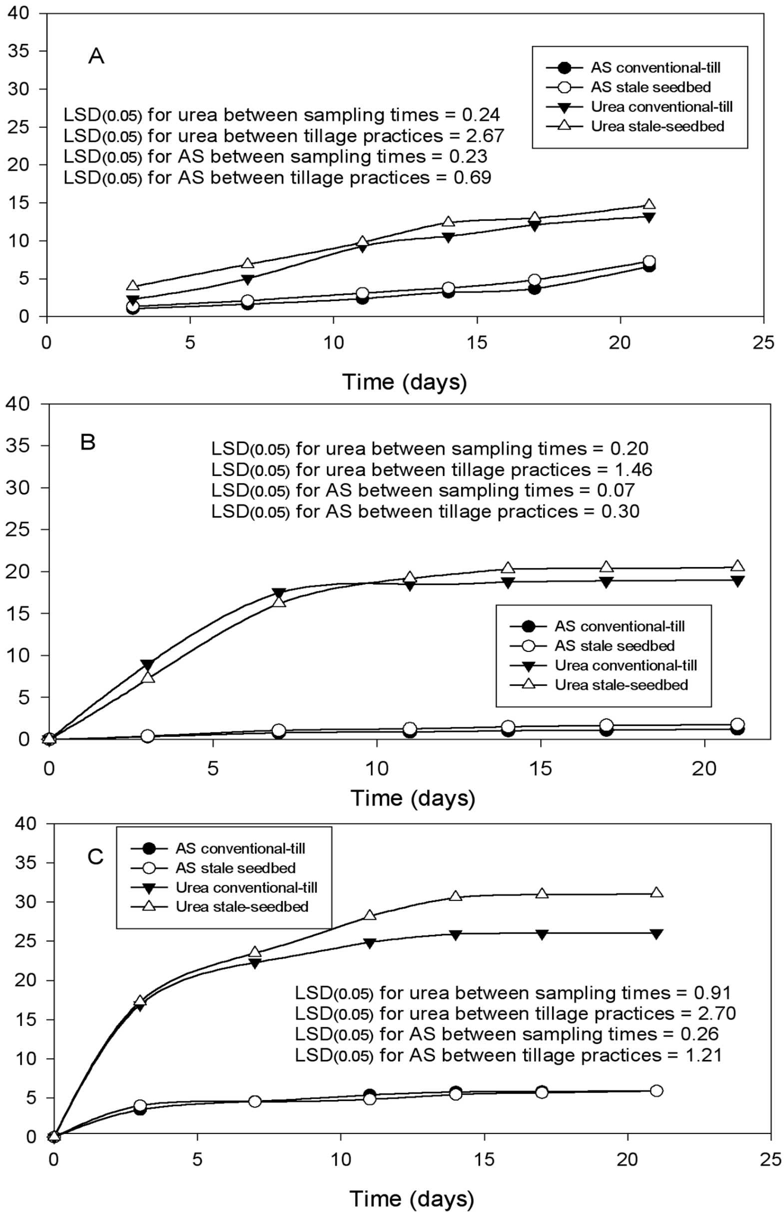

Fig. 1. Cumulative NH_3 volatilization losses from urea and ammonium sulfate (AS) applied to stale seedbed and conventional-till rice 14 days preflood at a rate of 150 lb N/acre at the SEREC in 2000 (A) and the RREC in 2000 (B) and 2001 (C).

A Comparison of Helena Chemical's Two CoRoN Liquid N Sources to Urea for Use at Midseason in Drill-Seeded, Delayed-Flood Rice

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

ABSTRACT

Studies were conducted in 2002 and 2003 to compare Helena Chemical's two CoRoN liquid N sources, HM9310 and HM0108, applied at low rates to the standard N rate and source, urea, normally used at midseason in rice. Rice-yield response to midseason N was only observed at the lowest preflood N rates applied in 2002 and 2003. Neither of the experimental N sources, HM9310 or HM0108, applied at 10 or 20 lb N/acre at midseason produced rice grain yields equivalent to those produced when 45 or 60 lb N/acre as urea were applied at midseason with the lowest preflood N rates. Only once was a noticeable yield increase above the control observed with a CoRoN liquid-N source. It is difficult to measure a grain yield response when only 10 or 20 lb N/acre are applied at midseason on the currently grown rice varieties that do not respond that well to midseason N. The fact that rice varieties typically take up 150 to 200 lb N/acre to produce maximum grain yields would suggest that an application of only 10 or 20 lb N/acre would just be too small to have much of an impact even if all of the N applied at midseason was taken up. One should be reminded that urea applied at midseason is taken up with a 65 to 80% efficiency, and if urea is applied at a 40 or 60 lb N/acre rate and another N fertilizer is applied at 10 or 20 lb N/acre rate, it cannot compete even if taken up by the rice with an unattainable 100% efficiency.

INTRODUCTION

If an adequate rate of preflood-N is applied and managed correctly, no additional N applications are required at midseason to reach maximum grain yield potential with the current rice varieties being grown. If additional N fertilizer is required it is recommended it be applied at midseason, between beginning internode elongation (IE) and 0.5-in. IE. Urea is the N source used for midseason N application and the prior recommendation in Arkansas was to apply 60 lb N/A in one or two applications at midseason (this has been recently changed to apply 45 lb N/acre in a single application at midseason). The N applied at midseason is taken up in about 4 days with a 65 to 80% efficiency. Study leaders are always looking for new N sources that can make N use by rice more efficient. Helena Chemical has two experimental N sources for use at midseason under the trade or company name of CoRoN, i.e. HM9310 and HM0108, that they hope can be applied at much lower rates than urea at midseason and result in equivalent or greater rice grain yields. The objective of this study was to compare the two CoRoN liquid N sources, HM9310 and HM0108, to the standard N source, urea, normally used at midseason in rice.

PROCEDURES

The studies were conducted during the 2002 and 2003 growing season on a DeWitt silt loam (Typic Albaqualfs) at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart Ark. The cultivars chosen for use in the study were the high-yielding, long-grain 'Wells' in 2002 and 'Cocodrie' in 2003. The rice was seeded at 110 lb/acre in nine row plots (7-in. spacing) of 15 feet in length. The rice was grown upland until the 4- to 5-leaf growth stage and then a permanent flood (2- to 4-in. depth) was established and maintained until maturity. A randomized complete block experimental design with four replications was utilized in both years. The preflood-N rates applied as prilled urea were 45 and 90 lb N/acre in 2002 and 60 and 120 lb N/acre in 2003. The preflood-N was applied to a dry soil surface the day before flooding in both years. The midseason-N treatments applied in 2002 were: i) no midseason N; ii) prilled urea applied at 60 lb N/acre in a single application at 0.5-in. IE; iii) HM9310 applied at 10 lb N/acre in two applications at 0.5-in. IE and 0.5-in. IE + 7 days; and iv) HM0108 applied at 10 lb N/acre in two applications at 0.5-in. IE and 0.5-in. IE + 7 days. The midseason-N treatments applied in 2003 were: i) no midseason N; ii) urea applied at 10, 20 and 45 lb N/acre in a single application at 0.5-in. IE; iii) HM9310 applied at 10 and 20 lb N/acre in two applications at 0.5-in. IE and 0.5-in. IE + 7 days; and iv) HM0108 applied at 10 and 20 lb N/acre in two applications at 0.5-in. IE and 0.5-in. IE + 7 days. The urea was applied as a solution at the 10 and 20 lb N/acre rates and prilled urea was applied at the 45 lb N/acre rate in 2003. The compositions of the CoRoN liquid-N sources used were: i) HM9310 contained 25% N with 2.475 lb N/gallon and weighed 9.9 lb/gallon and ii) HM0108 contained 12% N and 12% potassium with 1.284 lb N/gallon and weighed 10.7 lb/gallon. All liquid N sources were sprayed with a handheld boom using CO_2 as a propellent. 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 lbs. Statistical analyses were conducted with SAS and mean separations were based upon protected LSD where appropriate.

RESULTS AND DISCUSSION

Studies were conducted in 2002 and 2003 comparing the two Helena Chemical liquid CoRoN sources of N, HM9310 and HM0108, applied at midseason to the standard N source, urea, normally used at midseason in rice.

In 2002, when no midseason-N was applied to the rice plots, the preflood-N rates of 45 and 90 lb N/acre produced grain yields of 134 and 165 bu/acre, respectively (Table 1). The abnormally high native soil-N release in the field where the study was located caused rice grain yields to peak when only 90 lb N/acre was applied preflood and thus, the midseason-N applications did not significantly increase rice grain yield when this preflood-N rate was applied. Because no one ever knows exactly what the native soil-N release will be in a given field, multiple preflood-N applications have to be utilized to be sure an inadequate, early N uptake will be achieved to obtain a response from midseason-applied N. In this study, the 45 lb N/acre preflood-N application was inadequate enough to obtain a response from midseason-N and enable reseachers to evaluate and compare the different N sources applied at this time. When no midseason-N was applied, the 45 lb N/acre preflood-N application produced a rice grain yield of 134 bu/acre. When the 45 lb N/acre preflood-N application was followed with 60 lb N/acre as urea, the grain yield increased to 152 bu/acre. However, when the 45 lb N/acre preflood application was followed at midseason with 10 lb N/acre as HM9310, the rice grain yield was only 131 bu/acre and thus did not change significantly from the 134 bu/acre obtained when no midseason-N was applied. Conversely, when the 45 lb N/acre preflood application was followed at midseason with 10 lb N/acre as HM0108, the rice grain yield increased to 143 bu/acre. Consequently, neither of the experimental N sources applied at 10 lb N/acre at midseason produced rice grain yields equivalent to those produced when 60 lb N/acre as urea were applied at midseason. However, HM0108 did increase rice grain yields when only 10 lb N/acre was applied at midseason and this is quite intriguing since so little N was applied. It could be due to the potassium in the product if potassium was limiting in this soil; yet, so little potassium was applied it is difficult to believe it would cause a yield increase since potassium is taken up in the same quantities as N.

In 2003, when no midseason-N was applied to the rice, the preflood-N rates of 60 and 120 lb N/acre produced grain yields of 179 and 204 bu/acre, respectively (Table 2). When 60 lb N/acre were applied preflood, urea, HM9310 and HM0108 applied at 10 and 20 lb N/acre at midseason did not significantly increase rice grain yields compared to when no N fertilizer were applied at midseason. Only when 45 lb N/acre were applied as urea at midseason did rice grain yield significantly increase compared to the control when 60 lb N/acre were applied preflood. Grain yield increased from 179 bu/acre to 192 bu/acre when 45 lb N/acre were applied at midseason with the preflood-N rate of 60 lb N/acre. When 120 lb N/acre were applied preflood, none of the midseason treatments significantly increased rice grain yields. On the contrary, grain yields either significantly decreased or showed a trend to decrease when midseason-N was applied with the 120 lb N/acre preflood application. It appeared that as midseason-N rate increased, rice grain yields decreased when 120 lb N/acre were applied preflood. It is typical that grain yields decrease when the N rate used to reach maximum yield is exceeded and yields continue to further decrease as more N is applied. It is difficult to measure a grain yield response when only 10 or 20 lb N/acre are applied at midseason on the currently grown rice varieties that do not respond that well to midseason-N. Currently grown rice varieties typically take up 150 to 200 lb N/acre to produce maximum grain yields and an application of only 10 or 20 lb N/acre is just too small to have much of an impact even if all of the N applied at midseason is taken up. One should be reminded that urea applied at midseason is taken up with a 65 to 80% efficiency, and if urea is applied at a 45 lb N/acre rate and other N fertilizers are applied at a 10 or 20 lb N/acre rate, they cannot compete even if they are taken up with an unattainable 100% efficiency.

The two CoRoN N sources studied in Arkansas were also studied in 2003 in the rice-producing states of Louisiana, Mississippi, Missouri, and Texas. Application of the two CoRoN sources at midseason at the rates of 10 and 20 lb N/acre failed to significantly increase rice grain or milling yield in any state including Arkansas (Walker et al., 2004).

SIGNIFICANCE OF FINDINGS

Studies were conducted in 2002 and 2003 to compare Helena Chemical's two CoRoN liquid-N sources, HM9310 and HM0108, to the standard N source, urea, normally used at midseason in rice. Rice yield response to midseason-N was only observed at the lowest preflood-N rates applied in 2002 and 2003. Neither of the experimental N sources, HM9310 or HM0108, applied at 10 or 20 lb N/acre at midseason produced rice grain yields equivalent to those produced when 45 or 60 lb N/acre as urea were applied at midseason with the lowest preflood-N rates.

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Table 1. Comparison of CoRoN HM9310 and HM0108 to urea as N sources for midseason N application to Wells rice in 2002 at the Rice Research and Extension Center near Stuttgart, Ark.

	Midseason N rate		Preflood N rate	
Midseason N source	0.5-in. IE[z]	0.5-in. IE+7d	45 lb N/acre	90 lb N/acre
	------------ (lb N/acre) ------------		------ (grain yield, bu/acre) ----	
None	0	0	134	165
HM9310	5	5	131	158
HM0108	5	5	143	164
Urea prills	60	0	153	159
$LSD_{(0.05)}$			9.1	
C.V. (%)			4.4	

[z] IE = internode elongation.

Table 2. Comparison of HM9310 and HM0108 to urea as N sources for midseason N application to Cocodrie rice in 2003 at the Rice Research and Extension Center near Stuttgart, Ark.

	Midseason N rate		Preflood N rate	
Midseason N source	0.5-in. IE[z]	0.5-in. IE+7d	60 lb N/acre	120 lb N/acre
	------------ (lb N/acre) ------------		------ (grain yield, bu/acre) ----	
None	0	0	179	204
HM9310	5	5	184	196
HM9310	10	10	181	184
HM0108	5	5	183	190
HM0108	10	10	182	191
Urea solution	10	0	183	196
Urea solution	20	0	176	193
Urea prills	45	0	192	190
$LSD_{(0.05)}$			10.2	

[z] IE = internode elongation.

Grain Yield Response of Eight 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 which exist in the Arkansas rice-growing region. 'Cheniere', 'Cybonnet', 'Medark', 'Spring', and the RiceTec hybrids Clearfield 'XL8', 'XP 710', 'XP 716', and 'XP 723' were the new rice varieties evaluated for N-fertilizer response in 2004. Cheniere and Medark required 90 to 120 lb N/acre to achieve maximal grain yield when grown on silt loam soils and 150 to 180 lb N/acre when grown on clay soils. Cybonnet and Spring required 120 to 150 lb N/acre to achieve maximal grain yield when grown on silt loam soils and 150 lb N/acre when grown on clay soils. All of the N fertilizer applied to the aforementioned rice varieties was applied preflood, except 45 lb N/acre applied at beginning internode elongation. The RiceTec hybrids usually achieved maximal grain yields when 90 lb N/acre were applied preflood and 0 to 30 lb N/acre were applied at late boot (LB). Occasionally, the RiceTec hybrids required 120 lb N/acre applied preflood to reach maximal grain yield and this usually occurred when they were grown on a clay soil. The LB N application of 30 to 60 lb N/acre seldom resulted in a grain yield increase, but this is typical in Arkansas. The LB N application is recommended on the hybrids, mainly to minimize lodging and secondly to increase rice grain yield.

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 under varying N-fertilizer rates on clay and silt loam soils and determines the proper N-fertilizer rates for new cultivars across an array of soils and climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, California, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Eight rice cultivars and experimental varieties were studied in 2004. Four of the eight new cultivars and experimental varieties studied in 2004 are hybrids developed by RiceTec. RiceTec Clearfield XL8 is a hybrid variety tolerant to the broad-spectrum herbicide imidazolinone (Newpath). The other three RiceTec hybrids studied can obtain exceptional grain yields with similar amounts of N fertilizer compared to conventional cultivars. Cheniere and Cybonnet are new long-grain, semi-dwarf cultivars released from the Louisiana and Arkansas programs, respectively. Medark is a medium-grain, semi-dwarf variety released from the Arkansas program and Spring is a new long-grain rice variety that matures very early.

PROCEDURES

Locations where the cultivar x N rate studies were conducted and corresponding soil series are as follows: Lake Hogue, Poinsett County, Ark., Calhoun silt loam (Typic Glossaqualfs); Northeast Research and Extension Center (NEREC), Keiser, Ark., Sharkey clay (Vertic Haplaquepts); Rice Research and Extension Center (RREC), Stuttgart, Ark., DeWitt silt loam (Typic Albaqualfs); and the Southeast Research and Extension Center (SEREC), Rohwer, Ark, Perry clay (Vertic Haplaquepts). The experimental design utilized was a randomized complete block with six replications at all locations for all the rice cultivars studied, except the RiceTec hybrids which had a randomized complete block design with four replications. 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 Lake Hogue 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 N 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 210 lb N/acre applied in an assortment of split applications at preflood and late-boot (LB) with the preflood application ranging from 90 to 150 lb N/acre and the LB application ranging from 0 to 60 lb N/acre . The rice was drill-seeded at a rate of 110 lb/acre in plots 9 rows wide (row spacing of 7 in.), 15 ft in length at all locations, except RiceTec hybrids which were seeded at 35 lb/acre. Plots were flooded at each location when the rice was at the 4- to 5-leaf 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

Cheniere achieved a maximal grain yield on the silt loam soils at Lake Hogue and the RREC when 120 lb N/acre were applied (Table 1). Grain yields appeared to be stable when more than the optimal N rate was applied to Cheniere at the RREC, but not at Lake Hogue. The lower yields of Cheniere on the silt loam soil at Lake Hogue compared to at the RREC were due to a poor stand from damage by grape colaspis. The poor stand at Lake Hogue is also the reason for the higher variability in the data from this location. When Cheniere was grown on the clay soils at the NEREC and SEREC, maximal grain yield was not achieved until 180 lb N/acre were applied and yields appeared to be stable when 210 lb N/acre were applied. Rice requiring about 30 lb/acre more N when grown on clay soils compared to silt loam is typical. The 2003 data indicated Cheniere required 150 lb N/acre to reach maximum grain yield on silt loam soils (Norman et al., 2004) and the 2004 data indicate only 120 lb N/acre ware required. Thus, another year of data is required to solidify the proper N fertilizer rate for Cheniere.

Grain yields of Cybonnet maximized on the silt loam soils when 150 lb N/acre were applied at Lake Hogue and when 120 lb N/acre were applied at the RREC (Table 2). Grain yields appeared to be stable when more than the optimal N rate was applied to Cybonnet at the RREC, but not at Lake Hogue. The lower yields and larger variability of the data on the silt loam soil at Lake Hogue compared to at the RREC were due to a poor stand from damage by grape colaspis. When Cybonnet was grown on the clay soils at the NEREC and SEREC, maximal grain yields were achieved when 180 and 150 lb N/acre, respectively, were applied. The appropriate N rate for Cybonnet will be in the 120 to 150 lb N/acre range when grown on silt loam soils. The preflood-N rate should be increased by 30 lb N/acre when grown on clay soils.

Medark reached grain yields of over 200 bu/acre at two of the four locations where it was studied and came within 11 bu/acre of this yield at the other two locations in 2004 (Table 3). On the silt loam soils at Lake Hogue and the RREC, Medark grain yields did not significantly increase when more than 150 and 120 lb N/acre, respectively, were applied. Grain yields of Medark did not significantly increase when more than 120 lb N/acre were applied to the clay soils at the NEREC and SEREC. Grain yields of Medark appeared to be quite stable when a higher N rate than that required to achieve maximal grain yield was applied at all locations. This wide yield plateau over several N fertilizer rates will make it more difficult to over-fertilize Medark. There was some lodging of Medark at Lake Hogue because rains made it impossible to harvest at Lake Hogue when the rice was mature. The data collected in 2004 coupled with those of previous years indicate a proper N fertilization recommendation for Medark to reach its full yield potential would be 135 lb N/acre when grown on silt loam soils and 165 lb N/acre when grown on clay soils.

The very-short-season Arkansas release, Spring, matures so much earlier than other rice varieties that bird damage can skew the data in studies. In 2004, however, there was no bird damage to Spring at any of the locations. Grain yields of Spring maximized on the silt loam soils when 150 lb N/acre were applied at Lake Hogue and when 120 lb N/acre were applied at the RREC (Table 4). The lower yields and larger variability of the data of on the silt loam soil at Lake Hogue compared to at the RREC were due to a poor stand from damage by grape colaspis. When Spring was grown on the clay soils at the NEREC and SEREC, maximal grain yields were achieved when 180 and 150 lb N/acre, respectively, were applied. The 2004 data in conjunction with data collected in previous years indicate the appropriate N rate for Spring will be in the 120- to 150-lb N/acre range when grown on silt loam soils. The preflood-N rate should be increased by 30 lb N/acre when grown on clay soils.

RiceTec's Clearfield XL8 reached yields of over 200 bu/acre at all three sites in 2004 and produced a grain yield of 244 bu/acre at the RREC (Table 5). Clearfield XL8 achieved statistically maximal grain yields when a single preflood application of 90 lb N/acre was applied at the RREC and Lake Hogue, and when a single preflood application of 120 lb N/acre was applied at the NEREC. The extra 30 lb N/acre required at preflood on the clay soil at the NEREC compared to on the silt loam soils at the RREC and Lake Hogue is typical. The 150 lb N/acre preflood-N rate was excessive on the silt loam soils at the RREC and Lake Hogue and caused grain yields to decrease. The lower yields of Clearfield XL8 at Lake Hogue compared to the other two sites were due to some grape colaspis damage. When an LB application of N was coupled with the preflood rate that achieved statistically maximal grain yields, Clearfield XL8 had a tendency to slightly increase grain yields at the RREC and the NEREC but not at Lake Hogue. This minimal yield increase with the LB application of N is commonly what study leaders have observed in Arkansas. The LB application has been shown in previous research in Arkansas to help with lodging on these very-high-yielding hybrids especially when, due to muddy fields, the rice cannot be harvested timely. No lodging of Clearfield XL8 was observed in 2004 at any of the research sites. The 2004 data along with the 2003 data (Norman et al., 2004) indicate a sound N fertilizer recommendation for Clearfield XL8 would be to apply 90 lb N/acre preflood on silt loam soils followed by 30 lb N/acre at LB to help with lodging and possibly get a little yield boost from the LB application. When grown on clay soils Clearfield XL8 will require an addition 30 lb N/acre preflood to boost the preflood N rate to 120 lb N/acre.

XP710 produced grain yields well over 200 bu/acre at all application rates and timings studied at the three research sites, and at the RREC and NEREC produced maximal numerical grain yields of 260 bu/acre or more (Table 6). There was some grape colaspis damage at Lake Hogue in the area of the field where XP710 was located and that is likely to blame for the lower yields at this location. Cultivar XP710 achieved statistically maximal grain yields when a single preflood application of 90 lb N/acre was applied at all three research sites and numerically maximum yields on the silt loam soils at the RREC and Lake Hogue. When 150 lb N/acre were applied preflood, the grain yield of XP710 declined compared to when 90 or 120 lb N/acre were applied. The LB application of N showed no real benefit to the grain yield of XP710, except when 60 lb N/acre were coupled with a preflood-N rate of 120 lb N/acre at the NEREC. No lodging of XP710 was observed in 2004 at any of the research sites. The 2004 data along with the 2003 data (Norman et al., 2004) indicate a sound N fertilizer recommendation for XP710 would be to apply 90 lb N/acre preflood on silt loam soils followed by 30 lb N/acre at LB to help with lodging and possibly get a little yield boost from the LB application. When grown on clay soils, the preflood-N rate for XP710 should be increased by 30 lb N/acre over the 90 lb N/acre rate recommended on silt loam soils.

Cultivar XP716 had grain yields of over 250 bu/acre at the RREC, over 230 bu/acre at the NEREC, and over 200 bu/acre at Lake Hogue (Table 7). Cultivar XP716 achieved statistically maximal grain yields when a single preflood application of 90 lb N/acre was applied on the silt loam soils at the RREC and Lake Hogue and when a single preflood application of 120 lb N/acre was applied on the clay soil at the NEREC. However, although not statistically significant it was close; the 30 and especially the 60 lb N/acre LB N application appeared to help the grain yield of XP716 when 90 lb N/acre were applied preflood at the RREC. The LB N application did not appear to help the grain yield of XP716 at the other two sites. Although XP716 had lower yields at Lake Hogue compared to the other two research sites, there was no grape colaspis damaged observed in XP716 at this site. No lodging of XP716 was observed in 2004 at any of the research sites. This was the first year XP716 was in the N fertilizer-response studies and study leaders will need at least one year of data to make a sound N-fertilizer recommendation, but with this one year of results, it appears XP716 should be fertilized similarly to Clearfield XL8 and XP710.

Cultivar XP723 produced grain yields over 230 bu/acre at the RREC and NEREC and over 240 bu/acre at Lake Hogue (Table 8). Statistically maximal grain yields were achieved by XP723 at all three of the research sites when 90 lb N/acre were applied preflood. The 120 lb N/acre preflood N rate gave only a slightly higher numerical grain yield at the RREC and NEREC. The LB application appeared to only result in a noticeably higher numerical grain yield at the RREC when 30 lb N/acre were applied LB with the 90 lb N/acre preflood-N rate. A surprising observation was made at the NEREC; the LB application of 60 lb N/acre caused some lodging of XP723 when applied with the 120 lb N/acre preflood-N rate. The LB application has never aggravated lodging in any of the other studies done by this team with RiceTec hybrids, and thus the team believes this lodging result is an anomaly because no lodging of XP723 was observed at the NEREC when 120 lb N/acre were applied preflood with no LB N or a 30 lb N/acre LB application. Additionally, when 150 lb N/acre were applied preflood to XP723 at the NEREC, lodging was a problem and increasing the LB application from 30 to 60 lb N/acre helped. This was the first year XP723 was in the N fertilizer-response studies and the team will need at least one year of data to make a sound N fertilizer recommendation, but with this one year of results it appears XP723 should be fertilized similarly to the other hybrids studied in 2004.

SIGNIFICANCE OF FINDINGS

Nitrogen response curves to determine the proper N fertilization rate to obtain maximal grain yield potential were developed for the following rice cultivars in 2004: Cheniere, Cybonnet, Medark, Spring, and the RiceTec hybrids Clearfield XL8, XP710, XP716, and XP723. All of the named rice cultivars showed excellent yield potential when typical N fertilization rates for currently grown cultivars were applied. In these studies with conventional rice varieties, the RiceTec hybrids obtained yields previously unheard of at slightly lower N rates than those utilized by other varieties.

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Table 1. Influence of nitrogen (N) fertilizer rate on the grain yield of Cheniere rice at four locations in 2004.

	Grain yield			
N fertilizer rate	Lake Hogue[z]	NEREC	RREC	SEREC
(lb N/acre)	---------- (bu/acre[y]) ----------			
0	88	34	165	46
60	150	--	189	--
90	157	116	200	139
120	169	136	211	165
150	150	153	210	169
180	140	167	205	175
210	--	161	--	182
$LSD_{(0.05)}$	16.2	11.1	9.5	11.3

[z] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Stuttgart; RREC=Rice Research and Extension Center, Stuttgart; SEREC=Southeast. Research and Extension Center, Rohwer.

[y] A bushel (bu) of rice weighs 45 lb.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Cybonnet rice at four locations in 2004.

N fertilizer rate	Grain yield			
	Lake Hogue[z]	NEREC	RREC	SEREC
(lb N/acre)	(bu/acre[y])			
0	95	66	161	36
60	129	--	173	--
90	142	137	184	123
120	156	157	204	150
150	165	169	209	161
180	156	178	208	163
210	--	175	--	159
$LSD_{(0.05)}$	7.4	6.2	10.4	10.3

[z] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Stuttgart; RREC=Rice Research and Extension Center, Stuttgart; SEREC=Southeast. Research and Extension Center, Rohwer.
[y] A bushel (bu) of rice weighs 45 lb.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Medark rice at four locations in 2004.

N fertilizer rate	Grain yield			
	Lake Hogue[z]	NEREC	RREC	SEREC
(lb N/acre)	(bu/acre[y])			
0	88	34	165	46
0	82	66	132	45
60	134	--	178	--
90	161	139	194	168
120	154 (10[x])	159	209	197
150	163	157	217	200
180	116 (20)	160	207	186
210	--	149	--	184
$LSD_{(0.05)}$	21.4	7.1	10.8	10.9

[z] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Stuttgart; RREC=Rice Research and Extension Center, Stuttgart; SEREC=Southeast. Research and Extension Center, Rohwer.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in parentheses to the side of yield are lodging percentage.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Spring rice at four locations in 2004.

N fertilizer rate	Grain yield			
	Lake Hogue[z]	NEREC	RREC	SEREC
(lb N/acre)	(bu/acre[y])			
0	73	26	126	30
60	96	--	158	--
90	138	124	171	133
120	172	147	184	173
150	189	164	183	189
180	169	189	170	181
210	--	178	--	183
$LSD_{(0.05)}$	28.3	8.8	13.2	8.7

[z] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Stuttgart; RREC=Rice Research and Extension Center, Stuttgart; SEREC=Southeast. Research and Extension Center, Rohwer.
[y] A bushel (bu) of rice weighs 45 lb.

Table 5. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec Clearfield XL8 rice at three locations in 2004.

N fertilizer rate		Grain yield		
Total	Split[z]	Lake Hogue[y]	NEREC	RREC
(lb N/acre)		(bu/acre[x])		
90	90-0-0	203	186	233
120	90-0-30	197	185	222
150	90-0-60	193	197	244
120	120-0-0	196	190	237
150	120-0-30	196	202	213
180	120-0-60	187	203	226
180	150-0-30	186	196	196
210	150-0-60	--	194	185
$LSD_{(0.05)}$		14.2	14.8	21.9

[z] Split = nitrogen applied at preflood-beginning internode elongation-late boot.
[y] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Keiser; RREC=Rice Research and Extension Center, Stuttgart.
[x] A bushel (bu) of rice weighs 45 lb.

Table 6. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec XP710 rice at three locations in 2004.

N fertilizer rate		Grain yield		
Total	Split[z]	Lake Hogue[y]	NEREC	RREC
--------- (lb N/acre)--------------		----------------------------(bu/acre[x])------------------------		
90	90-0-0	227	252	269
120	90-0-30	224	235	267
150	90-0-60	220	242	258
120	120-0-0	219	248	238
150	120-0-30	214	241	244
180	120-0-60	212	260	235
180	150-0-30	220	238	223
210	150-0-60	218	217	202
$LSD_{(0.05)}$		18.3	17.3	25.6

[z] Split = nitrogen applied at preflood-beginning internode elongation-late boot.
[y] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Keiser; RREC=Rice Research and Extension Center, Stuttgart.
[x] A bushel (bu) of rice weighs 45 lb.

Table 7. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec XP716 rice at three locations in 2004.

N fertilizer rate		Grain yield		
Total	Split[z]	Lake Hogue[y]	NEREC	RREC
--------- (lb N/acre)--------------		----------------------------(bu/acre[x])------------------------		
90	90-0-0	209	208	250
120	90-0-30	200	207	260
150	90-0-60	190	209	268
120	120-0-0	211	231	251
150	120-0-30	209	235	250
180	120-0-60	208	235	253
180	150-0-30	206	228	245
210	150-0-60	200	223	241
$LSD_{(0.05)}$	14.5	18.4	18.4	

[z] Split = nitrogen applied at preflood-beginning internode elongation-late boot.
[y] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Keiser; RREC=Rice Research and Extension Center, Stuttgart.
[x] A bushel (bu) of rice weighs 45 lb.

Table 8. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of RiceTec XP723 rice at three locations in 2004.

N fertilizer rate		Grain yield		
Total	Split[z]	Lake Hogue[y]	NEREC	RREC
--------- (lb N/acre)--------------		----------------------------(bu/acre[x])------------------------		
90	90-0-0	247	235	233
120	90-0-30	241	234	247
150	90-0-60	233	212	238
120	120-0-0	243	238	238
150	120-0-30	244	240	235
180	120-0-60	231	215 (20[w])	223
180	150-0-30	230	217 (64)	238
210	150-0-60	224	213 (40)	233
$LSD_{(0.05)}$		18.1	31.7	19.8

[z] Split = nitrogen applied at preflood-beginning internode elongation-late boot.
[y] Lake Hogue=Poinsett County; NEREC=Northeast Research and Extension Center, Keiser; RREC=Rice Research and Extension Center, Stuttgart.
[x] A bushel (bu) of rice weighs 45 lb.
[w] Numbers in parentheses to the side of yield are lodging percentage.

Zinc Fertilization of Rice Grown on Clay Soils in Arkansas

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ABSTRACT

Zinc (Zn) fertilizer is not currently recommended for rice grown on clay or clay loam soils in Arkansas. In 2004, five field sites were established to evaluate the response of rice grown on clay soils to Zn fertilization. Shortly before or after seeding, granular Zn fertilizer was applied to the soil surface at rates of 0, 5, 10, and 20 lb Zn/acre. Tissue-Zn concentration and dry-matter accumulation 10 to 14 days after flooding and grain yield response to Zn fertilizer rate were evaluated. At the five sites, the mean soil pH ranged from 6.7 to 8.0 and Mehlich-3-Zn ranged from 1.2 to 3.9 mg Zn/kg. Three of the five sites had pH >7.0 and Mehlich-3 Zn <3.0 mg Zn/kg. Rice grain yield and dry-matter accumulation at midtillering were not significantly affected by Zn fertilizer rate, averaged across locations. Midtillering tissue-Zn concentrations increased as Zn rate increased, but showed that only one site had mean tissue-Zn concentrations that were low. Zinc does not appear to be a yield-limiting factor for rice grown on most clay soils.

INTRODUCTION

Zinc (Zn) fertilizer is not currently recommended for rice (*Oryza sativa* L.) grown on clay or clay loam soils in Arkansas. Although Zn-deficient rice is not common on clay soils, Zn deficiency has been documented on a few clay soils that have been precision-graded. When Zn-deficient rice has been diagnosed on clay soils in Arkansas, Mehlich-3-extractable Zn has been very low (<1.0 mg Zn/kg), suggesting Zn-fertilization recommendations for rice grown on clay soils may be needed. Few studies have evaluated rice response to Zn fertilization on clay soils in Arkansas. Wells (1980) reported that Zn fertilization had no influence on grain yield of rice grown on two alkaline clay soils. The objectives of this research were to: i) determine if routine soil-test parameters such as Mehlich-3-extractable Zn concentration and soil-water pH were correlated with whole-plant Zn concentrations at the midtillering growth stage, ii) evaluate rice grain yield response to Zn fertilization on clay soils in Arkansas, and iii) build a database of clay soil properties and plant information that will enable study leaders to develop research-based Zn fertilization recommendations for rice.

PROCEDURES

Small, replicated field studies were established on five clay soils in 2004 (Table 1). Studies were located in Desha, Lincoln, and Mississippi counties (Table 1). At each site, a composite soil sample was collected from the 0-to 4-in. depth in each unfertilized control. Soil samples were dried, crushed, and analyzed for soil-water pH (1:2 soil:water mixture) and soil nutrient concentrations by extraction with Mehlich-3 (Mehlich, 1984; Table 2). Shortly before or after seeding, granular Zn fertilizer (31% Zn, as $ZnSO_4$) was applied to the soil surface at rates of 0, 5, 10, and 20 lb Zn/acre. Zinc fertilizer rates were arranged in a randomized complete block design with four replications. Each plot was 16-ft long and 8-ft wide with row spacings of 6.5 to 7.5 in. Selected agronomic information is provided in Table 1. Near the 5-leaf stage, urea was applied to a dry soil surface and a permanent flood was established. All sites were drill-seeded and managed according to University of Arkansas guidelines for the delayed-flood production system for clay soils.

Whole, aboveground plant samples were taken from a 3-ft section in the second inside row of each plot 10 to 14 d after flooding. Plant samples were dried, weighed, ground to pass through a 1 mm sieve, and digested with concentrated HNO_3 and 30% H_2O_2 for elemental analysis (Jones and Case, 1990). At maturity, a small-plot combine was used to harvest the middle four or five rows of each plot. Grain yield was calculated using the harvested grain weight, grain moisture, and harvested area and adjusted to a uniform moisture content of 12% for statistical analyses.

Tissue-Zn concentration (mg Zn/kg), dry-matter accumulation (lb/acre), and grain yield (bu/acre) were analyzed in a split-plot design where location was the whole plot and Zn rate was the subplot. The Fishers Protected Least Significant Difference (LSD) procedure ($\alpha = 0.05$) was used to compare treatment means when appropriate. All statistical analyses were performed with SAS version 8.2.

RESULTS AND DISCUSSION

At the five sites, the mean soil pH ranged from 6.7 to 8.0 and Mehlich-3-Zn ranged from 1.2 to 3.9 mg Zn/kg (Table 2). Three of the five sites had pH >7.0 and Mehlich-3-Zn <3.0 mg Zn/kg. The location × Zn-rate interaction was not statistically significant for grain yield ($P = 0.1541$), whole-plant Zn concentration ($P = 0.0670$), or dry-matter accumulation at midtillering ($P = 0.1605$). Location was the only factor that significantly influenced rice dry-matter accumulation ($P < 0.0001$) at the midtillering stage and grain yield ($P = 0.0001$) at maturity (Table 3). Whole-plant Zn concentrations, averaged across Zn rates, ranged from 23.7 to 46.5 mg Zn/kg and were also significantly affected by location ($P < 0.0001$). The Sullivan site had the greatest Zn concentrations, which can be attributed to near neutral pH, moderate soil-Zn concentration, and a greater sand content of the soil compared to the other sites (data not shown). The Henry site (23.7 mg Zn/kg) had mean tissue-Zn concentrations near the established critical Zn concentration of 20 mg Zn/kg (Table 3). Despite low tissue-Zn at this site, Zn-deficiency symptoms were not observed and grain yield showed no response to Zn fertilization.

Zinc fertilizer rate ($P < 0.0001$) significantly affected whole-plant Zn concentration, but the magnitude of change was not as great as expected for the range of rates applied (Table 4). Whole-plant Zn concentrations, averaged across locations, increased from 32.1 mg Zn/kg for the unfertilized control to 37.0 mg Zn/kg for the 20-lb Zn/acre rate. The relatively small change in tissue-Zn concentrations in response to the soil-applied Zn fertilization rates suggests that broadcast Zn fertilizer rates would possibly need to be much higher for Zn-deficient clay soils than for Zn-deficient silt and sandy loam soils. Data from Wells (1980) also show that increasing rice tissue-Zn concentrations on clay soils requires much higher Zn rates than required for silt loam soils. Application of Zn fertilizer rates ranging from 5 to 20 lb Zn/acre did not benefit or harm rice dry-matter accumulation ($P = 0.8171$) and yield ($P = 0.9858$) on these five clay soils (Table 4).

Correlation of routine soil-test parameters for 13 site-years of data collected in 2003 (Hensley et al., 2004) and 2004 showed that linear and nonlinear models including only Mehlich-3-Zn were not significantly correlated with tissue-Zn concentration (data not shown). A nonlinear model [Seedling Zn (mg Zn/kg)= $136.1\text{pH} - 10.3\text{pH}^2 - 408.6$] for soil pH was significant and negatively related with tissue-Zn concentration ($r^2 = 0.6886$). Tissue-Zn concentration decreased as soil pH increased. Soils with a wider range of soil pH values are needed to fully evaluate this relationship. A multiple regression model including Mehlich-3 Zn, soil pH, and their interaction (model not shown, $r^2 = 0.6382$) was statistically significant, but failed to improve the correlation above that for soil pH alone. Zinc fertilization recommendations based on both soil pH and soil-test Zn are preferred because they account for both reduced Zn availability at high soil pH as well as the residual benefits (i.e., soil-test Zn) of previous Zn fertilizer applications. Soil pH was initially used to recommend Zn fertilization for silt and sandy loam soils with some success in Arkansas. However, years of Zn fertilization increased soil-test Zn to high enough concentrations that soil pH was no longer correlated with rice response to Zn fertilization (Slaton et al., 2002). Additional studies will be conducted to broaden the range of soil chemical properties included in the database before final Zn fertilization recommendations are developed for rice grown on clay soils.

SIGNIFICANCE OF FINDINGS

Five site-years of data from 2004 and eight from 2003 suggest that Zn is not a growth- and yield-limiting factor for rice grown on most clay soils in Arkansas. However, data did indicate that Zn availability, as indicated by tissue-Zn concentrations at midtillering, decreases as soil pH increases. Additional data are needed before final Zn fertilization recommendations can be made for rice grown on clay soils. This study's tentative Zn recommendation for clay soils, especially those that have been precision-leveled, is to follow the Zn fertilization guidelines for silt and sandy loam soils until additional data can be collected, especially on soils with high pH (>7.0) and soil-test Zn 2.0 mg Zn/kg.

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Table 1. Agronomic and field information for five sites used to evaluate rice response to zinc fertilization on clay soils in 2004.

County	Field name	Soil series	Cultivar	Plant date	Sample date
				--------(day - month) -----	
Desha	SEREC	Perry	Wells	20 April	17 June
Desha	Henry	Desha	Wells	20 April	15 June
Lincoln	McGraw	Portland	Francis	23 April	15 June
Mississippi	Sullivan	Sharkey-Steele	Wells	16 April	8 June
Mississippi	NEREC	Sharkey-Steele	Cocodrie	20 April	15 June

Table 2. Selected soil chemical characteristics of five sites used to evaluate rice response to zinc fertilization on clay soils in 2004.

Field name	Soil pH[z]	Mehlich-3-extractable soil nutrient concentrations[y,x]									
		P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
		(mg/kg)									
SEREC	8.0	39	303	4113	907	16	221	49	2.5	1.6	0.6
Henry	7.9	35	306	3778	1214	12	200	39	1.2	2.7	0.5
McGraw	7.3	12	318	3529	1165	8	201	76	2.3	2.1	0.4
Sullivan	6.7	27	188	2457	570	12	366	69	3.9	1.5	0.4
NEREC	7.4	34	361	4256	1093	18	239	40	3.1	2.7	0.8

[z] Soil pH measured in a 1:2 soil:water mixture.
[y] Mehlich-3 extraction procedure (1:10 extraction ratio).
[x] All values are the mean of four composite samples taken from the 0- to 4-in. depth.

Table 3. Effect of location, averaged across zinc application rates, on tissue zinc concentrations and dry-matter production 10 to 14 d after flooding and grain yield for studies conducted in 2004.

Field name	Tissue Zn	Dry matter	Grain yield
	(mg Zn/kg)	(lb/acre)	(bu/acre)
SEREC	27.4	1055	167
Henry	23.7	1126	207
McGraw	45.6	786	170
Sullivan	46.5	1669	168
NEREC	30.6	337	215
LSD(0.05)	2.2	250	15
P-value	<0.0001	<0.0001	0.0001
C.V., %	8.0	21.0	8.5

Table 4. Effect of zinc fertilizer rate, averaged across five sites, on tissue zinc concentrations and dry-matter production 10 to 14 d after flooding and grain yield for studies conducted in 2004.

Zinc rate	Tissue Zn	Dry matter	Grain yield
(lb Zn/acre)	(mg Zn/kg)	(lb/acre)	(bu/acre)
0	32.1	1065	186
5	34.6	987	184
10	35.4	979	186
20	37.0	1049	185
LSD(0.05)	1.8	NS[z]	NS
P-value	<0.0001	0.8171	0.9858
C.V., %	8.0	21.0	8.5

[z] NS = not significant.

Rice Response to Phosphorus and Potassium Fertilization in Arkansas

N.A. Slaton, R.E. DeLong, C. Baquireza, R.J. Norman, C.E. Wilson, and B.R. Golden

ABSTRACT

Phosphorus (P) and potassium (K) are macronutrients that must often be applied to maintain soil productivity and prevent deficiencies of these nutrients from limiting crop yields. The primary objectives of these studies were to evaluate rice-yield, growth, and tissue-concentration responses to P and K fertilization rates on silt loam soils in eastern Arkansas. Multiple test sites were established during 2004 to evaluate P rates (5 sites) from 0 to 100 lb P_2O_5/acre and K rates (6 sites) from 0 to 160 lb K_2O/acre. Phosphorus studies also included two times of P fertilization (preemerge and preflood). Rice grain yields were not affected by P fertilization at any of the five sites. Whole-plant-P concentration and dry-matter accumulation at the midtillering stage generally increased as P-fertilizer rate increased. Significant yield differences among K-fertilizer rates occurred at 3 of 6 sites. Symptoms associated with K-deficiency were observed at 4 of 6 sites, but significant yield increases, ranging from 4 to 23 bu/acre, occurred at only two sites. Data collected in 2004 have been added to the study's current database and will be used to correlate and calibrate soil test-based fertilizer recommendations for rice grown on silt loam soils in Arkansas.

INTRODUCTION

Phosphorus (P) and potassium (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 during the boot stage. Potassium-deficient rice has been documented on soils with a wide range of chemical properties in Arkansas, but deficiencies are most common on soils 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 seldom shown significant rice-yield increases from P and K fertilization.

Accurate fertilizer recommendations require that fertilization trials be conducted routinely to account for changes in production systems, cultivars, crop-nutrient removal due to increasing crop yields, and changes in soil fertility. A large number of research trials are needed to correlate and calibrate soil test-based fertilizer recommendations. The primary objectives of these studies were to evaluate rice-yield, growth, and tissue-concentration responses to P and K fertilization rates on silt loam soils in eastern Arkansas.

PROCEDURES

In 2004, P fertilization trials were established at five sites and K fertilization trials were established at six sites. Selected soil and agronomic information is listed for each site by nutrient trial in Table 1. Studies were established in grower fields (identified by cooperating grower's name) as well as on the Pine Tree Branch Station (PTBS) near Colt, Ark., and the Rice Research and Extension Center (RREC) near Stuttgart, Ark. The cooperating grower fields were in Poinsett or Cross county, Ark., and growers omitted P and K fertilizer applications to a 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 55°C in a forced-draft oven and 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 (Mehlich, 1984). Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma spectroscopy (ICPS). Selected soil chemical properties for each site are listed in Table 2. Soybean was the previous crop grown (in 2003) at all sites.

A recommended long- or medium-grain rice 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 as triple superphosphate (46% P_2O_5) were applied to the soil surface before emergence (preemerge) or before flooding at the 5-leaf stage (preflood) at all locations, except Lake Hogue where all P rates were applied when rice was at the 2-leaf stage (preflood). Potassium (60 lb K_2O/acre as muriate of potash) and Zn fertilizers (10 lb Zn/acre as $ZnSO_4$) were also broadcast to the soil surface before flooding. At the PTBS and the RREC, 120 lb N/acre as urea were applied at the 5-leaf stage and followed by flooding. At all grower field sites, N fertilization and flooding were managed by the cooperating growers. Whole-plant samples were harvested from a 3-ft section of the first inside row about 10 to 14 days after flooding (tillering stage). Plant samples were placed in paper bags, dried to a constant moisture at 60°C, weighed, and ground to pass a 1-mm sieve. A subsample of tissue was digested in concentrated HNO_3 and 30% H_2O_2 and elemental concentrations of the digests were determined by ICPS. 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, except Lake Hogue, were arranged in a randomized complete block design with a split-plot treatment structure where application time was the main plot and application rate was the subplot. Each treatment was replicated four times. Locations were analyzed separately. For Lake Hogue, treatments were arranged as a randomized complete block design with eight replications. 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. 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 and the RREC, 120 lb N/acre as urea were applied at the 5-leaf stage and followed by flooding. At all grower field sites, N fertilization and flooding were managed by the cooperating growers. Whole-plant samples were harvested from a 3-ft row section of the first inside row near the panicle differentiation stage (all sites except Hoskyn) and at the late-boot to early-heading stage. Plant samples were processed and harvest was performed as described previously for the P studies. After anthesis, rice height was measured from the soil surface to the tip of the erect panicles. Near maturity, 15 panicles were randomly collected from plots receiving 0, 80, and 160 lb K_2O/acre at the Murphy and PTBS sites. The total number of filled and blank kernels were counted for each panicle and the average number of total kernels and percentage of blanks were calculated to evaluate how K deficiency influences rice yield.

For all experiments, K rates were arranged as a randomized complete block design. Each treatment was replicated four (PTBS) or six (all other sites) 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 8.2.

RESULTS AND DISCUSSION

Phosphorus Trials

For all sites, except the RREC (interaction data not shown), the interaction between P-application time and rate did not significantly (P >0.05) influence dry-matter accumulation at the tillering stage, whole-plant tissue-P concentration at tillering, or grain yield at maturity (data not shown). The main effects of P application time and rate also failed to increase rice yields at all sites (Table 3), which is not surprising since soil pH was low to neutral (<7.0) at four sites and soil-test P was medium at the PTBS, which had a soil pH of 8.1 (Table 2).

Phosphorus application time, averaged across P rates, did not influence dry-matter accumulation at the midillering stage (data not shown). However, when averaged across application times, dry-matter accumulation often increased when P rates ≥50 lb P_2O_5/acre were applied (Table 4). Phosphorus application time, averaged across P rates, significantly affected whole-plant P concentration only at the Crouch site. Rice receiving P before emergence had greater P concentrations (0.235 %P) than rice fertilized with P preflood (0.224 %P). In general, whole-plant P concentrations increased as P rate increased at all sites. Tissue-P concentrations were >0.20% P at all sites, suggesting adequate P was available in all soils.

Potassium Rate Trials

Dry matter of rice near the panicle differentiation stage was not affected by K-fertilizer rate at any site (data not shown). However, as expected, tissue-K concentration increased significantly as K rate increased (Table 5). Rice receiving no K fertilizer at the Lake Hogue, Murphy, and PTBS sites had whole-plant K concentrations <1.40% near the panicle-differentiation stage. Published sufficiency ranges for K at panicle initiation are 1.0 to 2.20% K (Mills and Jones, 1996) and 1.80 to 2.6 % K (Doberman and Fairhurst, 2000) for mature rice leaves. The published sufficiency levels for rice are quite different and for mature leaves (i.e., Y-leaf) rather than whole plants. The actual critical K concentration for rice near midseason is not well defined in the literature and requires that additional data be collected to establish the critical values for rice grown on Arkansas soils. Regardless, the 2004 data suggest that silt loam soils in Arkansas have vastly different K availabilities.

By the late-boot stage, visible growth and/or plant color differences were evident among K rates at all sites, except the RREC. Although tissue analysis is not yet complete for all sites, the RREC data indicate that K concentrations declined during the rapid growth phase between panicle initiation and heading and that early-season K-fertilization rate continued to influence the nutritional status of rice (Table 5). Although rice dry-matter accumulation at the panicle differentiation stage was not affected by K rate, the visible differences in growth at the late-boot stage were confirmed by significant differences in plant height and dry-matter accumulation at some sites (Table 6). Dry matter was increased significantly by K rates ≥80 lb K_2O/acre at the Lake Hogue and

Murphy sites. A trend for dry matter to increase from K fertilization is also evident for the Crouch, Hoskyn, and PTBS sites. Plant height was also greater when K rates ≥80 lb K_2O/acre were applied at all sites, except at Hoskyn and at the RREC.

Analysis of plant samples collected at the late-boot stage is not yet complete for all sites. However, data show that rice K concentrations at the late-boot stage increase as K rates increase (Table 5). Tissue-K concentrations were similar for like K rates at the Lake Hogue and Hoskyn sites, but only the Lake Hogue site showed increased dry matter accumulation due to K fertilization (Table 6). The reason for this is not clear but may be related to differences in K nutritional requirements among cultivars, management differences, or other factors.

The Murphy site, seeded with the 'Bengal' cultivar, showed the most dramatic visual growth differences due to K-fertilizer rate. Shortly after panicle differentiation, the lower leaves developed tan-colored freckles on the leaf tips and margins that with time became reddish-brown, more numerous, progressed towards the base of lower leaves, and also affected the middle and upper leaves. These symptoms appeared at all K rates, but their severity increased as K rate declined. Similar but less severe symptoms were observed at Lake Hogue and the PTBS. Based on leaf color and plant height, the unfertilized control could be identified 65 to 100% of the time without a treatment diagram at these three sites.

Rice-grain yields were significantly affected by K rate at three of the six sites (Table 7). Rice yields increased numerically as K rate increased at the Lake Hogue and Murphy sites, which both have low soil pH. At the PTBS, the unfertilized control yield was only lower numerically than the 120-lb K_2O/acre rate. Panicle assays from the Murphy site showed that the percentage of blank kernels (mean was 26%) did not differ among K rates, but the number of total kernels increased (167, 186, and 197 kernels/panicle for 0, 80, and 160 lb K_2O/acre, respectively, LSD 0.10 = 9) as K rate increased.

SIGNIFICANCE OF FINDINGS

The primary benefits rice receives from P fertilization on many soils are increased vegetative growth after flooding and elevated tissue-P concentrations. Data also hint that P application before flooding generally produces equal early-season growth benefits as P applied near rice emergence when soil-P availability is adequate. Rice yields were not increased by P fertilization at five study sites during 2004. Phosphorus fertilizer should be applied when needed and when it is most convenient for the grower (preplant or preflood).

Potassium fertilization with rates ≥80 lb K_2O/acre resulted in significant rice yield increases at two sites that also had low tissue-K concentrations and the soil had relatively low exchangeable-K concentrations. Although the yield increases were significant, they were not as great as expected, with expectations based on rice appearance at heading. Apparently, the visual symptoms of moderate K deficiency are worse than the actual yield loss. Data do suggest that the Mehlich-3 extractant can identify some soils that will respond to K fertilization and that slightly acid soils are more likely to require high K rates than alkaline soils. Additional research sites are needed to correlate soil chemical properties with rice yields and tissue-K concentrations. Tissue-K concentration data also imply that rice with <1.5 to 1.70% K at the onset of reproductive growth may be K-deficient and should have received higher rates of K fertilizer.

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Table 1. Agronomic and field information for field sites used to evaluate rice response to P and K fertilization on silt loam soils during 2004.

Site	Nutrients tested	Cultivar	Soil series	Plant date[z]
				day - month
Crouch	P and K	Wells	Henry	24 April
Hoskyn	K	Wells	Stuttgart	20 April
Lake Hogue	P and K	Francis	Hillemann	6 May
Murphy	P and K	Bengal	Henry	30 April
PTBS	P and K	Wells	Calhoun	20 April
RREC	P and K	Wells	Dewitt	29 April

[z] Estimated or actual seeding date.

Table 2. Selected soil chemical characteristics of sites used to evaluate rice response to P and K fertilization on silt loam soils in 2004.

Field name	Soil pH[z]	Mehlich-3-extractable soil nutrient concentrations[y,x]								
		P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
		(mg/kg)								
Phosphorus trials										
Crouch	6.9	30	105	1043	184	10	321	32	7.5	0.7
Lake Hogue	6.3	13	84	1086	171	17	265	96	5.2	1.1
Murphy	6.1	9	73	962	160	10	321	187	1.9	1.2
PTBS	8.1	17	78	1910	308	6	259	177	1.1	0.9
RREC	6.0	12	120	981	164	9	392	141	2.4	1.3
Potassium trials										
Crouch	6.9	29	104	1039	184	11	317	34	7.5	0.8
Hoskyn	6.5	15	76	994	115	9	247	175	0.6	0.9
Lake Hogue	6.0	11	87	1083	184	23	263	102	4.3	1.0
Murphy	6.1	10	74	919	165	12	319	174	2.0	1.2
PTBS	8.1	16	64	1909	295	5	266	154	1.0	1.0
RREC	6.1	16	132	1048	159	9	400	127	3.4	1.3

[z] Soil pH measured in a 1:2 soil:water mixture.
[y] Mehlich-3 extraction procedure (1:10 extraction ratio).
[x] All values are the mean of four composite samples taken from the 0- to 4-in. depth.

Table 3. Effect of P rate, averaged across P application times (except for Lake Hogue), on rice grain yield for studies conducted in 2004.

Site	P-fertilizer rate (lb P_2O_5/acre)				$LSD_{0.10}$
	0	25	50	100	
	(bu/acre)				
Crouch	215	218	218	218	NS[z]
Lake Hogue	204	203	196	205	NS
Murphy	190	197	196	194	NS
PTBS	222	223	238	222	NS
RREC	240	241	242	229	NS

[z] NS = not significant at the 0.10 level.

Table 4. Effect of P rate, averaged across P application times (except for Lake Hogue), on rice dry-matter accumulation and tissue-P concentration 10 to 14 days after flooding for studies conducted in 2004.

	P-fertilizer rate (lb P_2O_5/acre)				
Parameter/site	0	25	50	100	$LSD_{0.10}$
Dry matter	(lb dry matter/acre)				
Crouch	1212	1498	1335	1582	233
Lake Hogue	1776	1816	1889	1980	113
Murphy	1321	1455	1499	1690	164
PTBS	1401	1446	1752	1851	251
RREC	831	740	945	847	128
Tissue P	(% P)				
Crouch	0.228	0.220	0.228	0.246	0.011
Lake Hogue	0.348	0.358	0.371	0.378	0.014
Murphy	0.255	0.264	0.283	0.279	0.013
PTBS	0.229	0.253	0.279	0.303	0.016
RREC	0.274	0.281	0.288	0.320	0.019

Table 5. Effect of 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 2004.

	K-fertilizer rate (lb K_2O/acre)					
Site	0	40	80	120	160	$LSD_{0.10}$
PD	(% K)					
Crouch	1.75	1.93	2.01	2.06	2.31	0.14
Hoskyn	--	--	--	--	--	--
Lake Hogue	1.20	1.45	1.57	1.75	2.15	0.22
Murphy	1.34	1.58	1.74	1.89	2.15	0.17
PTBS	1.34	1.52	2.03	2.18	2.25	0.28
RREC	2.88	2.94	3.15	3.25	3.37	0.20
Late boot	(% K)					
Crouch	--	--	--	--	--	--
Hoskyn	1.06	1.18	1.41	1.62	1.57	0.15
Lake Hogue	1.04	1.21	1.28	1.50	1.69	0.12
Murphy	--	--	--	--	--	--
PTBS	--	--	--	--	--	--
RREC	1.79	1.85	1.92	2.00	1.95	0.10

Table 6. Effect of K rate, by location, on rice height and dry-matter accumulation at the late boot to early heading stages for studies conducted in 2004.

Site	K-fertilizer rate (lb K_2O/acre) 0	40	80	120	160	$LSD_{0.10}$
Dry matter	(lb dry matter/acre)					
Crouch	9096	11336	11283	10571	10709	NS[z]
Hoskyn	9914	11147	11215	10714	10644	NS
Lake Hogue	9217	9528	10089	10390	10216	624
Murphy	7281	8657	8549	9740	9835	1467
PTBS	10915	10578	11603	12290	12727	NS
RREC	10534	9588	8953	9291	9992	NS
Height	(height, cm)					
Crouch	108	111	113	112	113	2
Hoskyn	100	100	103	105	101	NS
Lake Hogue	98	100	101	102	104	2
Murphy	88	93	94	96	98	4
PTBS	100	102	102	104	105	3
RREC	106	103	104	103	106	NS

[z] NS = not significant at the 0.10 level.

Table 7. Effect of K rate, by location, on rice grain yield for studies conducted in 2004.

Site	K-fertilizer rate (lb K_2O/acre) 0	40	80	120	160	$LSD_{0.10}$
	(bu/acre)					
Crouch	201	207	206	206	204	NS[z]
Hoskyn	196	191	203	198	200	NS
Lake Hogue	197	203	206	209	213	7
Murphy	183	187	198	204	206	7
PTBS	204	191	200	223	184	20
RREC	225	215	218	219	216	NS

[z] NS = not significant at the 0.10 level.

The Nitrogen Fertilizer Value of Preplant-Incorporated Poultry Litter for Flood-Irrigated Rice

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ABSTRACT

Poultry litter contains nitrogen (N), phosphorus, potassium, and many micronutrients and has been used as the primary N-fertilizer source for pastures and forage crops in western Arkansas for a number of years. The objective of this study was to determine the N-fertilizer value of preplant-incorporated fresh and pelletized litter in comparison to urea fertilizer applied before flooding rice (*Oryza sativa* L.) at the 5-leaf stage. Studies were conducted on two silt loams in 2004. Fresh and pelleted litter was preplant-incorporated at rates of 0, 30, 60, 120, 180, and 240 lb total-N/acre and compared with urea applied preflood at 0 to 150 lb N/acre. Studies were duplicated at each site with one study flooded at the 5-leaf stage and for the other study, the flood was delayed about 2 weeks. Rice-grain yield was used to estimate the value of litter as an N-fertilizer source. Fresh and pelletized litter behaved similarly with both litter sources being less efficient N fertilizers when compared with urea in the normal flood system. However, near maximal yields were produced by high litter-N rates in all four studies. Preplant-incorporated poultry litter applied at 240 lb total-N/acre produced yields similar to 60 to 90 lb N/acre as urea applied preflood in three of the four studies.

INTRODUCTION

Poultry litter contains nitrogen (N), phosphorus, potassium, and many micronutrients and has been used as the primary N-fertilizer source for pastures and forage crops in western Arkansas for a number of years. In Pennsylvania, manure-use recommendations indicate that 15 to 75% of the total-N content of poultry manure is plant-available for summer crops during the first year, depending on the times of application and incorporation following application (Beegle, 1997). The total-N content of poultry litter ranges from 34 to 136 lb N/ton (dry-weight basis) with an average of about 82 lb N/dry ton (Edwards and Daniel, 1992).

Poultry litter has been used as a soil amendment to help restore the productivity of precision-leveled soils in eastern Arkansas, but its contribution toward the seasonal nutrient requirements for rice has not been investigated until recently (Slaton et al., 2004a, b). The primary objective of this study was to compare the N-fertilizer value of preplant-incorporated fresh broiler and pelletized litter to urea fertilizer applied before flooding rice at the 5-leaf stage. A delayed-flood study was included in 2004 for the same purpose and to determine how delaying the flood influenced rice uptake of litter N. The study's hypothesis was that the N in poultry litter would be a less efficient N source for flood-irrigated rice when compared with urea applied preflood to rice at the 5-leaf stage (normal flood) and that delaying the flood would improve N uptake from poultry litter. The study's ultimate goal is to provide growers with recommendations on how to adjust preflood-urea rates on soils that receive poultry litter to supply the recommended rates of P and K.

PROCEDURES

Four studies were established in 2004. Two studies, a normal- and delayed-flood study, were established on a Calhoun silt loam at the Pine Tree Branch Station (PTBS) near Colt, Ark., and on a Dewitt silt loam at the Rice Research and Extension Center (RREC) near Stuttgart, Ark. A study was also established on a Sharkey clay at the Northeast Research and Extension Center in Kieser, Ark., but will not be reported due to excessive bird damage at seedling emergence and resulting low yields. Eight composite soil samples (0- to 4-in. depth), two from each replicate, were taken to characterize soil chemical properties before treatments were applied (Table 1). Soybean [*Glycine max* (Merr.) L.] was the previous crop at both locations.

Fresh-broiler and pelletized poultry litter (Lee Harris Farms and Company, 8868 Lee Lane, Bentonville, Ark.) was broadcast applied to plots that were 16-ft long and 6-ft wide. Fresh poultry litter was obtained from the University of Arkansas Savoy poultry production facility. Approximately 12 months had passed since the previous clean-out and the initial bedding application of a combination of rice hulls and sawdust. Both litter sources were analyzed for nutrient content (Table 2) using procedures outlined by Peters (2003).

Litter was applied at rates of 0, 30, 60, 120, 180, and 240 lb total-N/acre with rates calculated using the moist litter-N concentrations of each source. Moist-weight litter application rates ranged from 769 (30 lb N for pelleted litter) to 6452 (240 lb N for fresh) lb/acre. Poultry litter was shallowly incorporated with a small tiller (RREC) or a field cultivator (PTBS) within five hours after application to reduce volatilization losses of NH_3-N. To ensure that P and K were not yield-limiting factors, triple superphosphate (100 lb/acre) and muriate of potash (100 lb/acre) were also broadcast-applied to plots that received preflood urea-N before seeding. 'Wells' rice was drill-seeded (100 lb seed/acre) at each location with each plot containing 9, 16-ft long rows of rice with 7-in. drill spacings and an 18- to 24-in. wide alley separating adjacent plots.

For the normal-flood treatment, urea was broadcast-applied to plots that received no litter near the 5-leaf stage. At the PTBS and RREC, urea was applied to a dry soil surface at rates from 0 to 150 lb N/acre in 30 lb urea-N/acre increments. Plots were flooded within 2 days after urea was applied. No midseason N was applied. The dates of litter application, flooding, and several other agronomically important plot management events are listed in Table 3. The delayed-flood urea treatments were intended to be applied 2 weeks after the normal flood. Studies at the PTBS were conducted as planned, but both the normal- and delayed-flood urea applications were delayed at the RREC (Table 3), with urea being applied to a moist or muddy soil in both cases.

Whole, aboveground plant samples were taken preflood, at the 0.5-in. internode elongation (panicle differentiation) and early-heading growth stages of rice (Table 3). Plant samples were taken from a 3-ft section from the first inside row of each plot. Samples were dried to a constant weight in forced-draft oven, weighed, ground to pass a 1 mm sieve, and analyzed for N concentration by combustion. Aboveground rice-N content was calculated using rice-N concentration and dry-matter accumulation data and expressed as lb N/acre. At maturity, grain yields were determined from the middle four or five rows of rice using a plot combine and adjusted to a uniform moisture content of 12% for statistical analysis.

Each experiment was a randomized complete block design with a 3 (nutrient source) × 5 (application rate) factorial treatment structure and included an unfertilized control (0 lb N/acre). Each treatment was replicated four times. For each site, grain yield means were calculated for each N source and rate and the means for each N source were regressed against the applied N rate. The control (0 lb N/acre) yields were not used in regression analyses. The initial model included the linear and non-linear terms for N-rate and the interaction for N-source with the linear and non-linear rate terms. When appropriate, the most complex non-significant term of the model was eliminated sequentially until the simplest significant model was obtained. The slope and intercept for each N source were compared statistically by site-flood management.

RESULTS AND DISCUSSION

Grain Yield

Rice-grain yields ranged from 4249 to 9439 lb grain/acre for the two RREC studies and from 4907 to 9682 lb grain/acre for the two PTBS studies (Table 4). All studies except the delayed-flood study at the RREC produced high rice yields. For the RREC delayed-flood study, the urea-N treatments produced yields that were lower than expected and partially attributed to late application (Table 3) of urea to a moist soil surface. In general, yields of rice receiving preplant-incorporated poultry litter were greater than the yields produced by identical treatments in 2003 tests (Slaton et al., 2004b). Rice receiving preflood urea produced the numerically greatest yields at N rates of 120 lb N/acre for both normal- and delayed-flood systems at the PTBS, 150 lb N/acre for the normal flood at the RREC, and 30 lb N/acre for the delayed flood at the RREC (Table 4). Interestingly, grain yields in the control plots were slightly greater (519 - 584 lb grain/acre) for the delayed-flood system compared with the normal-flood system. Preplant-incorporated poultry litter applied at 240 lb total-N/acre produced similar yields as 60 to 90 lb N/acre as urea applied preflood in three of the four studies.

Delayed-Flood Rice Yields

The most complex model terms (i.e., the non-linear rate × source interaction and nonlinear rate terms) were not significant for any of the four sites and were eliminated from the models. The final significant model for both delayed-flood systems showed a significant N-source × N-rate (linear) interaction (Table 5). At the PTBS, slopes differed among N sources with the yield slopes for fresh and pelleted litter being similar and significantly lower than the slope for urea (Table 5). The intercepts among N sources were similar and significantly greater than zero for the PTBS delayed-flood system. At the RREC, the intercepts were significantly greater than zero and differed among N sources with the intercept for both forms of litter being equal and lower than the yield intercept for urea. As indicated by the significant interaction, the slope terms also differed among N sources with both litter forms having similar positive slopes that were significantly greater than the slope for urea. The slope for urea yields was also not significantly different than zero, indicating that rice yields did not increase or decrease as urea-N rate increased.

Normal-Flood Rice Yields

For the normal-flood system at both locations, only the main effects of N-source and N-rate (linear) were significant (Table 5). Within each site, rice yields increased linearly at a uniform rate [10.38 (PTBS) or 15.04 (RREC) lb grain/1 lb applied N] as litter- or urea-N rate increased. However, the intercept varied among N-sources with the intercept for urea being significantly greater than the intercepts for fresh and pelleted litter which were the same. The greater intercept for rice receiving urea-N indicates that urea is absorbed more efficiently than litter-N, allowing rice to reach maximal yields with lower total-N rates. The 2004 normal-flood data suggest that maximal rice yields can be produced with preplant-incorporated poultry litter, but higher rates of litter-N must be applied to achieve maximal yield.

SIGNIFICANCE OF FINDINGS

Data collected in 2003 (Slaton et al., 2004b) showed that maximal rice yields could not be achieved with litter total-N rates up to 240 lb N/acre and thus these litter-N rates had little value as an N-fertilizer. In contrast, the 2004 data suggest that preplant-incorporated poultry litter has appreciable value as an N-source for flood-irrigated rice. Although study leaders would not recommend the use of poultry litter rates high enough to supply the total N required to produce maximal rice yields on undisturbed silt loam soils, preflood rates of urea may need to be lowered to prevent over-fertilization with N when poultry litter is applied at rates of 2000 to 3000 lb/acre. These lower litter rates may be supplemented as alternatives to recommended rates of inorganic P and K fertilizers and also provide some starter N to the rice crop. Although total-N uptake by rice at the midseason and heading stages has not yet been completed for the 2004 studies, these data should support yield data and help to refine the N-fertilizer value of litter for rice. Final recommendations regarding the inorganic (urea) N-rate adjustments for rice receiving preplant-incorporated poultry litter should be available following the third year of evaluation (2005).

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Table 1. Selected soil chemical properties of research sites at the Pine Tree Branch Station (PTBS, Calhoun silt loam) and the Rice Research and Extension Center (RREC, Dewitt silt loam) for studies conducted using normal- (NF) and delayed-flood (DF) management during 2004.

Site	Soil pH[z]	Mehlich-3-extractable soil nutrient concentrations[y,x]							
		P	K	Ca	Mg	Na	S	Zn	Cu
		(mg/kg)							
PTBS-NF	7.3	18	153	1668	292	40	8.0	1.7	1.0
PTBS-DF	7.3	23	167	1726	230	31	8.0	1.4	1.0
RREC-NF	6.4	9	148	1146	164	96	12.0	1.8	0.8
RREC-DF	6.3	11	181	1049	156	69	9.0	1.6	0.9

[z] Extracted with the standard Mehlich-3 method (1:10 v:v extraction). All values are the mean of eight composite soil samples (0 to 4 in.) taken from the plot area.
[y] Multiply mg/kg by 2 to get lb/acre.

Table 2. Selected chemical and physical properties of two poultry litter sources used in trials conducted at the Pine Tree Branch Station (PTBS) and Rice Research and Extension Center (RREC) during 2004.

Litter source[z]	pH	C	N	P	K	Zn	NH_4-N	NO_3-N	Moist
		(%)				(mg/kg)			(%)
Fresh	8.2	31.5	3.7	1.6	2.5	374	2627	194	23.7
Pelletized	7.5	33.5	3.9	1.0	2.3	371	278	613	14.3

[z] All values are the mean of two sub-samples from each litter source.

Table 3. Selected dates of agronomically important management events for studies conducted at the Pine Tree Branch Station (PTBS) and the Rice Research and Extension Center (RREC) during 2004.

Event	Location- flood management			
	PTBS		RREC	
	Normal	Delayed	Normal	Delayed
	(month / day)			
Litter application and seeding	4/19	4/19	4/20	4/20
Preflood N applied	6/3	6/16	6/7	6/28
Flood established	6/3	6/17	6/8	6/28
Samples at panicle differentiation	6/29	--	6/29	--
Samples at heading	7/22	7/28	7/22	7/29

Table 4. Mean grain yield of rice as affected by N source (urea or fresh and pelleted litter) and rate for normal- and delayed-flood studies conducted at the Pine Tree Branch Station (PTBS) and the Rice Research and Extension Center (RREC) during 2004.

		Location- flood management			
		PTBS		RREC	
N source	N rate	Normal	Delayed	Normal	Delayed
	(lb N/acre)	(lb grain/acre)			
Control	0	4907	5426	4249	4833
Urea	30	6568	6281	6361	6621
Urea	60	7764	6955	7295	6295
Urea	90	8378	8202	9180	6320
Urea	120	9682	8498	7996	6311
Urea	150	8823	8359	9077	6212
Fresh	30	5755	5760	5531	5655
Fresh	60	6069	5853	6970	5992
Fresh	120	6609	6882	7750	7328
Fresh	180	7624	6900	6783	8190
Fresh	240	7687	7303	8692	8695
Pelleted	30	5732	5666	4637	5495
Pelleted	60	6456	6240	5772	5827
Pelleted	120	7293	6531	6674	6893
Pelleted	180	6702	7415	8012	8482
Pelleted	240	8430	7696	9439	8773

Table 5. Regression model coefficients and ANOVA P-values for grain yield of rice as affected by N source and rate for normal- and delayed-flood studies conducted at the Pine Tree Branch Station (PTBS) and the Rice Research and Extension Center (RREC) during 2004.

		Location- flood management			
	Model	PTBS		RREC	
N source	factor	Normal	Delayed	Normal	Delayed
Urea	Intercept[z]	7197 a	5949	6466 a	6592 a
	Slope[y]	10.38	16.96 A	15.04	-2.39 A[x]
Fresh	Intercept	5284 b	5581	5023 b	5247 b
	Slope	10.38	6.79 B	15.04	13.65 B
Pelleted	Intercept	5458 b	5503	4784 b	4940 b
	Slope	10.38	8.55 B	15.04	15.27 B
N-source	0.0005	0.5889	0.0107	0.0020	
N-rate	0.0002	<0.0001	0.0001	<0.0001	
N-source × N-rate	NS	0.0483	NS	0.0002	
N-rate × N-rate	NS	NS	NS	NS	
N-source × (N-rate)^2	NS	NS	NS	NS	

[z] For each column (site-year) Intercept values followed by the same lowercase letter are not different at (P < 0.05) as determined by contrast comparisons.

[y] For each column (site-year) slope values followed by the same uppercase letter are not different at (P < 0.05) as determined by contrast comparisons.

[x] Coefficient is not different from zero.

Rice Response to Boron Application Rate and Time in Arkansas, Louisiana, Mississippi, and Missouri

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ABSTRACT

This report describes the results of boron (B)-fertilization trials initiated by scientists at the University of Arkansas, Louisiana State University, Mississippi State University, and the University of Missouri during 2004. The overall objective of these studies was to evaluate rice-grain yield response to B fertilizer application time (i.e., growth stage). Boron was applied at 0.33 lb B/acre as Solubor DF (17.5% B) at three different growth stages including preflood, late-tillering or panicle initiation, and late-boot stage before flag-leaf emergence. All B-application times were compared to an unfertilized control. In 2004, no statistically significant grain yield increases or decreases were measured among B treatments for the six study sites. Sixteen site-years of data collected since 2002 suggest that B is not a yield-limiting factor for flood-irrigated rice in the mid-South rice-producing region of the U.S.

INTRODUCTION

Boron deficiency of soybean [*Glycine max* (L.) Merr.] has become relatively common in northeast Arkansas (Slaton et al., 2002). Rice (*Oryza sativa* L.) is grown in rotation with soybean in all the mid-South rice-producing states (i.e., Arkansas, Louisiana, Missouri, and Mississippi) and limited information is available describing whether rice responds to B fertilization, especially for rice grown in the U.S.

Trials examining B fertilization of rice have been conducted in Arkansas, Louisiana, Mississippi, and Missouri since 2002. Significant, but nominal (~5 to7% increase) rice-yield increases from B fertilization were found in 4 of 10 site-years of research conducted during 2002 and 2003 (Slaton et al., 2003; 2004). This report describes the results of B-fertilization trials initiated by scientists at the University of Arkansas, Louisiana State University, Mississippi State University, and the University of Missouri during 2004. The overall objective of these studies was to evaluate rice grain yield response to B fertilizer application time (i.e., growth stage) in field studies. The ultimate goal of these trials was to provide growers with unbiased, research-based answers concerning the need for direct B fertilization of rice.

PROCEDURES

In 2004, studies were established at six sites to evaluate the effect of B fertilizer application time on rice grain yield in Arkansas (3), Louisiana (1), Mississippi (1), and Missouri (1). Studies were established at the Pine Tree Branch Station near Colt, Ark., (St.Francis-ARK, Calhoun series); in grower fields located in Cross (Cross-ARK, Henry series) and Poinsett counties, Ark. (Poinsett-ARK); at the Crowley Rice Research Station in Crowley, La. (CRRS-LA, Crowley series); at the Delta Research Extension Center near Stoneville, Miss. (DREC-MS, Sharkey series); and at the Missouri Rice Research Farm located near Qulin, Mo. (MRRF-MO, Crowley series). The soil series and selected soil chemical properties for each site are listed in Table 1. Composite soil samples were taken before the first B application and analyzed for soil chemical properties by laboratories in each state (Table 1).

Management of rice during the growing season was similar among the studies. Seedbeds were prepared using conventional tillage and recommended long- or medium-grain rice cultivars were drill-seeded at each site (Table 2). Phosphorus and potassium fertilizers were applied to each study to ensure these nutrients were not yield-limiting factors. Near the 5-leaf stage, 120 to 150 lb N/acre as urea were broadcast to a dry soil surface and followed by flooding. Rice management with respect to fertilization, irrigation, and pest control was similar to guidelines recommended by each state's cooperative extension service for the dry-seeded, delayed-flood rice cultural system.

Boron was applied at a single rate of 0.33 lb B/acre as Solubor DF (17.5% B) at three different times (i.e., growth stages) including preflood, late-tillering or panicle initiation, and the boot stage before flag-leaf emergence and compared with an unfertilized control. Boron was applied with a backpack sprayer calibrated to deliver 10 gal/acre. At each application time, the appropriate amount of Solubor was mixed with water to deliver the specified rates. Boron rates were omitted from the 2004 studies because studies conducted in 2002 and 2003 generally showed that grain yields usually differed among B application times, averaged across B rates, suggesting that application time was more important than B-application rate.

At all locations, whole-plant samples were taken near the panicle initiation or differentiation stages and flag-leaf samples were taken at the late-boot to early-heading stages for elemental analysis. Whole-plant samples were harvested at the soil level from a 3-ft section of the first inside row, dried, weighed, and ground for digestion. Whole-plant samples were taken only from the control and B treatments that had been applied on the basis of panicle differentiation. Twenty flag leaves were randomly selected from each plot at the late-boot stage for elemental analysis. Tissue analysis to determine B concentration has not yet been completed for the Missouri site. At maturity, the center rows of each plot were harvested with a small-plot combine for grain yield. Grain moisture was adjusted to a uniform content of 12% for statistical analysis.

At all sites, B-fertilizer treatments were replicated eight times and arranged in a randomized complete block design. Analysis of variance was conducted for all data using the PROC GLM procedure of SAS. Mean separations were performed by Fishers protected least significant difference (LSD) at a significance level of 0.10.

RESULTS AND DISCUSSION

Rice-grain yields were not affected by B-application time at any of the six study sites (Table 3). Numerical yield values among sites showed no consistent trend for any B-application time to produce higher yields than the unfertilized control. Yield data suggest that B is not a yield-limiting nutrient of flood-irrigated rice grown in the mid-South rice-producing states.

Whole-plant B concentrations near the panicle differentiation stage showed significant differences only at the three sites in Arkansas, with the preflood and late-tillering application times significantly increasing plant-B concentrations compared with the control (Table 4). Whole-plant B concentrations ranged from 3.4 to 5.8 mg B/kg in the unfertilized controls of the five completed studies. Boron concentration sufficiency ranges of 6 to 10 mg B/kg (Mills and Jones, 1996) and 6 to 15 mg B/kg (Doberman and Fairhurst, 2000) at panicle initiation for mature rice leaves have been proposed. Although tissue-concentration data from our studies were for whole-plants (i.e., not mature leaves) taken near panicle initiation, data suggest that the sufficient B concentration for rice may be lower than 6 mg B/kg.

Flag-leaf B concentrations for the unfertilized controls at heading ranged from 4.5 to 8.1 mg B/kg at the five study sites with completed data (Table 5). Diagnostic B concentrations for this plant part and growth stage were not found in the literature. Flag-leaf B concentrations were generally slightly greater than B concentrations of whole plants taken near panicle initiation for all sites except the clay soil in Mississippi. Significant differences in flag-leaf B concentrations were found only for the site in Louisiana where the unfertilized control had significantly lower B concentrations than rice that received B (Table 5).

SIGNIFICANCE OF FINDINGS

Rice-grain yields in mid-South rice-producing states generally do not benefit from direct fertilization with B. No significant response has occurred in 12 of 16 site-years of data collected since 2002. When statistically significant yield increases did occur, yields were about 5 to 7% greater than the unfertilized control, but no single B-application rate or time consistently increased rice yields in these ‘responsive’ studies. Apparently, rice has a low requirement for B and is able to produce near maximal yields on most soils used to grow rice without supplemental B suggesting that soil, irrigation water, or both provide sufficient B for rice grown in the mid-South. Perhaps the most significant finding of this research is that direct application of up to 1 lb B/acre to rice did not reduce growth and yield of flood-irrigated rice and that the minimal critical tissue-B concentration may be lower than published values.

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Table 1. Selected soil chemical properties for B fertilization trials conducted in Arkansas, Louisiana, Mississippi, and Missouri during 2004.

Location	Soil series	Soil pH	Soil nutrients P	K	Ca	Mg	S	Zn	B
			(mg/kg)						
Cross-ARK[z]	Henry	6.0	13	104	981	185	12	2.2	0.1
Poinsett-ARK[z]	Henry	6.9	32	106	1067	185	12	7.5	0.3
St Francis-ARK[z]	Calhoun	8.0	18	94	1877	311	5	1.3	0.2
CRRS-LA[z,y]	Crowley	7.2	7	74	1227	245	6	3.4	0.5
DREC-MS[x]	Sharkey	8.1	90	236	5150	1086	—	4.3	1.9
MRRF-MO[w]	Crowley	5.9	17	73	—	—	2	1.3	0.15

[z] Soil samples were extracted with Mehlich-3 solution at a soil:solution ratio of 1:10. Values are the mean of four composite soil samples collected from the 0- to 4-in. depth.
[y] Composite soil sample from the 0- to 6-in. depth.
[x] Soil samples were extracted with the Lancaster method for P, K, Ca, Mg, and Zn, and Mehlich-3 for B. Values are the mean of four composite soil samples from the 0- to 6-in. depth.
[w] Soil samples were extracted with ammonium acetate for cations, Bray 1 for P, DPTA for micronutrients, and hot-water extraction for B. The soil pH is salt pH rather than water pH. Values are the mean of four composite soil samples from the 0- to 6-in. depth.

Table 2. Summary of application times, sample dates, and other management practices for B fertilization trials conducted in 2004.

Item/event	Arkansas Cross	Arkansas Poinsett	Arkansas St Francis	Louisiana CRRS	Mississippi DREC	Missouri MRRF
	(month / day)					
Cultivar	Bengal	Wells	Wells	Wells	Cocodrie	Cocodrie
Emergence	8 May	26 April	6 May	4 April	25 April	10 May
Preflood N	24 May	27 May	3 June	26 April	25 May	7 June
0.5-in. IE	28 June	21 June	27 June	—	18 June	—
50% heading	23 July	17 July	24 July	30 June	21 July	—
Harvest	27 Sept.	14 Sept.	8 Sept.	3 August	24 August	3 October
Boron fertilization applications						
Preflood	3 May	3 May	11 May	26 April	27 May	7 June
Midseason	23 June	23 June	16 June	7 June	11 June	7 July
Late boot	14 July	14 July	14 July	21 June	2 July	1 August
Plant sample dates						
Panicle differentiation	29 June	29 June	23 June	10 June	22-June	—
Flag leaves at late boot	28 July	22 July	21 July	12 July	11-July	—

Table 3. Effect of B (0.33 lb B/acre) application time on main crop rice grain yield for trials conducted in Arkansas, Louisiana, Mississippi, and Missouri during 2004.

	Grain yield					
B application	Arkansas			Louisiana	Mississippi	Missouri
time	Cross	Poinsett	St Francis	CRRS	DREC	MRRF
	(bu/acre)					
Control	178	203	201	173	169	182
Preflood	183	204	198	176	172	182
Late tillering	179	207	203	177	169	182
Boot	177	205	198	173	175	182
P-value	0.6121	0.2852	0.5947	0.5471	0.3733	0.9492
C.V., %	5.3	2.5	4.3	4.3	4.3	7.1

Table 4. Effect of B (0.33 lb B/acre) application time on rice whole-plant B concentration near the panicle differentiation stage for trials conducted in Arkansas, Louisiana, Mississippi, and Missouri during 2004.

	Flag-leaf B					
B application	Arkansas			Louisiana	Mississippi	Missouri
time	Cross	Poinsett	St Francis	CRRS	DREC	MRRF
	(mg B/kg)					
Control	3.4	3.7	4.2	3.8	5.8	—
Preflood	3.6	4.1	4.4	3.9	5.9	—
Late tillering	3.8	4.8	4.5	4.2	5.8	—
LSD0.10	0.2	0.4	0.2	NS	NS	—
P-value	0.0068	0.0003	0.0756	0.4682	0.8630	—
C.V., %	6.0	9.6	7.9	15.0	9.1	—

Table 5. Effect of B (0.33 lb B/acre) application time on rice flag-leaf B concentration at the late boot or early heading stage for trials conducted in Arkansas, Louisiana, Mississippi, and Missouri during 2004.

	Flag-leaf B					
B application	Arkansas			Louisiana	Mississippi	Missouri
time	Cross	Poinsett	St Francis	CRRS	DREC	MRRF
Control	5.6	6.1	8.1	6.8	4.5	—
Preflood	5.5	6.4	8.3	7.3	4.8	—
Late tillering	5.4	5.9	8.1	7.2	4.5	—
Boot	5.5	6.0	8.7	7.3	4.3	—
LSD0.10	NS	NS	NS	0.3	NS	—
P-value	0.9052	0.5920	0.3131	0.0546	0.2706	—
C.V., %	13.1	11.9	7.7	5.0	10.8	—

Rice Irrigation-Water Management for Water, Labor, and Cost Savings

P. Tacker and W. Smith

ABSTRACT

Field demonstrations of Multiple-Inlet Rice Irrigation (MIRI) were conducted in 12 counties with 17 producers on 19 different fields. Additional MIRI work was coordinated through county agents in 10 counties and involved several other producers. Multiple-inlet field tours were conducted in several of the Delta counties, including Jefferson, Lonoke, Prairie, and Cross. A field comparison of MIRI on a clay soil showed a 23% reduction in water usage for the complete season. Two MIRI field comparisons on silt loam soils showed that for the complete season, there was a 22% water usage reduction on one field and a reduction of 28% on the other. While helping a cooperator determine the flow rate of his well with a flowmeter, the measurements revealed less flow than the cooperator was expecting. He knew that this flow rate would not be adequate to keep up with the rice water demand throughout the season. The producer contacted a well driller who was able to re-work the well to increase the flow. The cooperator was very pleased that this problem was discovered and corrected before the rice was in a critical need for water.

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) water conservation, and (3) improved water management and fertilizer efficiency. The mechanics of this system need to be introduced to growers and adequately evaluated on production-sized fields with varying soil, water, and topographical conditions. This can be best done 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 separated by several miles. Managing these units becomes time- and labor-intensive. This can result in someone spending a lot of time behind the windshield to determine if the pumping units are working properly. Many times a pumping unit may shut off soon after it is turned on without anyone knowing. When this happens, critical pumping time to the crop is lost. Pump-unit monitors with possible pump shut-off systems can be used to address this problem. The pump monitors can be programmed to call a cell phone and/or send an e-mail to notify a producer if water stops running from the pump. This could save valuable pumping time and possibly reduce the amount of labor needed to check pump units. The units also have the ability to shut a pumping unit down if needed. Current evaluations of the pump-unit monitors are ongoing at the experimental research centers. The evaluations will test for practicality, dependability, and affordability. Efforts are ongoing to work with producers, as well as control-equipment companies, to determine the possibilities of demonstrations in the future.

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 teach growers how to use the two methods with hands-on experience being invaluable. If the measured flow is substantially less than expected, a pumping-plant performance evaluation can be conducted. The evaluation helps determine what can be done to improve the situation. This provides very valuable information to the grower involved. The information is then used to advise many other growers of the factors considered when determining pumping-plant performance.

On-farm demonstrations cannot be conducted on every farm. However, experience and information gained on one farm are often applicable to other farms in the same area. The extension staff involved in on-farm demonstrations will become better able to advise growers on rice 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 will be coordinated with interested county extension agents and growers. When possible, the initial focus will be in designated and pending critical groundwater-usage areas. Priority will also be given to opportunities that allow for comparison of a conventionally irrigated field to a field that is irrigated with multiple inlets.

Measurements will be taken of water savings, cost savings, and other impacts of different irrigation-water management efforts. These efforts will include multiple-inlet rice irrigation, possible pump monitor systems, pump flow measurement, and pumping-plant performance evaluation.

Information and experience gained from on-farm irrigation demonstrations will be distributed through field tours, meetings, presentations, and publications.

RESULTS AND DISCUSSION

Project investigators and county extension agents worked directly with 17 producers in 12 counties on 19 different field demonstrations of MIRI (Table 1). Assistance with MIRI was indirectly provided to several additional growers in 10 counties by phone or through county extension agents. Many of the counties are either designated or pending designation as critical groundwater-usage areas. Multiple-inlet field tours were also included in several of the Delta counties including, but not limited to, Jefferson, Lonoke, Prairie, and Cross counties.

Three field comparisons of MIRI to conventional rice irrigation were conducted in Crittenden and Poinsett counties (Table 3). The Crittenden county MIRI field with a clayey soil showed a 23% water savings for the entire growing season. The Poinsett county comparison of two fields with a silt loam soil showed 22% less water usage for the season on one of the fields. This result was even more impressive given that polypipe rather than a flume ditch was used as a supply line to reach the MIRI field. The overall run distance of the tubing supply line and the MIRI field was about 4500 feet. This tested the length water can be pumped with poly pipe. It was a success in saving water and labor. The other Poinsett County field comparison also showed significant water savings of 28%.

Another producer in Poinsett County was impressed with the MIRI demonstration on his farm. He stated: “I thought it helped a lot on labor, but I didn’t know how much water it saved until I looked at my energy bill and it was $170 dollars less than the previous year.” Savings were achieved even though he pumped on the field in 2004 compared to 2003. The producer’s father also used MIRI on his hilly land and he stated: “We were able to set the spills and let it go. It helped out a lot with labor and worked well on the hills.” Both producers plan to use MIRI on more fields next year.

During an on-farm demonstration, a Cross County cooperator was surprised to find that the flow from his well was less than expected. The use of a flowmeter assisted in determining that the flow rate would not be adequate to keep up with the water demand of the rice field throughout the season. The producer contacted a well driller who was able to re-work the well to increase the flow. The cooperator was pleased that this problem was discovered and corrected before the rice was in critical need of water.

Two Prairie County producers initially questioned whether MIRI could help, but after seeing the results they were “…impressed and plan to use it on more fields next year.” An Arkansas County demonstration cooperator did not see significant water savings at first. After noting significant flow variations in the flowmeter readings from the well, he was able to determine there was a problem with the pump. He commented: “I know there is a problem now and I will be able to have it fixed before next year. Without the flowmeter I would have never known anything was wrong.” Even without shown water savings, he said: “I was pleased with the reduction in labor and the ability to water up the field much faster." The overwhelming response of these producers and many others was positive.

Remote monitors were installed on two pump units at the Northeast Research and Extension Center at Keiser. The initial indications are that the monitors performed very successfully. On one occasion, the system was used to remotely shut off the pump during a thunderstorm.

Experience from this year's work indicates that there is a great deal of potential for other growers to implement MIRI and remote pump monitors if demonstrations can continue to be conducted. There are still certain areas and counties in the state where MIRI has not yet been adopted and where the remote pump-monitor system has not been introduced.

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 countless 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 issues.

Cooperating growers involved in on-farm demonstrations will learn irrigation water management techniques for reducing water use, labor, and pumping cost. This will allow production to become more time-efficient and cost-efficient. To date, demonstrations show the potential value to the grower is an average reduction of 25% in both water usage and pumping cost. Also noted is an average labor reduction of 30%, a reduction in cold water rice, and increased fertilizer efficiency. The field experience and information gained from the demonstrations will be provided to other growers through field tours, meetings, and publications.

ACKNOWLEDGMENTS

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Table 1. Multiple-Inlet Rice Irrigation (MIRI) field demonstrations - 2004.

County	Fields	Producers
Arkansas*[z]	1	1
Crittenden	1	1
Cross*	1	1
Drew	1	1
Independence	1	1
Lonoke*	3	2
Mississippi	1	1
Monroe*	1	1
Poinsett*	3	3
Prairie*	3	2
St. Francis	1	1
White*	2	2
Total: 12	19	17

[z] Counties that are designated or pending designation as critical groundwater areas are indicated with an asterisk.

Table 2. Results of Multiple-Inlet Rice Irrigation (MIRI) field comparison studies - 2004.

Crittenden County:		
Daurghette Farm	Clay Fields	23% less water used during the season
Poinsett County:		
Jones Farm	Silt loam fields	22% less water usage for the season
Walls Farm	Silt loam fields	28% less water usage for the season

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

C.E. Wilson, Jr., R.J. Norman, K.A.K. Moldenhauer, J.W. Gibbons, and A.L. Richards

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 2004 were: 'Banks', 'Bengal', 'Cheniere', 'Cocodrie', 'Cybonnet', 'Francis', 'Medark', RiceTec 'CL XL8', and 'Wells'; RiceTec experimental hybrids 'XP 710', 'XP 712', 'XP 716', and 'XP 723'; and Arkansas experimental line RU0101093.

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 three years. When a new cultivar is released, the data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study are to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal-unit accumulations. In addition, 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 2004 study was conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark., on a DeWitt silt loam soil. Thirteen rice cultivars and hybrids (Ahrent, Banks, Bengal, Cheniere, Cybonnet, CL 161, CL XL8, Cocodrie, Drew, Francis, LaGrue, Medark, and Wells); four RiceTec experimental hybrids (XP 710, XP 712, XP 716, and XP 723); and one experimental line (RU0101093) 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 RiceTec hybrids which were sown at 16 seeds/ft^2 according to recommendations provided by RiceTec. The seeding dates were 2 April, 29 April, 21 May, and 7 June 2004. 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-leaf growth stage immediately prior to flooding. The flood was maintained 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 0.5-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 (α = 0.05) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 5 to 19 days (Table 1). As the seeding date was delayed, the time between seeding and emergence was generally shorter. The earlier rice was seeded, the time required from seeding to emergence and seeding to flooding was generally longer, ranging from 25 days to 49 days (Table 1). The days from emergence to flooding ranged from 19 to 30 days.

The time required from emergence to 00.5-in. IE averaged 48 days across all varieties and seeding dates (Table 2). Varieties seeded in early April required approximately 5 days longer to reach 0.5-in. IE than when seeded later. Varieties with the shortest vegetative growth period include Cocodrie, RU0101093, and RiceTec XP 723. With an average of 45 days, the vegetative growth stage is approximately 5 days earlier than other commonly grown varieties such as Bengal and Wells. The DD50 accumulation during vegetative growth ranged from a low of 1191 for Cocodrie to a high of 1393 for Medark and XP 712 when averaged across seeding dates. This difference in DD50 accumulation translates to approximately 7 days in 2004.

The time required for development between emergence and 50% heading averaged 88 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, RU0101093 is much earlier. The time required to reach 50% heading for RU0101093 averaged 74 days and ranged from 67 to 87 days. This cultivar is approximately 10 days earlier than common cultivars such as Cocodrie and Wells. Although Cocodrie has a relatively short vegetative period, the time required to reach 50% heading is similar to Wells, indicating a longer reproductive period. In contrast, RU0101093 has relatively short vegetative and reproductive growth requirements. The DD50 unit accumulations ranged from a low of 2014 for RU0101093 to a high of 2500 for Drew. The average DD50 unit accumulation required to reach 50% heading was 2366 heat units.

When averaged across seeding dates, the cultivars with the highest grain yields included CL XL8, XP 710, and XP 712 (Table 4). The highest-yielding conventional varieties were Francis and Wells. Most varieties performed best when seeded in early April or late April. As previously observed, Bengal, Francis, and Wells were stable when seeded late. However, these data also suggest that Medark, CL XL8, and XP 712 also have good yield potential when seeded late.

Long-grain varieties with the greatest milling yield potential include Cybonnet and CL 161 (Table 5). Seeding date did not significantly influence head rice yields. However, the head rice yields of most cultivars were higher when seeded in early April than at other seeding dates. Some cultivars have demonstrated little tolerance to wet and dry conditions associated with the inability to harvest at 17 to 18% moisture. RU0101093 appears to be particularly sensitive to harvest moisture in maintaining good head rice yields.

SIGNIFICANCE OF FINDINGS

The data from 2004 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.

Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2004 at the Rice Research and Extension Center near Stuttart, Ark.

	Seeding date			
Parameter	2 Apr	29 Apr	21 May	7 Jun
Emergence date	21 April	8 May	27 May	12 June
Flood date	21 May	3 June	15 June	6 July
Days from seeding to emergence	19	9	6	5
Days from seeding to flooding	49	35	25	29
Days from emergence to flooding	30	26	19	24

Table 2. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-in. internode elongation and of selected rice varieties in studies conducted at the RREC during 2004.

	Seeding date									
	2 Apr 04		29 Apr 04		21 May 04		7 Jun 04		Mean	
Variety	Days	DD50's	Days	DD50's	Days	DD50's	Days	DD50's	Days	DD50's
Ahrent	.	.	.	.	.	.	.	.	.	.
RU0101093	51	1144	43	1183	41	1161	44	1320	45	1202
Banks	52	1175	48	1309	45	1282	50	1487	49	1313
Bengal	57	1324	52	1408	48	1383	48	1426	51	1385
Cheniere	53	1204	49	1334	44	1252	49	1456	49	1311
CL161	.	.	.	.	.	.	.	.	.	.
Cocodrie	51	1144	46	1259	38	1067	43	1295	45	1191
CyBonnet	50	1110	48	1309	42	1191	43	1295	46	1226
Drew	.	.	.	.	.	.	.	.	.	.
Francis	51	1144	49	1334	45	1282	45	1343	48	1276
Lagrue	.	.	.	.	.	.	.	.	.	.
Medark	56	1296	52	1408	48	1383	50	1487	52	1393
CLXL8	53	1204	49	1334	44	1252	44	1320	48	1277
XP710	50	1110	47	1284	42	1191	43	1295	46	1220
XP712	56	1296	52	1408	48	1383	50	1487	52	1393
XP716	55	1269	49	1334	48	1383	49	1456	50	1360
XP723	51	1144	45	1234	41	1161	43	1295	45	1208
Wells	56	1296	49	1334	45	1282	50	1487	50	1349
Mean	53	1197	48	1318	44	1259	46	1381	48	1289
$LSD_{(0.05)}$	0	0	0	0	0	0	0	0		
C.V., %	0	0	0	0	0	0	0	0		

Table 3. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice varieties in studies conducted at the RREC during 2004.

	Seeding date									
	2 Apr 04		29 Apr 04		21 May 04		7 Jun 04		Mean	
Variety	Days	DD50's	Days	DD50's	Days	DD50's	Days	DD50's	Days	DD50's
Ahrent	.	.	96	2692	77	2215	.	.	87	2453
RU0101093	70	1672	86	2424	67	1946	.	.	74	2014
Banks	89	2254	96	2692	77	2215	.	.	87	2387
Bengal	87	2195	97	2707	78	2230	.	.	87	2377
Cheniere	87	2195	96	2692	77	2215	.	.	87	2367
CL161	87	2203	96	2692	77	2215	.	.	87	2370
Cocodrie	85	2131	98	2722	79	2245	.	.	87	2366
CyBonnet	88	2227	98	2722	79	2245	.	.	88	2398
Drew	90	2283	99	2749	80	2271	.	.	90	2434
Francis	84	2097	99	2741	80	2263	.	.	88	2367
Lagrue	.	.	99	2741	80	2263	.	.	90	2502
Medark	85	2131	99	2741	80	2263	.	.	88	2378
CLXL8	85	2131	95	2671	76	2193	.	.	85	2332
XP710	87	2195	98	2722	79	2245	.	.	88	2387
XP712	85	2131	99	2741	80	2263	.	.	88	2378
XP716	87	2195	99	2741	80	2263	.	.	89	2400
XP723	84	2084	99	2741	80	2263	.	.	88	2363
Wells	85	2131	94	2641	75	2163	.	.	85	2312
Mean	85	2141	97	2698	78	2221	.	.	87	2366
$LSD_{(0.05)}$	1.03	1.32	0.12	0.14	0.15	0.17				
C.V., %	1.2	40.3	0.2	5.3	0.17	5.4				

Table 4. Influence of seeding date on grain yield of selected rice varieties studies conducted at the RREC during 2004.

	Seeding date				
Variety	2 Apr 04	29 Apr 04	21 May 04	7 Jun 04	Mean
	(bu/acre)				
Ahrent	161.0	180.7	156.3	142.1	160.0
RU0101093	187.4	177.0	157.5	137.8	164.9
Banks	186.0	193.4	169.2	134.4	170.7
Bengal	202.0	202.6	155.1	158.3	179.5
Cheniere	188.0	203.9	165.0	148.6	176.4
CL161	169.5	180.4	135.6	125.2	152.7
Cocodrie	182.0	201.9	158.7	140.8	170.8
CyBonnet	190.6	178.5	146.0	134.6	162.4
Drew	172.2	185.2	148.6	141.8	162.0
Francis	211.6	214.0	162.3	163.3	187.8
Lagrue	174.9	208.7	142.0	123.8	162.4
Medark	193.6	180.7	151.9	152.9	169.8
CLXL8	216.1	244.4	214.3	156.1	207.7
XP710	239.1	250.0	212.2	141.0	210.6
XP712	214.1	247.6	200.5	158.0	205.1
XP716	245.8	226.2	179.3	75.5[z]	181.7
XP723	235.4	254.5	211.6	79.1[z]	195.2
Wells	202.9	194.5	171.7	156.2	181.3
Mean	198.5	206.9	168.8	137.2	177.8
$LSD_{(0.05)}$	12.8	16.1	13.1	14.4	6.9
C.V., %	4.5	5.5	5.5	7.4	5.6

[z] The abnormally low yield was due to shattering and bird damage.

Table 5. Influence of seeding date on milling yield of selected rice varieties studies conducted at the RREC during 2004.

Variety	Seeding date 2 Apr 04	29 Apr 04	21 May 04	7 Jun 04	Mean
	------------------------------- (% HR - % TR[z])--------------------------------				
Ahrent	66-72	58-71	58-69	58-70	60-70
RU0101093	65-72	50-72	50-72	56-71	55-72
Banks	64-71	59-72	63-71	61-71	62-71
Bengal	70-74	63-74	56-72	67-73	64-73
Cheniere	66-73	61-73	62-72	59-72	62-73
CL161	68-72	64-72	65-72	67-72	66-72
Cocodrie	65-73	62-73	63-72	62-72	63-72
CyBonnet	69-73	62-72	63-71	65-72	65-72
Drew	67-73	63-72	59-72	63-72	63-72
Francis	67-73	59-73	59-71	63-72	62-72
Lagrue	64-71	59-71	57-69	61-71	60-71
Medark	70-75	63-74	64-73	65-73	66-74
CLXL8	62-73	53-73	55-73	54-72	56-72
XP710	60-72	53-72	53-71	48-70	53-71
XP712	65-73	56-73	60-72	64-72	61-73
XP716	69-73	65-73	64-72	69-72	67-73
XP723	65-73	55-73	60-72	56-72	59-72
Wells	65-74	56-73	56-72	58-73	59-73
Mean	66 – 73	59 – 73	59 – 72	61 – 72	61 – 72
$LSD_{(0.05)}$	2 – 1	4 – 1	4 – 1	2 – 1	2 – 1
C.V., %	1.8-0.8	4.3 – 0.7	3.8 – 0.9	2.5 - 0.6	3.4 – 0.8

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

Influence of Simulated Hail Injury to Rice at Seedling Growth Stages

C.E. Wilson, Jr., D.L. Frizzell, N.A. Slaton, R.J. Norman, and A.L. Richards

ABSTRACT

Hail injury at specific growth stages can cause significant yield loss. This usually occurs when the stems are injured or the plant is defoliated during reproductive growth stages. However, recent questions have been raised concerning the effects of injury to rice at seedling growth stages. Therefore, the current study was initiated to evaluate the influence of simulated hail injury to rice at seedling growth stages. Four varieties (‘Bengal’, ‘Cocodrie’, ‘Francis’, and ‘Wells’) were planted in 4-row plots and defoliated at either 2 weeks after emergence (2- to 3-leaf growth stage), 4 weeks after emergence (4- to 5-leaf growth stage), or 6 weeks after emergence (mid-tillering). Hail injury was simulated by removing 0, 33, 66, or 100% of the above-ground material in each of the four rows. The dry matter removed was determined and stand counts were made 5 to 7 days after defoliation. Grain yields were determined at maturity. Grain yields were not significantly affected by defoliation at ground level and generally decreased as defoliation intensity and time of defoliation after emergence increased. Bengal tolerated defoliation the best. Simulated hail injury at seedling to early-tillering growth stages indicates defoliation at these early growth stages can cause grain yield decreases, which varies with variety.

INTRODUCTION

Hail injury can cause significant yield loss to several crops when it occurs during specific growth stages. Rice (*Oryza sativa*, L.) susceptibility to hail injury has been shown to be significant when the crop reaches the reproductive growth stage (Counce et al., 1994a). As the flag leaves and panicles are damaged, resulting yield losses can be

10 to 15% (Counce et al., 1994b). Crop insurance is available to producers to protect them against losses due to hail storms. However, it is an expense that producers must weigh against the probability of experiencing hail injury.

Recently, questions have been raised by producers, insurance adjusters, and others on the potential yield loss from hail injury at seedling growth stages. Therefore, this study was conducted to evaluate the influence of simulated hail injury to four rice cultivars at two seedling growth stages on tiller production and grain yield.

PROCEDURES

The study was conducted during 2004 at the Southeast Research and Extension Center near Rohwer, Ark., on a Perry clay (very fine, smectitic, thermic Chromic Epiaquerts). Four rice cultivars (Bengal, Cocodrie, Francis, and Wells) were seeded on 20 April at the recommended rate of 40 seeds ft^{-2} into 4-row plots that were 6 in. apart and 16-ft long. Weeds were controlled by a pre-emergence application of clomazone (Command; 0.6 lb ai/acre) + quinclorac (Facet 0.5 lb ai/acre) and followed by a preflood application of propanil (Stam, 4 lb ai/acre) + carfentrazone-ethyl (Aim, 0.025 lb ai/acre) on 4 June. An additional application of halosulfuron (Permit, 0.057 lb ai/acre) was made to control yellow nutsedge on 9 June. Nitrogen fertilizer was applied at a rate of 150 lb N/acre as urea on 9 June and the permanent flood was established on 10 June.

To simulate hail injury, plots were defoliated at four levels by removing a portion of the above-ground tissue (0, 33, 66, and 100%). For the 33 and 66% defoliation rates, the above-ground tissue was removed by removing 1 in. or 2 in. for each 3 in. of row. Defoliation was performed at either 2 wk after emergence (2- to 3-leaf growth stage) or 4 wk after emergence (4- to 5-leaf growth stage. An additional defoliation was added 6 wk after emergence (midtillering) for the 33 and 66% defoliation rates. All of the plant material removed from each plot was dried at 65°C to constant moisture and weighed. Tiller counts were made initially and 14 d after the second defoliation. Grain yields were determined by harvesting a 12-ft section of the two center rows at maturity and adjusted to 12% moisture content.

The experiment was arranged in a randomized complete block design with a factorial arrangement of cultivars (4 levels), defoliation rates (4 levels), and defoliation dates (3 levels). Analysis of variance procedures were conducted with the PROC GLM procedure in SAS and mean separations were conducted with Fisher's protected Least Significant Difference method at a significant probability of 0.05.

RESULTS AND DISCUSSION

Cultivars were significantly different in tiller density and grain yield. Cocodrie had the highest tiller density 6 weeks after emergence among the four cultivars (Table 1). The dry matter removed during defoliation was not significantly different among the four cultivars examined (Table 1). Overall, grain yields were highest with Bengal and Francis, followed by Wells and Cocodrie. Significant lodging was observed with Bengal.

Increasing defoliation rate increased dry-matter removal and decreased tiller density and grain yield (Table 2). When measured 6 weeks after emergence, defoliation rates of 67 and 100% significantly reduced stand density for each cultivar except Cocodrie. Only the 100% defoliation significantly reduced stand density for Cocodrie.

Grain yields of Bengal were least affected by defoliation (Table 2). Although a trend for reduced yields was observed, defoliation did not significantly affect grain yields of Bengal. In contrast, the 67 and 100% defoliation rates significantly reduced yields of Cocodrie, Francis, and Wells. Yields of Francis and Wells were reduced with the 33% defoliation rate.

Defoliation timing had a significant effect on total dry matter removed, tiller density, and grain yields (Table 3). The rice recovered better through tillering when defoliation occurred 2 weeks after emergence than after beginning tillering (i.e., 4 weeks after emergence). Grain yields were generally reduced as defoliation occurred at later growth stages (Table 3). Except for Bengal, the lowest yields occurred when defoliation occurred 6 weeks after emergence. Defoliation at 4 weeks after emergence resulted in greater yield loss than at 2 weeks after emergence only for Wells.

In general, the largest effect on grain yields occurred at either the 67 or 100% defoliation, particularly when the defoliation occurred 4 or 6 weeks after emergence (Table 4). However, Cocodrie, Francis, and Wells were unable to fully recover from 100% defoliation, regardless of when the defoliation occurred.

SIGNIFICANCE OF FINDINGS

Tiller density and grain yields were significantly reduced with increasing defoliation rate during 2004. When defoliation time was delayed from 2 weeks to 4 and 6 weeks after emergence, grain yield was more severely influenced. Reduced grain yields were observed at 67 and 100% defoliation rates for Cocodrie, Francis, and Wells. Bengal tolerated defoliation the best of the four cultivars. When results are compared with results from previous years, this study suggests that simulated hail injury at seedling growth stages may negatively impact grain yields if weather conditions are not favorable for optimal tillering. Disruption of the growing point below ground level may negatively affect yields by not allowing optimal tiller production.

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LITERATURE CITED

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Table 1. Effect of simulated hail injury and cultivar on dry matter removed, tiller density, and grain yield in rice at SEREC during 2004.

Cultivar	Dry matter removed	Tiller density	Grain yield	Lodging
	(lb/acre)	(tillers/ft^2)	(bu/acre)	(%)
Bengal	40.8	30.9	183.4	26.4
Cocodrie	48.7	43.1	161.9	0.0
Francis	44.0	32.2	180.1	0.5
Wells	50.3	37.4	169.8	0.0
LSD (α = 0.05)	13.5	4.9	8.1	7.0

Table 2. Effect of defoliation timing on stand density 6 weeks after emergence, total dry matter removed, and grain yield following simulated hail injury by four rice cultivars at SEREC during 2004.

Defoliation	Stand density				Total dry matter removed				Grain yield			
rate	Bengal	Cocodrie	Francis	Wells	Bengal	Cocodrie	Francis	Wells	Bengal	Cocodrie	Francis	Wells
(%)	(tillers/ft^2)				(lb/acre)				(bu/acre)			
0	42.1	56.7	45.5	49.0	0.0	0.0	0.0	0.0	187.0	193.3	215.7	193.6
33	33.7	46.1	38.6	41.1	35.1	45.0	43.5	43.8	191.4	176.4	191.2	170.0
67	28.8	47.9	32.3	38.8	46.5	66.3	47.3	49.9	177.1	161.6	173.0	167.5
100	18.8	21.8	12.6	20.7	81.7	83.6	85.1	107.6	177.1	109.3	138.7	149.1
LSD (α = 0.05)	9.9				26.9				18.1			

Table 3. Effect of defoliation timing on stand density 6 weeks after emergence, total dry matter removed, and grain yield following simulated hail injury by four rice cultivars at SEREC during 2004.

Defoliation	Stand density				Total dry matter removed				Grain yield			
rate	Bengal	Cocodrie	Francis	Wells	Bengal	Cocodrie	Francis	Wells	Bengal	Cocodrie	Francis	Wells
(%)	(tillers/ft^2)				(lb/acre)				(bu/acre)			
2 wae[z]	31.6	47.6	32.9	40.2	9.7	15.1	16.2	19.2	185.0	169.0	193.1	184.6
4 wae	30.1	38.6	31.6	34.5	71.9	82.3	71.7	81.4	177.0	157.0	173.3	165.9
6 wae	--	--	--	--	--	--	--	--	193.1	157.4	168.0	148.0
LSD (α = 0.05)	7.0				19.0				12.8			

[z] wae = weeks after emergence.

Table 4. Effect of cultivar, defoliation timing, and defoliation rate in four rice cultivars measured at 42 days after emergence on grain yield at SEREC during 2004.

Defoliation	Grain yield											
	Bengal			Cocodrie			Francis			Wells		
rate	2 wae[z]	4 wae	6 wae	2 wae	4 wae	6 wae	2 wae	4 wae	6 wae	2 wae	4 wae	6 wae
(%)	(bu/acre)											
0	195.7	208.4	-	193.8	192.8	-	209.3	222.1	-	192.6	194.6	-
33	205.8	172.3	196.1	193.4	161.7	174.0	198.4	190.1	185.1	195.6	154.7	159.7
67	178.2	163.2	190.0	187.3	156.7	140.8	196.1	172.1	150.9	180.1	186.1	136.3
100	190.3	164.0	-	101.6	117.0	-	168.6	108.8	-	170.1	128.2	-
LSD(α = 0.05)	25.6											

[z] wae = weeks after emergence.

Moisture Adsorption Effects on Rice Milling Quality of Current Cultivars

R.C. Bautista, T.J. Siebenmorgen, and R.M. Burgos

ABSTRACT

Rapid water adsorption by mature, low-moisture content (MC) rice kernels can have detrimental effects on milling quality due to kernel fissuring. Recent reports of milling quality reductions in field samples of newly released varieties have prompted the need to determine critical MC levels below which rapid moisture addition will cause fissuring. This study investigated how water-soaking as a means of simulating field moisture-adsorption affects the incidence of fissuring and milling quality, specifically HRY. Results showed that milling quality of water-soaked rough rice was affected by rough rice initial MC (IMC) and soaking temperature. For all varieties, the percentage of fissured kernels increased with a decrease in rough rice IMC and a decrease in water temperature. Consequently, HRY decreased as rough rice IMC decreased. Among varieties, 'Francis' had lower HRYs and higher percentages of fissured kernels than 'Bengal' and 'Wells' at a given soaking treatment combination. The results of this study will be helpful in understanding kernel fissuring susceptibility and resultant milling quality reduction for rice subjected to water adsorption.

INTRODUCTION

Recent reports have purported HRY reduction due to field moisture adsorption by low-MC rice. Moisture adsorption by low-MC rough rice has been shown to be a major cause of breakage and milling quality reduction, thereby reducing the economic value of rice. Jindal and Siebenmorgen (1986) reported significant HRY reduction due to water adsorption of rice with IMCs less than 13%. Individual kernel MCs vary at harvest and are characterized by a multi-modal distribution, particularly at bulk average harvest

MCs greater than 16%. As the bulk average HMC decreases, the potential for more and more kernels reaching the level at which moisture adsorption can occur increases. Due to individual kernel MC variability in the field, there is a high probability that kernels with lower MC exposed to wet environments will fissure and cause HRY reduction (Siebenmorgen, et al., 1998; Jindal and Siebenmorgen, 1986; Chen and Kunze, 1982). Support of this hypothesis was offered by Bautista et al. (2000) who showed that the percentage of fissured kernels was strongly correlated to the number of kernels with MC less than 14%. Thicker kernels have been shown to be more susceptible to kernel fissuring than smaller ones when soaked in water (Jindal and Siebenmorgen, 1994).

It is known that different rice varieties respond differently to kernel fissuring due to moisture adsorption (Chen and Kunze, 1982; Bautista and Bekki, 1997). Therefore, understanding water adsorption effects on kernel fissure occurrence of current, commonly grown cultivars would be helpful in developing pre- and post-harvest recommendations for maintaining milling quality. The study was conducted to determine fissuring susceptibility and HRY reduction of current, selected rice varieties due to water adsorption. A laboratory soaking test was used to simulate field moisture adsorption effects.

PROCEDURES

Three rice varieties, Francis and Wells (long-grains) and Bengal (medium-grain), were collected from the Rice Research and Extension Center foundation seed plots in Stuttgart at approximately 21% harvest MC. Lot samples (10 kg each) were cleaned using a grain cleaner (MCI® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and placed in sealed containers inside a cooler (4°C) until use. Upon testing, each lot was dried slowly by spreading thinly on screened trays and placing inside a conditioning chamber maintained at 21°C and 56% relative humidity, corresponding to an 11.8% rough rice equilibrium MC. Samples of rough rice (2 kg) were drawn from each lot sample at IMCs shown in Table 1 by pulling samples from the lot while drying in the conditioning chamber and bulk MC was measured with a single-kernel MC meter (CTR800E Shizuoka Seiki, Shizuoka, Japan). A microprocessor-controlled water bath (Precision 280, Precision Scientific, Winchester, Va.) capable of maintaining water temperature precisely within 1°C of set point was used for the soaking tests. Treatment combinations included rough rice IMC and water temperature (Table 1). For each combination, rice samples (400 g) were wrapped in vinyl screen cloth, soaked for two hours by submersing in the water bath, drained for 30 minutes, blotted with a paper towel, and allowed to aerate by spreading the kernels thinly on a dry, screened tray inside the lab for an hour until the surface water had evaporated. The soaked samples were placed in an equilibration chamber to gently dry to approximately 12% MC. The number of fissured kernels were enumerated by manually removing the hulls of 200 randomly selected kernels and inspected using a fissure inspection instrument (Kett Grainscope, Kett Co., Japan). Duplicate samples of 150 g rough rice for each treatment combination, including a non-soaking control, were milled using a McGill No. 2 mill and head rice was separated using a shaker table. HRY was calculated and determined.

RESULTS AND DISCUSSION

Fissuring and HRY responses to water soaking for the three varieties are shown in Figure 1. After soaking in water, the percentage of fissured kernels increased with a decrease in rough rice IMC for all varieties. For Bengal, more than 10% of kernels fissured at 16% IMC at all water temperature levels, which was more than that observed for Francis and Wells at the same IMC. For Bengal, Francis, and Wells, rapid increase in fissured kernels percentage was observed at 14% IMC, an indication that a critical MC level was reached at this IMC for kernel fissuring.

Water temperature had an inverse effect on kernel fissuring; fissured kernels percentage increased with a decrease in water temperature. While it is known that higher water temperature hastens water adsorption in rice kernels, it did not produce an increase in kernel fissuring. It is speculated that the fast adsorption of water in rice kernels could have caused a more rapid diffusion of water from the outer to central portions of the kernel. This in turn would have produced relatively lower internal kernel MC gradients and thereby reduced the internal kernel stress due to an MC gradient. Among varieties, Francis had the greatest percentage of fissured kernels at 20°C water temperature. Bengal and Francis had similar and greater percentage of fissured kernels than Wells at the 40 and 30°C water temperatures. Similarly, a study comprised of exposing Japanese medium-grain 'Mutsuhomare' brown rice kernels to 98% relative humidity for six hours showed that greater fissured kernels percentage was obtained for 20° than at 40°C (Bautista, 1998).

Figure 2 shows a varietal comparison of the effects of IMC on HRY for the soaking temperatures of 20, 30, and 40°C. For all varieties, HRY decreased relative to non-soaked samples, with an increase in rough rice IMC. At the soaking treatment of 12% IMC and 20°C water temperature, HRY reduction was greatest for Francis (37 percentage points) followed by Bengal (34 percentage points) and Wells (26 percentage points). For Francis and Wells, significant reduction in HRY ($P<0.0001$) occurred at 14% IMC and for Bengal at 16% IMC for a soaking temperature of 20°C. It was observed that at 18% IMC, Bengal incurred an HRY reduction of 2 percentage points, while Francis and Wells incurred 2.6 and 2.7 percentage points, respectively. Bengal and Wells had similar HRYs for the 30 and 40°C water temperatures at various IMCs, which were greater than Francis. It was apparent that reduction in HRY was consistent with the observation found for percentage of fissured kernels; the greater the percentage of fissured kernels, the greater was the reduction in HRY.

SIGNIFICANCE OF FINDINGS

The patterns of HRY reduction due to water soaking were similar across the varieties tested, however, slight differences in the extent of HRY reduction among varieties were found. Rough rice IMC affected milling quality; the lower the IMC prior to soaking, the greater the reduction in HRY. Soaking of rough rice with 12% IMC in 20°C water reduced the HRY by as much as 37 percentage points for Francis, 34 percentage points for Bengal, and 26 percentage points for Wells. The results of this study confirm the negative effect of water adsorption of rice on milling quality. The practical applications of this study reside in the detrimental effects of rainfall or very high-humidity air on rice left to over-dry in the field or in storage. Further studies are being conducted to investigate water adsorption effects on different varieties from different production locations.

ACKNOWLEDGMENTS

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Table. 1. Summary of experimental variables used in the soaking tests.

Variety	Rough rice initial MC	Water temperatures	Soaking time
	(%)	(°C)	(h)
Bengal	12.4, 14.2, 15.8, 18.5	20, 30, 40	2
Francis	12.4, 14.2, 15.9, 17.1	20, 30, 40	2
Wells	12.1, 14.3, 16.1, 17.9	20, 30, 40	2

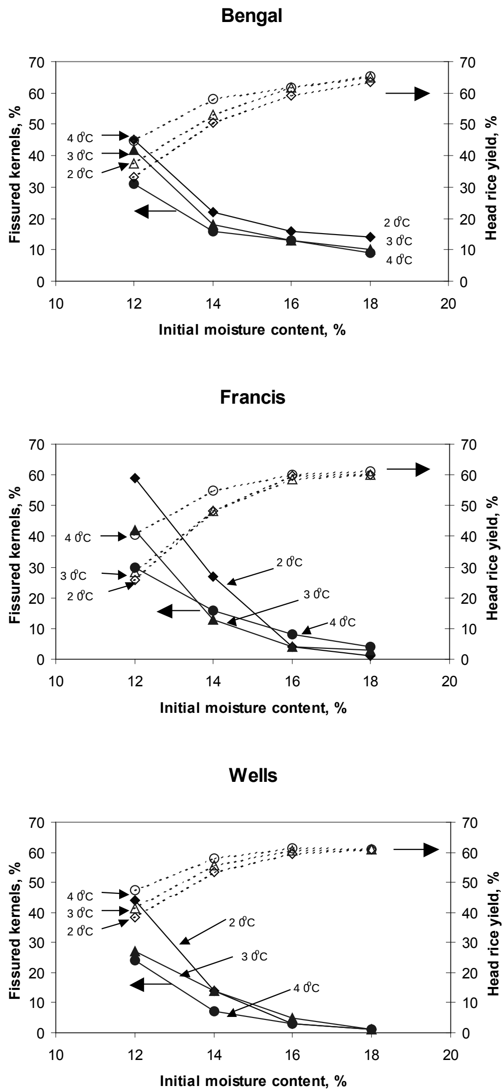
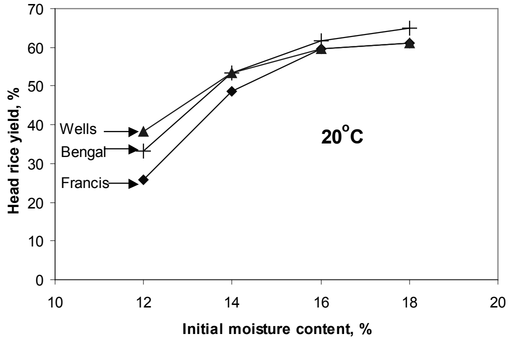
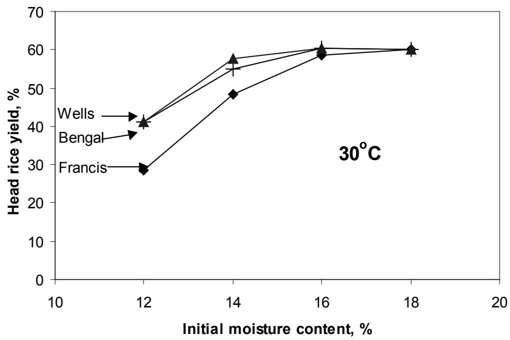


Fig. 1. Fissuring and head rice yield responses of Bengal, Francis, and Wells rough rice at different initial moisture contents to soaking in water at different temperatures for two hours, dried to 12.5% MC, and milled. Each data point represents the average of two replications.





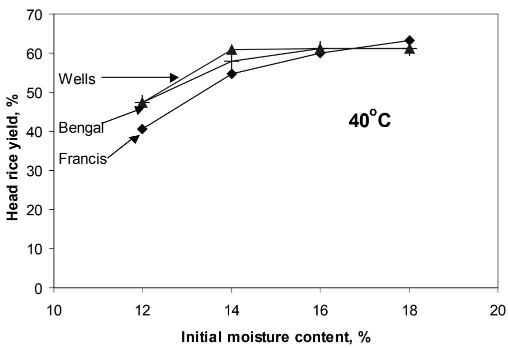


Fig. 2. Head rice yield comparisons of Bengal, Francis, and Wells rough rice at different initial moisture contents soaked in 20, 30, and 40° water for two hours, dried to 12.5% MC, and milled. Each data point represents the average of two replications.

Small Sample Mill Protocol Development: Evaluation of a Genogrinder 2000

R.C. Bautista, T.J. Siebenmorgen, A. Mauromustakos, and R.M. Burgos

ABSTRACT

This study is part of a continuing effort to develop a protocol for milling small-quantity brown rice samples typically produced from breeding lines. A laboratory mill, the Genogrinder 2000, was evaluated for milling small-quantity samples of 'Bengal' (medium-grain) and 'Francis' (long-grain) brown rice. Operating parameters including the milling duration, oscillation speed, tube size, and brown rice mass were used to determine the milling performance of the mill in terms of brown rice mass loss percentage (MLP). Mass loss percentage indicates the amount of bran removed during milling. Results indicated that milling with the Genogrinder 2000 was significantly affected by brown rice mass, milling duration, and oscillation speed. Mass loss percentage was greater for rough rice samples at 15% moisture content (MC) than 12% MC for both varieties. Mass loss percentage was linearly correlated with milling duration and oscillation speed. The Genogrinder 2000 was found suitable for milling small quantity samples of brown rice with minor modifications of the tube holders and could thus serve as an effective tool for breeders and physiologists.

INTRODUCTION

A small-quantity sample mill is needed for milling 2 to 10 g of brown rice that is typically produced from breeding lines. Recently, two small-quantity sample mills were evaluated; the IRRI Test Tube mill and the Kett Polisher (Bautista and Siebenmorgen, 2003). The Kett polisher was found unsuitable because of its propensity to chip off ends of rice kernels. The IRRI mill was found suitable for small-quantity sample milling; however, the IRRI mill is not commercially available and is only made to order.

The Genogrinder 2000 (Spex Centriprep, Metuchen, N.J.), a commercially available laboratory grain mill, was recently discovered as a machine that operates in a manner similar to that of the IRRI mill. The Genogrinder 2000 is used for grinding (pulverizing) small amounts of grain, typically less than one gram. The unit has two canisters with multiple compartments that contain samples. Grinding is achieved by oscillating the canisters vertically at speeds of 500 to 2000 cycles per minute (cpm) with steel balls and kernels inside the canister compartments.

A perceived limitation of this unit for milling small-quantity samples of brown rice is the small canister volume currently available. It was postulated that with minor modification of the canisters, the Genogrinder 2000 could be a possible, commercially available alternative for milling small-quantity samples of brown rice. Thus, the objective of this study was to evaluate the performance of the Genogrinder 2000 in milling small-quantity samples of rice, based on brown rice MLP, upon modification of the canisters to allow milling of 2 to 10 g of brown rice.

PROCEDURES

Varieties Bengal (medium-grain) and Francis (long-grain) were harvested from foundation seed plots of the University of Arkansas Rice Research and Extension Center at Stuttgart, Ark., in the fall of 2003 using a plot combine. Lot samples of rough rice (10 kg for each variety) were cleaned using a grain cleaner (MCi® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and conditioned in an environmental chamber to approximately 12.5% MC. After conditioning, lot samples were placed in sealed plastic bags and placed inside a cooler maintained at approximately 4°C. Brown rice was prepared for each milling run by taking enough rough rice samples from the 4°C cooler, allowing the samples to equilibrate for 24 h to a lab temperature of approximately 21°C, and hulling. A laboratory huller (Type THU, Satake Co., Hiroshima, Japan) with a 0.48 mm clearance between the rollers was used for removing hulls to obtain brown rice.

Table 1 shows the experimental parameters for evaluating the operation of the Genogrinder 2000. Performance evaluation was based on the MLP of brown rice as an indicator of degree of milling:

$$\text{Mass Loss Percentage (MLP), \%} = \frac{\text{(Mass of brown rice - Mass of milled rice (head rice and brokens)}}{\text{Mass of brown rice}} \text{ X 100}$$

A 12% MLP was considered optimum, based on the American Association of Cereal Chemists standard for the degree of milling. Using the MLP as a response parameter, the following parameters were evaluated per variety. The experiment included three oscillation speeds: 1400, 1600, and 1800 cycles per minute (cpm) and three tube sizes: 11, 18.5, and 26 mL, based on a preliminary investigation comprising a wide range of tube sizes from 7 mL to 26 mL. Tube sizes that resulted in an MLP too far from the 12% level were eliminated. Brown rice masses of 2 to 10 g were selected based on the typical amounts of brown rice produced from a single rice plant (Counce and Wells, 1990). From this preliminary work, brown rice samples of 2 and 4 g were used in the 11 mL tube due to tube space limitation; 2, 4, 6, 8, and 10 g were used in the 18.5 and 26 mL tubes. Milling durations of 5, 10, and 15 min were used, as shown in Table 1. Lot samples of Bengal and Francis were conditioned to approximately 12 and 15% MC.

The commercial Genogrinder 2000 unit has two canisters that are oscillated vertically through the action of an eccentric shaft. In order to facilitate milling various amounts of brown rice, the canisters that were on the unit were replaced with two retrofitted tube holders. The tube holders were fabricated from a 5 mm thick Plexiglas sheet to replace the canisters. Each tube holder (13.3 mm X 8.6 mm X 4.1 mm) could accommodate six tubes; thus a maximum of 12 samples were milled simultaneously.

For each treatment combination, 5 g of aluminum oxide grit size # 46 (Duralum special white, Washington Mills Electro Minerals, Inc., Buffalo, N.Y.) were mixed with the brown rice in a tube as an abrasive. Bran and spent aluminum oxide were removed from the milled rice using a sieving screen (#20 Central Scientific Co., Chicago, Ill.).

RESULTS AND DISCUSSION

Figures 1 and 2 show the MLPs achieved when using different amounts of brown rice in the various tube sizes at various oscillation speeds and brown rice masses for Bengal and Francis, respectively. The figures show that the desired MLP of 12% was achieved with a range of experimental combination. Even for the smallest sampled masses of 2 g, vigorous shaking at 1800 cpm for 15 min in all three tube sizes resulted in MLPs exceeding 12%. The results showed that MLPs for different brown rice masses and tube sizes were affected by oscillation speed and milling duration ($P<0.0001$). Generally, the relationship between MLP and brown rice mass was parabolic, indicating a peak in MLP at certain brown rice masses for different milling durations and oscillation speeds. For Bengal, as shown in Figure 1, the desirable 12% MLP was attained at 1600 cpm in 15 min milling duration for 4, 6, 8, and 10 g brown rice mass using the 26 mL tube. For 1800 cpm, 10 min milling duration was sufficient to mill 4 to 8 g brown rice mass. For Francis, as shown in Figure 2, the 12% MLP was attained at 1600 and 1800 cpm at different milling durations for different brown rice masses. For instance, a 12% MLP level was attained at 1600 cpm for 4 to 10 g brown rice in 10 min milling duration using an 18.5 mL tube; in the 26 mL tube at these conditions, all rice masses exceeded the 12% MLP when milled for 15 min. For 2 and 10 g brown rice, the 12% MLP level was attained at 1800 cpm in 10 min using an 18.5 mL tube.

There was significant effect of brown rice MC on MLP ($p<0.001$); for both varieties, greater MLPs were obtained for brown rice at 15% MC than at 12% MC. Between varieties, long-grain Francis had greater MLP values than medium-grain Bengal for comparable settings/conditions. Bautista and Siebenmorgen (2003) reported similar observation wherein a long-grain variety Drew had greater MLP than a medium-grain Bengal using the IRRI test tube mill at any given oscillating speed and milling duration.

SIGNIFICANCE OF FINDINGS

This study evaluated the operating parameters of a Genogrinder 2000 in milling small-quantity samples of Bengal and Francis brown rice. A desirable milling degree of 12% MLP was attained for all brown rice masses in 10 min using an 11, 18.5 mL or 26 mL tube at 1800 cpm. Overall, the Genogrinder 2000 was found useful for milling small-quantity samples of brown rice. Milling parameter combinations required to attain a desirable milling degree were determined for a range of brown rice masses for a typical long- and medium-grain variety.

The Genogrinder 2000 was found suitable for milling small quantities of brown rice with replacement of the canisters with modified tube holders. Details of the tube holder design can be obtained by contacting the authors. Further evaluation to compare HRY of Genogrinder 2000 and McGill No.2 will be important.

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Table 1. Design parameters used in the Genogrinder 2000 operating parameters evaluation. The experiment was designed as a full factorial[z] with a total of 432 samples for brown rice.

Rice variety	Tube size	Mass of brown rice	Oscillation speed	Milling duration	Moisture content	Number of replications
	(mL)	(g)	(cpm)	(min)	(% w.b.)	
Bengal, Francis	11	2, 4	1400, 1600, 1800	5, 10, 15	12, 15	2
Bengal, Francis	18.5	2, 4, 6, 8, 10	1400, 1600, 1800	5, 10, 15	12, 15	2
Bengal, Francis	26	2, 4, 6, 8, 10	1400, 1600, 1800	5, 10, 15	12, 15	2

[z] For 11 mL tube, only 2 and 4 g brown rice samples were used due to tube space limitation and thus reduced the total samples from 540 to 432.

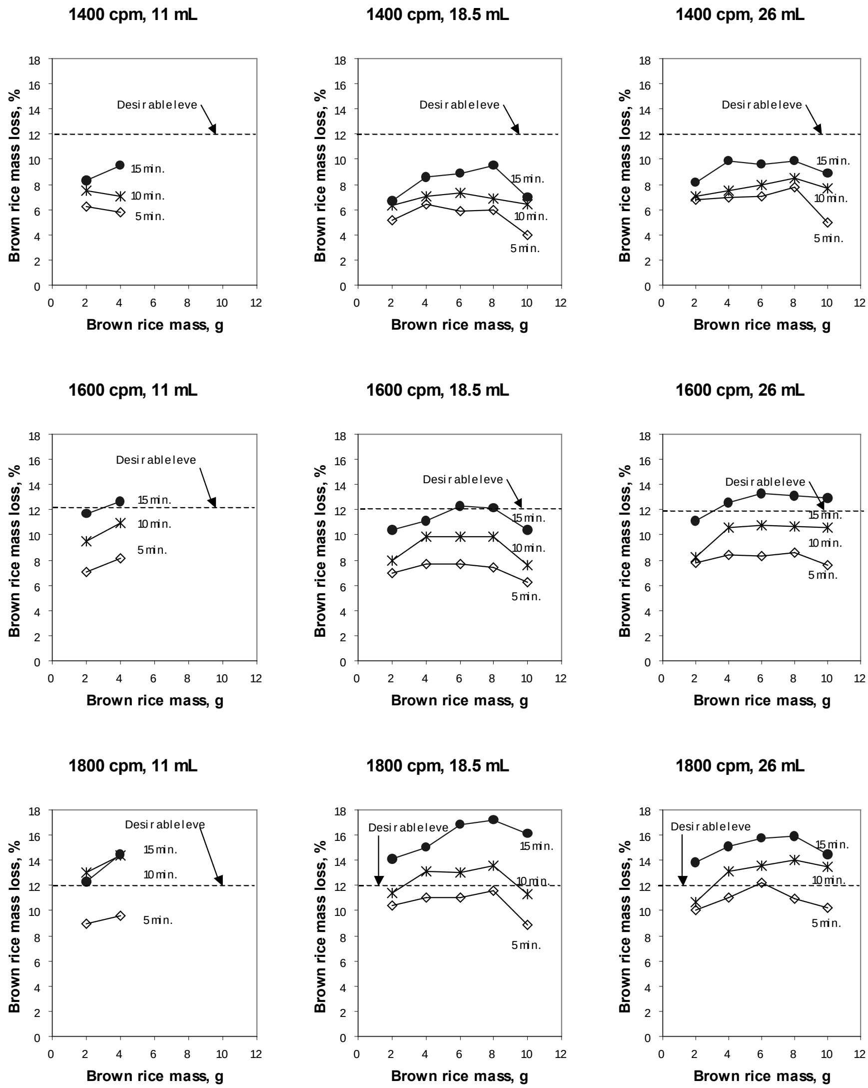

Fig. 1. Bengal brown rice mass loss percentage after milling using the Genogrinder 2000 at various oscillation speeds, milling durations, and tube sizes for different amounts of brown rice at 12% MC. Note that for the 11 mL tube, only 2 and 4 g brown rice samples were run due to space limitation. Each data point is the average of two replications.

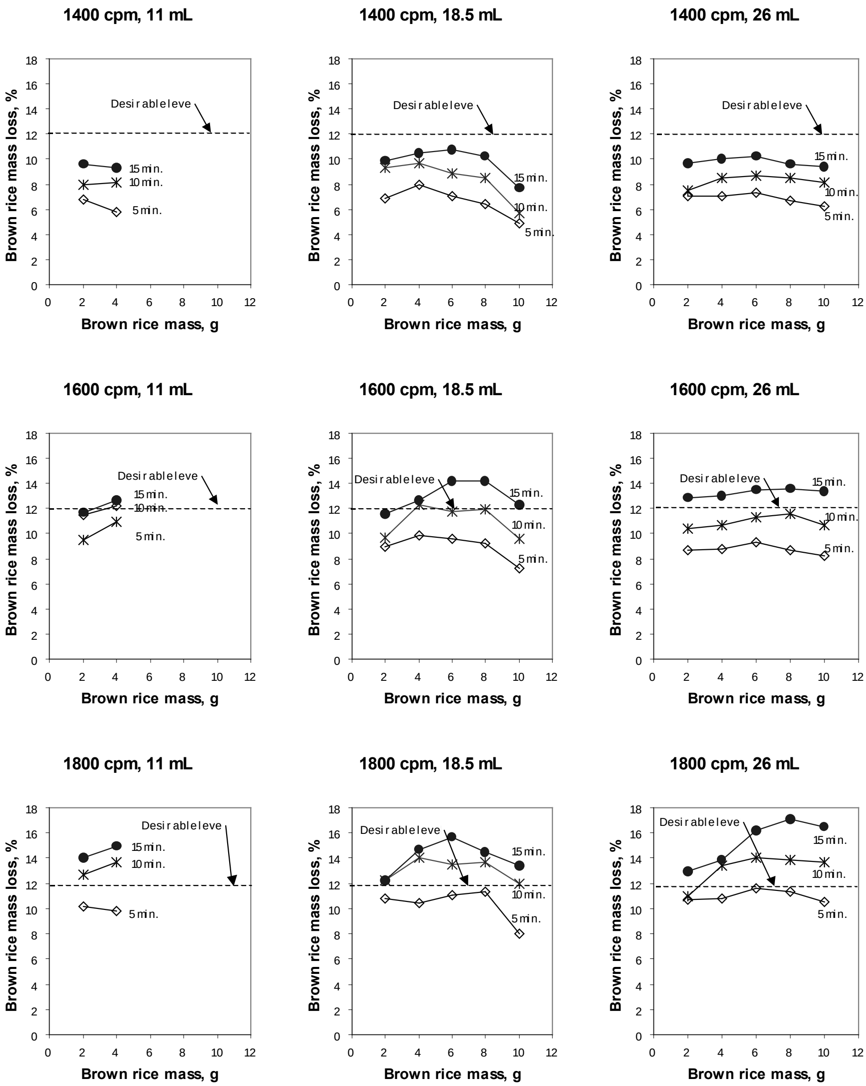

Fig. 2. Francis brown rice mass loss percentage after milling using the Genogrinder 2000 at various oscillation speeds, milling durations, and tube sizes for different amounts of brown rice at 12% MC. Note that for the 11 mL tube, only 2 and 4 g brown rice samples were run due to space limitation. Each data point is the average of two replications.

Milling Quality Trends with Harvest Moisture Content and the Relationship to Individual Kernel Moisture Content Distribution

R.C. Bautista and T.J. Siebenmorgen

ABSTRACT

This study investigated the individual kernel moisture content (MC) distribution effects on rice milling quality, specifically head rice yield (HRY). Rice varieties 'Bengal', 'Cypress', and 'Drew' were harvested from two locations in Arkansas in 1999 and 2000 at various harvest moisture contents (HMCs). HRYs for a given variety and location were found to be related to the percentages of kernels in a sample having less than 14% MC and the percentages of kernels greater than 22% MC. As the percentage of kernels with MC <14% increased, the propensity for moisture adsorption fissuring increased whereas breakage due to the presence of immature kernels increased as the percentage of kernels >22% increased; both situations result in decreased HRY. Generally, the HMC at which HRY was maximum corresponded to the HMC at which both of these percentages were minimized.

INTRODUCTION

Past research has indicated variability in rice milling quality among rice varieties and this was mostly tied to the average MC at harvest and associated fissuring characteristics (Geng et al. 1984; Chau and Kunze, 1982). It has been shown that large variations in kernel MCs on panicles exist at harvest. Harvesting rice at high MC was also shown to cause HRY reduction due to immature kernels, Siebenmorgen et al. (1992). Immature kernels are normally weak and break during milling. It has also been shown that as the bulk average MC decreases, the potential for more kernels reaching the level at which moisture adsorption can cause fissuring increases (Bautista et al., 2000; Jodari and Linscombe, 1996; Kocher et al., 1995; Siebenmorgen et al., 1998). The objective of this study was to determine the effect of individual kernel MC distribution on milling characteristics for rice varieties grown in different locations and years and harvested at various MCs. It is hypothesized that milling quality is affected by individual kernel MC distributions, and that location and harvest years affect these distributions.

PROCEDURES

Individual Kernel MC Distributions

Samples of Bengal (medium-grain), Cypress, and Drew (long-grains) rice were harvested at the University of Arkansas research and extension centers near Keiser and Stuttgart, Ark., in 1999 and 2000. Panicles were collected at HMCs that ranged from approximately 12 to 24%. Each lot sample comprised approximately 2 kg of hand-harvested panicles at approximately two percentage point increments in MC (Table 1). Immediately after harvest, ten panicles were randomly selected from each lot sample for MC measurements. The individual kernel MCs and average HMC of 300 kernels from these ten panicles were tested with a single-kernel MC meter (Shizuoka Seiki CTR 800E, Shizuoka, Japan).

Fissured Kernels

Kernels from five panicles were manually dehulled for brown rice and were investigated for fissures immediately after harvesting. A fissure inspection box illuminated by a soft light fluorescent bulb (12 W, 120 V) was utilized to enumerate fissured kernels for each sample. Brown rice kernels were spread on top of the glass cover and inspected with a magnifying glass. The percentage of fissured kernels was calculated based on the total number of fissured kernels out of 200 kernels.

Milling Analysis

The remaining panicles from each sample lot were threshed by hand, cleaned, and gently dried in a walk-in conditioning chamber (21°C and 56% RH) to approximately 12% MC. Two 150 g rough rice samples from each sample lot were dehulled using a laboratory huller (Satake Rice Machine, Hiroshima, Japan) to produce brown rice. Brown rice was milled using a laboratory mill (McGill mill No. 2, RAPSCO, Texas) for 30 s. A 1500 g mass was placed on the mill lever arm, 150 mm from the center of the milling chamber. Head rice was separated from brokens using a sizing machine (Grainman, Model 61-115-60, Grain Machinery Manufacturing Corp., Miami, Fla.) with screen size #10/64 for medium-grain and #12/64 for long-grain.

RESULTS AND DISCUSSION

Table 1 shows the summary of samples collected. Readers are referred to a report by Bautista and Siebenmorgen (2004) for a detailed description of kernel MC trends with varying HMCs for varieties Bengal, Cypress, and Drew from 1998 to 2000. In general, individual kernel MC distributions were multi-modal, especially at HMCs greater than 16%. Figure 1 shows typical individual kernel MC distributions for Bengal at two HMC levels.

Kernel Moisture Content Distributions

Figure 1 shows a typical moisture content distributions of individual kernels from rice panicles at high HMC (23.1%) and low HMC (13.2%). A multimodal distribution in individual kernel MC was observed at HMCs greater than 16%. At lower HMCs, less than 16%, the distributions tended to be single modal.

The critical moisture content (CMC) is introduced here as referring to the MC level below which a kernel is susceptible to fissure damage due to rapid kernel moisture adsorption. The CMC is known to vary with rice variety, but if 14% MC is considered as the CMC threshold (Siebenmorgen et al. 1990; Juliano and Perez, 1993), then it is assumed that kernels below 14% MC will incur fissures from re-wetting by adsorption of moisture from sources such as rain or extremely humid air, or from intra-kernel moisture migration between high and low MC kernels. Mixing of wet (>22%) and dry (<14%) kernels has also been shown to cause fissuring damage to dry kernels (Siebenmorgen et al., 1990; Calderwood, 1979). Also, immature kernels (>22%MC) when dried will typically break during milling, Siebenmorgen, et al. (1992). A study conducted by Siebenmorgen et al. (1992) for three long-grain varieties indicated no HRY decline for average HMCs ranging from 15 to 22%.

The percentage of kernels with MCs greater than 22% and less than 14% in 1999 is shown in Figure 2. For all varieties harvested from Stuttgart and Keiser, the MCs of a significant number of kernels were less than 14% MC even at HMCs of about 20%. The number of kernels from a panicle with MCs less than 14% MC increased with a decrease in HMC, whereas the percentage of kernels with MCs greater than 22% decreased with a decrease in HMC. In either case, there were differences in the percentage of kernels with less than 14% and greater than 22% MC at given HMCs among varieties. From the standpoint of maintaining high milling quality at low HMCs, it is desirable to have a lower percentage of kernels that are less than 14% MC.

Fissured Kernels at Harvest

Figure 2 also shows the percentage of fissured kernels at various HMCs in 1999. The percentage of fissured kernels increased with an increase in the number of kernels less than 14% MC, as accompanied by a decrease in HMC, for all varieties. Among varieties, Bengal and Drew had similar percentages of fissured kernels at given HMC levels at both Stuttgart and Keiser. Cypress had lower percentages of fissured kernels at both locations. Similar trends were observed in 2000 (data not shown), wherein Cypress in general had lower fissured kernel percentages than Bengal and Drew at different HMCs. Rainfall or rewetting of kernels occurring when rice is maturing in the field can influence fissuring, wherein low MC kernels could rapidly adsorb moisture and fissure. For instance, in Stuttgart a 38.1 mm rainfall was recorded when Bengal was at 19% HMC, Cypress was at 21% HMC, and Drew was at 19.5% HMC. The associated percentages of kernels less than 14% MC was 25% and the fissuring rate was 5% for Bengal at 19% HMC; for Cypress at 21% HMC, percentage of kernels at less than 14% MC was 15% and the fissuring rate was 2%; and for Drew at 19.5% HMC, 24% kernels were less than 14% MC and 4% were fissured. The occurrence of rain at these HMC levels for both locations indicated an increase in fissured kernels, which could be due to the presence of kernels with less than 14% MC. Further decline in HMC showed an increase in both the percentage of kernels with MCs less than 14% and fissured kernels. Siebenmorgen et al. (1992) showed that reductions in HRY at the late stages of harvest were mainly due to kernel fissuring.

Milling Quality

HRY curves for Bengal, Cypress, and Drew harvested in 1999 at Stuttgart and Keiser are shown in Figure 2. The three varieties showed differences in HRY responses. Analysis of variance showed significant difference in HRY as a function of HMC ($P<0.0001$) for each variety. The overall HRY versus HMC trends were similar across varieties, yet the magnitude of HRY reduction at either high or low HMCs was somewhat variety-dependent, with Cypress being less susceptible to moisture adsorption than Bengal or Drew.

The HRY versus HMC curves indicate a peak in HRY over a range of average HMCs. The decline in HRY after the peak was correlated with the percentage of kernels at less than 14% MC for each variety. There was also a decline in HRY observed with an increase in HMC, particularly at HMCs greater than 22%. A rapid decrease in HRY occurred when the percentage of kernels less than 14% MC was greater than 30% of the kernel population among each variety and location. Kernels with MCs greater than 22% did not produce as drastic a decline in HRY at HMCs greater than 22% for all varieties and both locations. Thus, the 22% MC may not be the best cut-off MC to characterize kernels as immature as HRY reductions at high HMCs were not directly correlated to the number of kernels greater than 22% MC increased.

It also appears that for all varieties, the peak HRYs were within or near the intersection of the percentage of kernels with less than 14% MC and the percentage with greater than 22% MC curves. It is apparent that the percentages of kernels less than 14% and greater than 22% MC could be used as indicators of the optimal HMC at which to harvest, since the peak HRYs were normally at or near the intersection of these curves.

SIGNIFICANCE OF FINDINGS

Components of the rice individual kernel MC distributions at harvest were correlated to milling quality of the three varieties grown in Stuttgart and Keiser, Ark. The percentage of kernels with less than 14% MC increased with a decrease in HMC and also caused an increase in the number of fissured kernels, particularly after rainfall. The percentage of kernels greater than 22% decreased with a decrease in HMC. The peak HRY was observed to occur at an HMC that also occurred near the intersection of the curves quantifying the percentage of kernels with MCs less than 14% and greater than 22% MC. This finding could be used as an indicator of the optimal timing for harvesting rice.

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Table 1. Summary of the number and harvest moisture content (HMC) range of Bengal, Cypress, and Drew rice from Keiser and Stuttgart, Ark., in 1999 and 2000.

Year	Variety	Location	Number of HMCs; HMC range
			(% w.b.)
1999	Bengal	Stuttgart	6; 12.4 - 22.4
		Keiser	6; 14.0 – 24.0
	Cypress	Stuttgart	6; 13.2 - 22.3
		Keiser	6; 12.8 – 22.0
	Drew	Stuttgart	7; 12.2 – 23.1
		Keiser	7; 12.9 – 23.4
2000	Bengal	Stuttgart	7; 12.2 – 23.6
		Keiser	7; 13.1 – 24.0
	Cypress	Stuttgart	5; 13.7 – 21.6
		Keiser	No samples
	Drew	Stuttgart	5; 14.5 – 24.4
		Keiser	5; 13.9 – 23.7

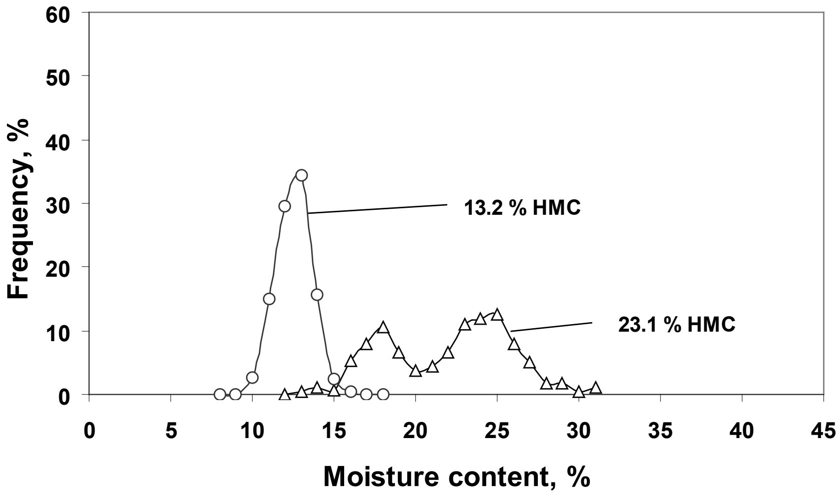

Fig. 1. Individual kernel moisture content frequency distributions at selected average harvest moisture contents (HMCs) for rice variety Bengal harvested in 1999 at Keiser, Ark. Each curve represents the pooling of kernel MCs from ten panicles at each HMC level.

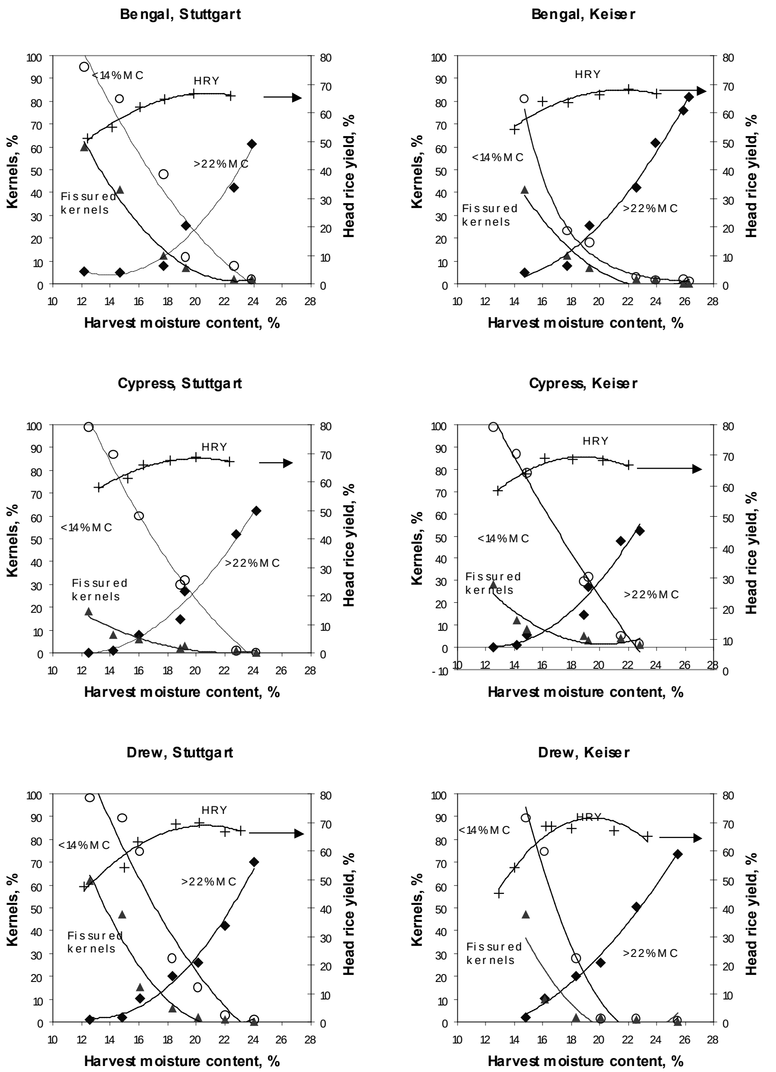

Fig. 2. Fissured kernels, percentages of kernels with MC >22% and <14%, and head rice yields at different harvest moisture contents for Bengal, Cypress, and Drew harvested from Keiser and Stuttgart, Ark., in 1999. Each point in the fissured kernel curves represents the average percentage of fissured kernels from five panicles of rice; each data point in the head rice yield (HRY) curve is the average of two milling replications.

Prediction of Cooked Rice Texture in Long-Grain Rice using Rapid Visco Analyser Data[1]

W.-K. Chung and J.-F. Meullenet

ABSTRACT

The texture of cooked rice is an important aspect of rice quality. However, rice texture is difficult to assess and assessment is not always performed in a quality-control setting. In contrast, rice-flour pasting properties are routinely measured and could potentially be used to infer rice textural quality. Textural attributes of cooked rice (100 samples) were predicted using pasting properties data. Two textural attributes (hardness and stickiness) were evaluated using a double compression test in combination with a texture analyzer. Rapid Visco Analyzer (RVA) parameters as well as the RVA profile and its 1st and 2nd derivatives were used as predictors of rice firmness and stickiness. Both hardness and stickiness were relatively well predicted by RVA profile data (R^2>0.69). However, the calculated RVA parameters did not seem to be good predictors of cooked rice textural attributes.

INTRODUCTION

Rice functional quality is usually defined in terms of cooking quality, pasting properties, and cooked rice texture. Pasting properties are the most commonly assessed set of quality characteristics because the methods are well established and have been proven to be a reliable predictor of rice flour quality. The same cannot be said of instrumental texture tests as there is not a standard method and the existing methods are not easy to perform or proven reliable. The differentiated viscogram has been used for determining relationships between protein, starch, and pasting properties (Meadows,

[1] This is a completed study.

2002) and derivation methods are commonly used for the analysis of spectroscopic data (Sohn et al., 2004; Blanco and Bano, 2003). The objective of this study was to attempt the prediction of cooked rice texture from RVA data.

PROCEDURES

Sample Collection and Preparation

Rice samples ('Cocodrie' and 'Wells', long-grain cultivars) used in this study were harvested in 7 different fields across Arkansas, Lousiana, Mississippi, and Texas in the fall of 2003. In each field, rice was harvested from 6 to 8 locations (Table 1). Rice samples were dried in an equilibrium chamber (21°C/50% RH) until equilibrated to 12%. Rough rice samples were milled with a McGill No.2 mill. A cyclone sample mill (UDY Corp., Ft. Collins, Colo.) was used to grind the samples and produce rice flour.

Instrumental Textural Analysis

Rice samples were cooked according to methods by Chung and others (2003). In this method, 10 g of milled rice were combined with 17 g of water in a 100 mL beaker and cooked for 30 min and warmed for 5 min in a rice cooker (National, model SR-W10FN, Japan). Each rice sample was cooked twice for instrumental evaluation. Six replicated measurements were performed for each sample. A texture analyzer (TA-XT*plus*, Texture Technologies Corp., Scarsdale, N.Y.) was used to perform a double compression test and hardness and stickiness determined as the maximum compression force (N) and the adhesion work (N.s) during the upward travel of the compression plate.

Pasting Properties by an RVA

Amylography was performed on rice flour using a Rapid Visco-Analyzer (model-4, Newport Scientific, Warriewood, Australia) according to AACC method 61-02.

Parameters recorded included peak viscosity (P), trough viscosity (H), final viscosity (F), breakdown (P-H), setback (F-H), peak time (min), and pasting temperature (°C). The RVA profile and its 1st and 2nd derivatives were also used as predictive variables of cooked rice texture.

Data Analysis

Regression was used to evaluate the relationship between instrumental textural attributes and either RVA parameters or RVA profile data including derivatives using a multivariate analysis software, Unscrambler (Version 7.5, CAMO, Trondheim, Norway). To compare the effectiveness of the various models evaluated for a given attribute, a test described by Snedecor and Cochran (1967) designed to compare two correlated variances was performed so that RMSEP (Root Mean Square Error of Prediction) from the various models could be compared statistically.

RESULTS AND DISCUSSION

Pasting Properties and Textural Attributes

The mean, maximum, minimum, and standard deviation of the pasting parameters and instrumental textural properties of the 100 rice samples are shown in Table 2. Peak and breakdown viscosities of Cocodrie ranged from 126.0 to 227.8 RVU and from 38.3 to 108.3 RVU, respectively, while peak and breakdown viscosities of Wells ranged from 166.0 to 228.8 RVU and from 56.4 to 90.7 RVU, respectively.

Cooked rice hardness for Cocodrie ranged from 66.0 to 105.3 N while stickiness ranged from 1.2 to 4.7 N.s. Hardness of Wells ranged from 83.9 to 97.5 N while its stickiness ranged from 1.5 to 3.4 N.s.

Prediction of Cooked Rice Hardness from RVA Data

The modeling results for predicting cooked rice hardness from RVA parameters were poor (R^2=0.10, r^2_{val}=0.03, Table 3). However, hardness was rather well predicted by the RVA profile data (R^2=0.69, Table 3). At the onset of pasting, the data from the RVA profile showed a strong positive correlation to hardness. As pasting progressed, before reaching the peak viscosity, the RVA profile data exhibited negative correlations with hardness. Viscosities measured around the peak viscosity were positively correlated to hardness (Figure 1A).

Cooked rice hardness was well predicted by either the 1st or 2nd derivative of the RVA profile (R^2=0.74 and 0.85, respectively, Table 3). At the onset of pasting, before reaching the peak viscosity, the data from 1st and 2nd derivatives of RVA profile showed negative correlation to hardness. This result is in agreement with Meadows (2002) who showed that the first component to gelatinize is amylopectin. As pasting progressed after reaching the peak viscosity, the correlation between the data from 1st derivative and hardness became positive. (Figure 1B and 1C). This is also in accordance with results by Meadows who postulated that amylose components solubilize later in the pasting process. The RMSEP for the RVA profile, 1st and 2nd, derivatives was significantly lower (4.55, 5.12, and 5.26, respectively) according to the comparison of two correlated variances (Snedecor and Cochran, 1967) than that for the model using the RVA parameters (RMSEP=6.74) as predictors. Accordingly, larger discrimination indexes were achieved for the RVA profile, 1st and 2nd derivatives (RPD=1.49, 1.33, and 1.29, respectively, Table 3).

Prediction of Cooked Rice Stickiness from RVA Data

Cooked rice stickiness was marginally well predicted by RVA parameters (R^2=0.59, r^2_{val}=0.53, Table 3). The weighted regression coefficients for the seven RVA parameters showed that breakdown viscosity and peak time were positively correlated (r=0.85 and 0.68, respectively) while trough viscosity was negatively correlated (r=-0.94) (Table 4) with cooked rice stickiness.

Stickiness was well predicted by the RVA profile (R^2=0.77, r^2_{val}=0.61, Table 3). At the onset of pasting, the RVA profile exhibited a negative correlation with stickiness. The most influential part of the profile seemed to be past the trough with first negative and then positive coefficients, indicating that the rate of increase in viscosity during cooling of the paste was most highly correlated with rice stickiness (Figure 2A).

Cooked rice stickiness was also well predicted by either the 1st or 2nd derivative of the RVA profile (R^2=0.81, R^2=0.98, Table 3). The RMSEP for the 2nd derivative (0.33) was significantly lower than that of RVA parameters, RVA profile, and 1st derivative (RMSEP=0.43, 0.44, and 0.48, respectively). Therefore, the largest discrimination index was achieved for the 2nd derivative (RPD=2.12) (Table 3).

SIGNIFICANCE OF FINDINGS

The results show that RVA profile, 1st and 2nd derivative of RVA profile rather than calculated RVA parameters, should be used for predicting cooked rice texture. This has potential applications in breeding for the selection of cultivars exhibiting desired textural traits as RVA measurements are sometime made in the quality evaluation process or in the rice processing industry as a quality control tool.

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Table 1. List of rice samples used in this research.

	Field	No. rice sample	Cultivar
Large field trial	Litton, Miss.	12	Cocodrie
	Pentecost, Miss.	12	Cocodrie
	Vanndale, Ark.	12	Cocodrie
Small plot replication trial	Shoffner, Ark.	8	Cocodrie
		8	Wells
	Prather, Miss.	8	Cocodrie
		8	Wells
	R&D, La.	8	Cocodrie
		8	Wells
	Eagle Lake, Texas	8	Cocodrie
		8	Wells

Table 2. Pasting properties and instrumental textural parameters of the rice samples used in this study.

	Cocodrie				Wells			
	Mean	Max	Min	SD[z]	Mean	Max	Min	SD
Peak viscosity (RVU)	174.1	227.8	126.0	26.2	206.2	228.8	166.0	13.8
Trough (RVU)	113.7	150.3	37.0	16.5	132.6	153.4	108.7	10.6
Breakdown (RVU)	60.4	108.3	38.3	15.8	73.6	90.7	56.4	8.8
Final (RVU)	227.2	266.3	158.3	20.3	246.6	267.1	225.7	9.9
Setback (RVU)	113.5	171.9	65.1	13.0	114.0	122.6	98.4	5.1
Peak time (min)	5.9	6.1	5.7	0.1	6.0	6.2	5.7	0.1
Pasting temp (°C)	82.1	87.9	78.0	2.7	80.3	83.6	78.8	1.1
Hardness (N)[y]	87.6	105.3	66.0	7.7	90.1	97.5	83.9	3.9
Stickiness (N.s)	2.5	4.7	1.2	0.8	2.4	3.4	1.5	0.4

[z] Standard deviation.

[y] Instrumental hardness and stickiness by a double compression test using a texture analyzer.

Table 3. Model statistics for prediction of cooked rice texture from RVA parameters and viscograms.

Attribute	SD[z]	Predictor	PC[y]	R^2 [x]	r^2_{val} [w]	RMSEP [v]	t-test pair comparisons of RMSEP[u]	RPD [t]
Hardness	6.8	RVA parameters	2	0.10	0.03	6.74	a[s]	1.01
		RVA profile	7	0.69	0.55	4.55	b	1.49
		1st derivative	4	0.74	0.42	5.12	b	1.33
		2nd derivative	2	0.85	0.32	5.26	b	1.29
Stickiness	0.7	RVA parameters	6	0.59	0.53	0.43	a	1.63
		RVA profile	8	0.77	0.61	0.44	a	1.59
		1st derivative	4	0.81	0.53	0.48	a	1.46
		2nd derivative	7	0.98	0.76	0.33	b	2.12

[z] Standard deviation (texture attribute).
[y] Optimal number of principal components.
[x] Calibration coefficient of determination.
[w] Validation coefficient of determination (full cross-validation).
[v] Rood Mean Square Error of Prediction determined by full cross-validation.
[u] Comparison of correlated variances t-test performed according to Snedecor and Cochran (1967).
[t] Discrimination index RPD = SD/RMSEP.
[s] Values for textural attributes with different letters are significantly different (P=0.05).

Table 4. Weighted regression coefficients for the RVA parameters for predicting cooked rice hardness and stickiness

	Hardness	Stickiness
Peak viscosity (RVU)	NS[z]	NS
Trough (RVU)	NS	-0.939
Breakdown (RVU)	NS	0.850
Final (RVU)	NS	NS
Setback (RVU)	0.266	NS
Peak time (min)	NS	0.681
Pasting temp (°C)	NS	NS

[z] NS means non-significant variable for prediction model for cooked rice texture.

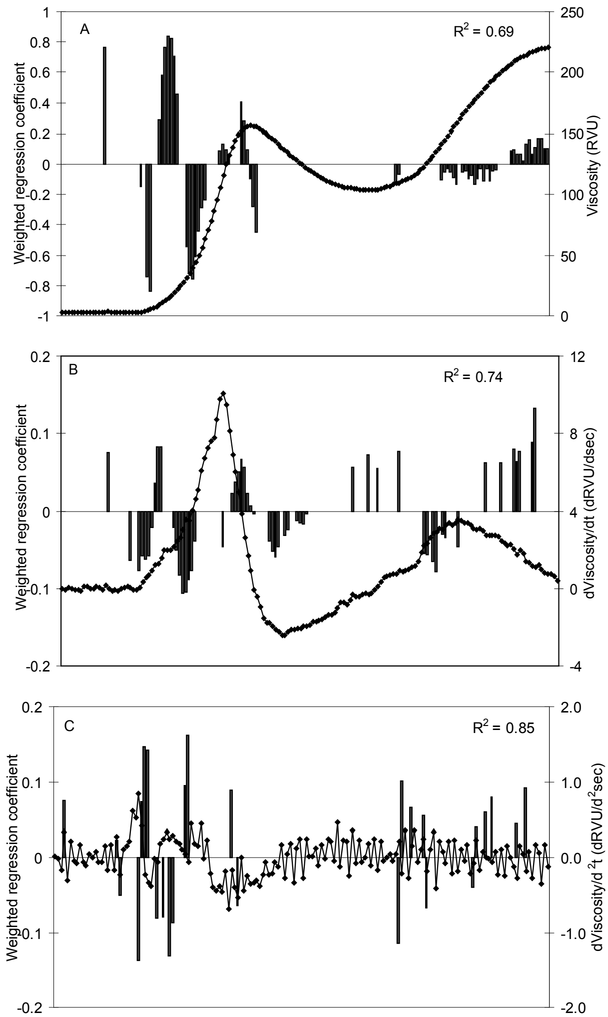

Fig. 1. Prediction of cooked rice hardness by RVA profile (A), 1st derivative (B), and 2nd derivative (C) of RVA profile.

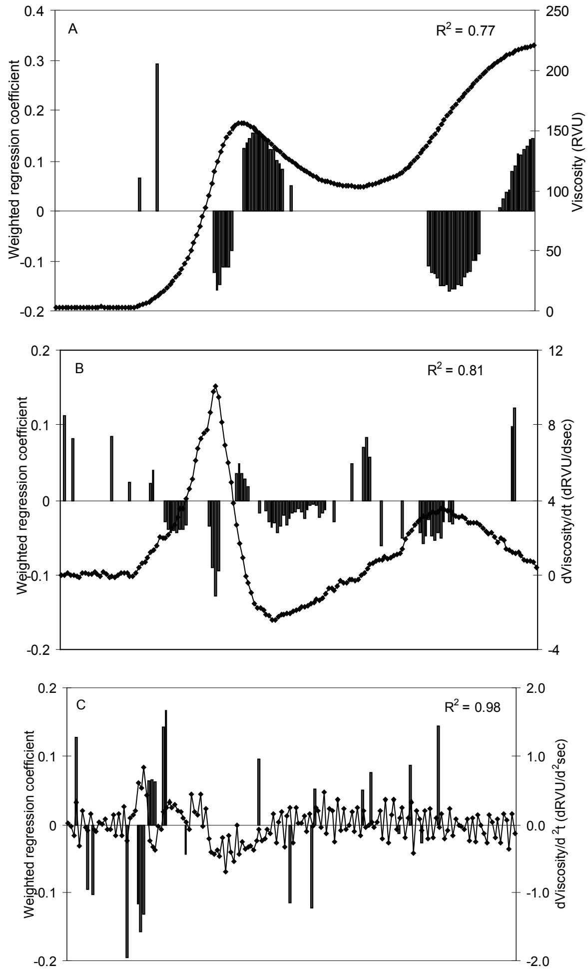

Fig. 2. Prediction of cooked rice stickiness by RVA profile (A), 1st derivative (B), and 2nd derivative (C) of RVA profile.

The Effects of Kernel Damage Caused by Combine Harvester Settings on Milled-Rice Free Fatty Acid Levels.

D.J. Feliz, A. Proctor, M.A. Monsoor, and R.L. Eason

ABSTRACT

Increasing milled rice free fatty acid (FFA) levels could subsequently develop off-flavors and compromise milled-rice brewing quality. Controlling milled-rice FFA by harvesting practices could be important in maintaining brewing quality as some rice is damaged by hull removal and/or bran disruption during harvesting. Cocodrie was harvested at three different combine-harvester settings and the percent of kernel damage (w/w) was measured to determine the effect of harvester speed on kernel damage. Harvester cylinder speed had a significant effect on rough rice kernels damage. The percent of damaged kernels for 550, 850, and 1000 RPM cylinder speed was 1.2, 4.0, and 9.0%, respectively. The FFA level of milled rice with varying kernel damage was investigated over 6 months of the storage period. The faster harvester cylinder speeds that produced greater kernel damage also resulted in significantly greater FFA levels in 'as harvested' rice with time. However FFA development from undamaged rice from each harvest treatment was identical.

INTRODUCTION

Milled-rice FFA and surface-oil content continue to be vital quality factors that determine rice acceptability to the brewing industry. The amount of milled-rice FFA is used as a quality indicator for rice by the brewing industry. A milled-rice FFA level of 0.1% is sufficient for the brewing industry to reject an entire rice batch (Marlin, 2000). Therefore, understanding where and how FFA develops is of economic interest to rice growers and processors. Previous studies have shown that milled-rice storage, transport temperature, and humidity are key factors influencing FFA levels (Lam et al., 2001; Monsoor and Proctor, 2003). Monsoor and Proctor (2003) found that commercially milled broken rice had significantly greater surface lipid and FFA than whole kernels. Monsoor et al. (2004) found that the surface lipids and FFA of broken kernels generated through abrasive milling after various drying treatments were significantly greater than those of whole kernels generated through the same milling and drying treatments. They also found that broken rice produced significantly greater off-flavors relative to those of whole kernels when stored at 37°C and 70% RH for 30 days (Monsoor and Proctor, 2004). Kernel damage had a significant effect on the lipid and flavor quality of milled rice used as a brewing adjunct.

The field rice moisture content in large part determines the harvester “settings” and these settings could later impact milled-rice surface FFA quality. Rough rice damage results from abrasion due to the combine-harvester settings that initiate FFA formation. Harvesting and handling conditions may well be important factors in determining degree of rough rice damage and subsequent milled-rice surface FFA development and reduction in rice brewing quality. Therefore, controlling milled-rice FFA by harvesting practices could be important in maintaining brewing quality as some rough rice is damaged by hull removal and/or bran disruption during harvesting. Understanding these relationships will have an economic impact on the rice industry in promoting rice quality and sales. The objectives of this research were 1) to determine the effects of combine-harvester settings on rough-rice kernel damage; and 2) to determine the effects of rough-rice kernel damage and subsequent storage on milled-rice FFA levels.

PROCEDURES

Harvesting and Drying

The long-grain rice variety ‘Cocodrie’ was harvested at 16% moisture content at the Pine Tree Experiment Station, Colt, Ark. A harvester (John Deere) with rasp at 1.8- mph ground speed was used to harvest the rice samples. A 60-kg batch of harvested rice from each of three combine-harvester cylinder speeds of 550, 850, and 1000 rpm was obtained. This was done to subject the rough rice samples to a range of abrasive harvesting conditions. Rough rice samples obtained through these three harvester settings were stored in plastic sacks immediately after harvest, and transported to the Food Science Department at the University of Arkansas, Fayetteville, Ark., for drying. Each batch was spread out on a concrete floor indoors for four days at approximately 27°C and 60% RH to produce 12% rough-rice equilibrium moisture content (EMC).

Determination of Damaged Kernels at Each Cylinder Speed

Triplicate 1 kg samples of ‘as harvested’ rice (rough rice samples before removing the damaged rice kernels) were taken from each 60 kg batch to determine the percent of damaged kernels i.e. kernels that had the hull removed with or without bran damage. 'Sound' rice (rice containing no damaged kernels) and the damaged kernels were separated. The weight of the damaged kernels was determined and expressed as a percent of the total weight of the sample on a wet basis. The percent of damaged kernels for each cylinder speed was calculated as the mean of three replicate samples.

Rough Rice Room Temperature Storage Study

Rough rice samples of 'as harvested' and 'sound' rice from 550-, 850-, and 1000-rpm cylinder speeds were stored at room temperature (23°C) in plastic sacks. Samples were obtained at monthly intervals from 0 times (control) to six months. Rough rice samples were milled and the lipid quality of the milled rice samples was measured.

Rice Dehulling and Milling

From each rough rice sample, 150 g rough-rice subsamples were hulled in a Satake rice sheller (Satake Engineering Co. Ltd. Tokyo, Japan). The resultant brown rice was then milled for 30 s using a McGill No. 2 mill (Rapsco, Brookshire, Texas).

Head Rice Yield and Degree of Milling

The head rice within the milled rice fraction was separated using a double-tray shaker table (Grainman Shaker Table, Grain Machinery MFG Corp., Miami, Fla.) with both trays having indented holes to separate the broken kernels from the head rice. The hole size of the trays was 4.76 mm. The HRY was calculated by expressing the milled rice (head rice) mass as a percentage of the original 150 g rough rice mass. The degree of milling (DOM) of the head rice was determined using a Satake degree-of-milling meter mm1-B, (Satake Engineering Co., Tokyo, Japan). The milling meter displays DOM as a value from 0 (for brown rice) to 199 (for pure white rice). Each determination was the mean of three replications.

Surface Lipid and FFA Content of the Milled Rice

Surface lipid of the milled head rice samples was extracted with 8 mL of isopropanol (IPA) by vortexing 10 g of rice sample and measured (Lam and Proctor, 2001) and the FFA content of the extracts was determined colorimetrically (Lam and Proctor, 2001). Three measurements of surface lipid and FFA contents were carried out for milled rice samples.

Statistical Analysis

The percent of damaged kernels, head rice yield, and degree of milling, as well as surface FFA level, from the storage study were analyzed statistically. Tukey HSD at the 5% significance level was used to compare means for combinations of treatments and time. Statistical computing was done with the JMP 5 software package (SAS institute Inc.).

RESULTS AND DISCUSSION

Damaged Kernels at Each Cylinder Speed

Table 1 shows the percent of damaged kernels produced by combine-harvester settings. Combine-harvester cylinder speed had a significant effect on rough-rice kernels damaged. The percent of damaged kernels for 550, 850, and 1000 cylinder speed was 1.2, 4.0, and 9.0%, respectively. Increasing combine-harvester cylinder speed increased the percent of damage rice. These rough rice damage results from faster combine-harvester settings were probably due to the greater abrasive force generated by the harvester at greater speeds.

Head Rice Yield and Degree of Milling

The head rice yield and the degree of milling from different combine-harvester settings are presented in Table 2. There was no significant difference between head rice yields from 'sound' rice and 'as harvested' rice at 550 or 850 rpm harvester cylinder speeds. However, at 1000 rpm there was significantly less head rice yield from 'as harvested' rice relative to 'sound' rice. This difference was probably due to the greater amount of damaged kernels at the 1000 rpm cylinder speed. The differences in degree of milling for 'sound' rice compared to 'as harvested' rice were not significant for all combine-harvester speeds. It appeared that the combine-harvester settings (550, 850, and 1000 rpm) do not have any significant effect on the bran removal rate of long-grain Cocodrie rice.

Milled-Rice Surface FFA Levels of Rough Rice Stored at 23°C

Figure 1 shows the changes in milled-rice surface FFA content of Cocodrie stored at 23°C for six months. At the beginning of the study, the FFA levels were similar for all the treatments groups. At month one, FFA content of all treatments had increased relative to their initial values. The 'as harvested' rice had a higher FFA formation rate than 'sound' rice for all combine-harvester speeds. However, there were very little differences in FFA development in the 'sound' rice samples. The differences in FFA content between 'as harvested' rice and 'sound' rice became greater as storage proceeded. Faster combine cylinder speeds resulted in significantly greater FFA levels in 'as harvested' rice with time. The FFA content of 1000-rpm 'as harvested' rice almost reached the 0.1% (w/w) level, which has been regarded as a critical quality value. The greater FFA development at faster cylinder speeds reflects the larger number of damaged rough rice kernels that were producing FFA during storage. However, there was no difference in

FFA development in sound rice, indicating that damage during harvesting promotes FFA development.

The greatest change in FFA levels in the 'as harvested' rice occurred during the first two months of the study. This was probably due to bran disruption and subsequent bran-lipase and bran-oil interaction (Morrison, 1978). After month two, FFA levels for rough rice of all combine harvester speeds subsequently stabilized with no net increase until month four. This stabilization of FFA levels was probably due to the feedback inhibition of rice barn lipases (Garcia et al., 1991; Lam et al., 2001; Monsoor and Proctor, 2003). A second increase in FFA development occurred after month four in 'as harvested' rice. This increase in FFA levels was probably due to hydrolysis of lipids caused by microbial contamination of stored rice (Phillips et al., 1989; Lam and Proctor, 2003). This finding agrees with Lam and Proctor, (2003) who found that the change in FFA levels occurred in three stages when milled rice was stored at 37°C and 70% RH. In the first stage FFA level increased rapidly, then FFA levels stabilized with no net increase in FFA, and the third and final stage registered the largest overall increase in FFA level.

SIGNIFICANCE OF FINDINGS

The amount of damaged rice positively correlated with the cylinder speed of the combine-harvester setting. The lipid quality and FFA development of rough rice depended on the amount of damaged kernels. This probably explains why rough rice with greater percentages of harvest-damaged kernels was associated with greater FFA and off-flavor development. Combine-harvester speed setting had a significant effect on the brewing rice quality by increasing FFA levels through harvest-damaged kernels. Removing damaged kernels upon harvesting would promote rice brewing quality.

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Table 1. Percent of damaged kernels caused by combine settings on Cocodrie rice using a 9500 John Deere harvester.

Cylinder speed	Damaged kernels[z] % ± std dev
(rpm)	(w/w)
550	1.2 ± 0.02 a[y]
850	4.0 ± 0.12 b
1000	9.0 ± 0.12 c

[z] Damaged kernels are defined as kernels that had the hull removed with or without bran disruption. Each determination was the mean of three replications.

[y] Values not sharing a common letter are different at the 5% level of significance by Tukey's HSD.

Table 2: Percent of head rice yields and the degree of milling from different combine settings on Cocodrie rice.

Rice	Cylinder speed	Head rice yield[z]	Degree of milling
	(rpm)	(%)	
Sound[y]	550	67.2 ± 0.19 a[x]	107.0 ± 3.00 ab
As harvested[w]	550	67.1 ± 0.32 a	103.0 ± 1.00 b
Sound	850	66.5 ± 0.20 ab	111.3 ± 2.89 ab
As harvested	850	65.7 ± 0.32 ac	103.7 ± 3.51 ab
Sound	1000	65.2 ± 0.18 c	113.7 ± 1.53 a
As harvested	1000	63.9 ± 1.30 d	105.0 ± 1.73 ab

[z] Each determination was the mean of three replications and expressed with ± Std Dev. The head rice yield is expressed as weight % on wet basis.

[y] Sound rice – harvested rough rice with harvest-damaged kernels removed.

[x] Values in the same column not sharing a common letter are different at the 5% level of significance by Tukey's HSD.

[w] As harvested rice – rough rice as obtained from the harvester.

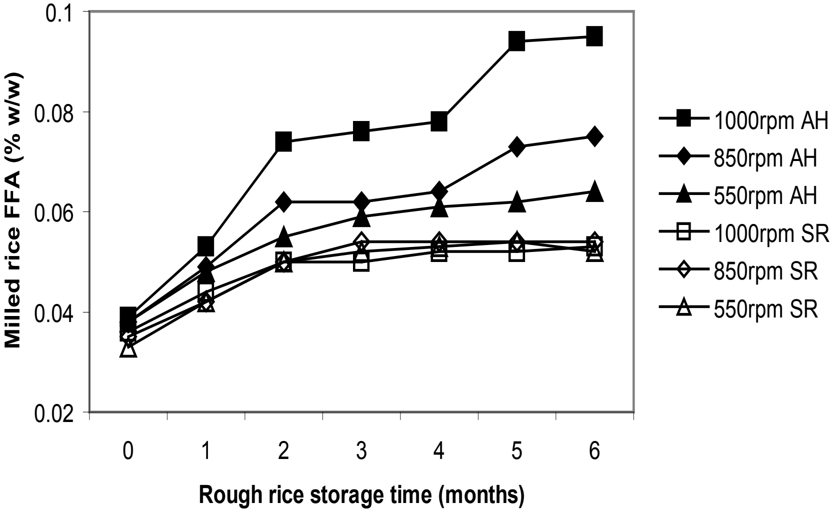

Fig. 1. Milled rice FFA levels obtained after rough rice storage at room temperature for up to six months. (SR = Sound rice; AH = As harvested rice).

Comparison of Instrumental Tests for the Assessment of Cooked Rice Texture and Their Correlations to Sensory Profiles[1]

A. Han, W.-K. Chung, and J.-F. Meullenet

ABSTRACT

Texture is an important quality characteristic of rice. However, there is not an accepted instrumental standard to measure properties such as cooked rice firmness or stickiness. The textural parameters of cooked rice measured by different instrumental tests were compared and analyzed to determine their correlation with perceived sensory textural attributes. The rice-to-water cooking ratios were adjusted according to the rice type (long- and medium-grain); in addition, each rice cultivar was cooked with two different rice-to-water ratios to create a wide variation in texture. The prediction models showed that the parameters from all instrumental tests, except those from the extrusion test, satisfactorily predicted rice stickiness (R^2>0.55). Sensory hardness was best predicted by either a single compression test performed on samples cooked for sensory analysis or by an extrusion test (R^2>0.56).

INTRODUCTION

In today's global market it is important for the rice industry to better understand rice quality characteristics such as texture. Sensory analysis is used to assess cooked rice texture. However, sensory analysis can be time-consuming and expensive. Many researchers have proposed instrumental methods to evaluate the texture of cooked rice (Champagne et al., 1998; Juliano et al., 1984; Meullenet et al., 2000; Okabe, 1979; Perez and Juliano, 1981; Rousset et al., 1995). In addition, some research has also

[1] This is a completed study.

demonstrated the importance of the cooking method employed (Juliano et al., 1981; Juliano and Pascual, 1980; Juliano and Perez, 1983). For this study, it was decided to cook the medium-grain rice samples with less water than the long-grain rice samples, since medium-grains uptake less water than long-grains. Also, in order to provide a larger variation in textural properties, each cultivar was cooked using two different (high and low) rice-to-water ratios. The objectives of this study were (1) to assess the texture of the rice samples cooked with different rice-to-water ratios and (2) to assess prediction models of the sensory perception of rice texture from the various instrumental test methodologies evaluated.

PROCEDURES

Samples Collection and Preparation

Four rice cultivars ('Bengal', 'Francis', 'Wells', and 'XL8') were collected in the fall of 2003 from the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark. The rough rice samples were dried in an equilibrium chamber (21°C/50% RH) to 12% MC and pulled periodically after 0, 6, 12, 18, 24, and 36 wk of storage for evaluation. The rice samples were milled using a continuous mill (MC-250, Satake, Japan) to a constant degree of milling as measured by a whiteness meter.

Sensory Analysis

Samples were cooked in household rice cookers according to two different rice-to-water ratios for each rice type (1:2.0 and 1:1.7 for long-grains, and 1:1.7 and 1:1.5 for medium-grains). The panelists evaluated each rice sample twice. The panelists evaluated five textural attributes (manual stickiness, initial cohesion, toothpull, manual hardness, and hardness). Bengal rice was also cooked with different rice-to-water ratios and used as a reference on some of the scales. The reference samples were coded as Rice 1 (1:1 rice-to-water ratio), Rice 2 (1:1.3 rice-to-water ratio), Rice 3 (1:1.5 rice-to-water ratio), and Rice 4 (1:2.5 rice-to-water ratio).

Instrumental Texture Analysis

A miniature precision cooker (Fig. 1) was used to cook the rice samples for all the instrumental tests. The rice samples were also cooked with the same rice-to-water ratios as was done for the sensory analysis. The double compression test (Test I) consisted of compressing ten intact cooked rice kernels twice to a 90% deformation. The data were reported as a force-time curve (Fig. 2). The single compression test (Test II) compressed the rice samples once to a constant bottom gap of 0.3 mm (Fig. 3). The same single compression test (Test III) was also used to test rice samples prepared for sensory analysis. For the extrusion test (Test IV), 35 grams of cooked rice were placed inside of an extrusion cell and extruded through 33 holes. The data were also reported as a force-time curve (Fig. 4). For Tests I to III, two aliquots of rice were cooked and six measurements were taken from each aliquot. For Test IV, three aliquots were cooked and one measurement was taken from each aliquot.

Statistical Analysis

The least significant difference (LSD) was calculated using SAS to differentiate the means across the cultivars and the different rice-to-water ratios. Partial least squares regression was used to predict the sensory attributes using the instrumental parameters with a multivariate analysis software – Unscrambler (version 7.5, CAMO, Trondheim, Norway).

RESULTS AND DISCUSSION

The mean separation for Test IV results showed that hardness for Bengal rice was significantly higher than hardness for Francis and XL8 (Table 1). Results for Tests II and III were in partial agreement as Bengal was not significantly different from Francis. These results were confirmed by the sensory data as sensory hardness for Bengal was significantly higher than that of the long-grain rice samples (Table 2). These results indicate that adjusting the rice-to-water ratio according to the grain type greatly affected cooked rice firmness as Bengal has been known as being less firm than long-grain cultivars when cooked at similar rice-to-water ratios. However, the adjustment of water-to-rice ratios according to grain types did not eliminate differences observed in cooked rice stickiness between medium- and long-grain cultivars (Table 1). Similar results were observed by the sensory panel (Table 2).

The mean separation across the high and low rice-to-water ratios showed that the rice samples cooked with higher rice-to-water ratios had lower instrumental hardness (Table 3) and stickiness (Table 4) than the rice samples cooked with lower rice-to-water ratios; however, when the rice samples were cooked in large amount with the household rice cooker, instrumental stickiness was not affected (Test III, Table 4) by the water-to-rice ratio. Results for the sensory analysis also showed that the rice samples cooked with a higher rice-to-water ratio were less firm than the rice samples cooked with a lower rice-to-water ratio; however, the rice-to-water ratio did not significantly affect either manual stickiness or toothpull (Table 5). Initial cohesion was the only sensory stickiness attribute that was significantly higher for the rice samples cooked with the higher rice-to-water ratio.

The prediction models using the PLS regression showed that Test II was the better method to predict manual stickiness and toothpull (R^2=0.58, RMSEP=0.35, Table 6). For Test II, the compression fixture was held still for 5 sec at the bottom of the compression before returning to its original position, allowing the rice samples to adhere better to the compression fixture. Therefore, this holding time may have had a positive effect on correlations between sensory and instrumental measures of stickiness.

The prediction models also showed that Tests III and IV were better methods to predict sensory hardness attributes (Table 6); the prediction model for Test IV being slightly better than that for Test III. In addition, since Test III requires large amounts of rice samples for cooking, Test IV would be a more suitable test to use in some situations where sample availability is sparse.

SIGNIFICANCE OF FINDINGS

This study showed that the rice-to-water ratio used for cooking significantly influences the texture of cooked rice. Manual stickiness and toothpull were well predicted using a fixed compression-gap compression test on 10 kernels while an extrusion test on a 35-g sample was best to predict cooked rice firmness.

ACKNOWLEDGMENTS

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Table 1. Mean separation of instrumental texture parameters of cooked rice across cultivars.

Parameters	Bengal	Francis	Wells	XL8
H1-I (N)	70.1 c[z]	73.8 b	82.2 a	80.5 a
H1-II (N)	99.4 c	99.5 c	113.7 a	108.2 b
H1-III (N)	103.4 b	102.5 b	114.3 a	115.2 a
A1-IV (N.s)	825.4 a	705.1 b	773.1 ab	707.5 b
A2-I (N.s)	7.4 a	4.1 b	4.0 b	4.0 b
A2-II (N.s)	13.2 a	6.7 b	7.0 b	6.7 b
A2-III (N.s)	10.3 a	6.8 b	7.2 b	5.7 c

[z] The grand means with the same letter in the same row are not significantly different.

Table 2. Mean separation of sensory texture attributes of cooked rice across cultivars.

Attributes	Bengal	Francis	Wells	XL8
Manual stickiness	6.6 a[z]	5.9 b	5.9 b	6.0 b
Initial cohesion	5.9 a	5.5 b	5.2 c	5.5 b
Toothpull	5.2 a	4.4 b	4.3 b	4.5 b
Manual hardness	6.3 a	5.5 c	5.8 bc	5.9 b
Hardness	5.8 a	4.9 c	5.0 bc	5.4 b

[z] The grand means with the same letter in the same row are not significantly different.

Table 3. Mean separation of cooked rice hardness between the high and low rice-to-water ratio by all the instrumental tests.

Ratio	H1-I (N)	H1-II (N)	H1-III (N)	A1-IV (N.s)
High	72.4 b[z]	99.0 b	101.3 b	624.6 b
Low	80.9 a	111.7 a	116.2 a	885.9 a

[z] Means with the same letter in the same column are not significantly different.

Table 4. Mean separation of cooked rice instrumental stickiness for the high and low rice-to-water ratios.

Ratio	A2-I (N.s)	A2-II (N.s)	A2-III (N.s)
High	4.4 b[z]	7.8 b	7.5 a
Low	5.4 a	9.0 a	7.5 a

[z] Means with the same letter in the same column are not significantly different.

Table 5. Mean separation of cooked rice sensory stickiness for the high and low rice-to-water ratios.

Ratio	Manual stickiness	Initial cohesion	Toothpull	Manual hardness	Hardness
High	6.1 a[z]	5.7 a	4.6 a	5.3 b	4.6 b
Low	6.0 a	5.3 b	4.6 a	6.4 a	6.0 a

[z] Means with the same letter in the same column are not significantly different.

Table 6. Model statistics for predicting sensory texture attributes by instrumental texture parameters using partial least squares regression.

	Instrumental paramater[z]	Manual stickiness	Initial cohesion	Toothpull	Manual hardness	Hardness
Test I	R^2	0.58	0.32	0.50	0.44	0.42
	r^2_{val}	0.49	0.25	0.38	0.37	0.29
	RMSEP	0.33	0.49	0.39	0.66	0.87
	RMSEC	0.30	0.47	0.35	0.62	0.78
	PC	4	1	4	2	3
Test II	R^2	0.58	0.31	0.58	0.22	0.30
	r^2_{val}	0.55	0.25	0.49	0.14	0.18
	RMSEP	0.31	0.55	0.35	0.75	0.88
	RMSEC	0.30	0.52	0.32	0.70	0.81
	PC	1	2	2	2	2
Test III	R^2	0.55	0.27	0.29	0.56	0.56
	r^2_{val}	0.45	0.18	0.23	0.52	0.50
	RMSEP	0.35	0.56	0.42	0.57	0.75
	RMSEC	0.31	0.53	0.40	0.54	0.70
	PC	2	2	1	2	2
Test IV	R^2	0.02	0.18	0.07	0.55	0.67
	r^2_{val}	0.01	0.10	0.02	0.52	0.64
	RMSEP	0.48	0.57	0.49	0.58	0.65
	RMSEC	0.46	0.54	0.48	0.55	0.62
	PC	1	1	1	1	1

[z] The instrumental parameters that were used to predict the sensory attributes are mentioned in statistical analysis. R^2 : Calibration coefficient of determination. r^2_{val} : Validation coefficient of determination (full cross-validation). RMSEP : Root mean square error of prediction. RMSEC : Root mean square error of calibration. PC : Number of principal components chosen in the regression model (explains most of the variation in sensory attributes).

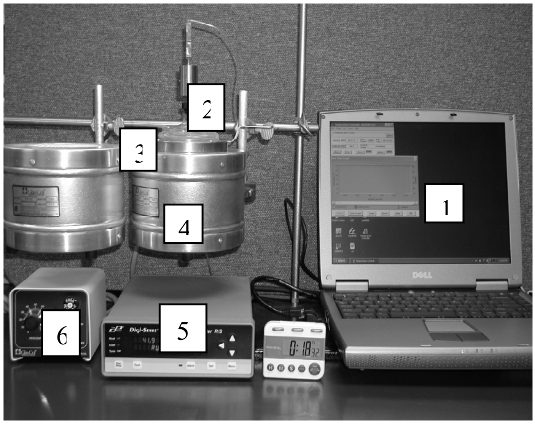

Fig. 1. Minature/precision rice cooker. 1. Computer with temperature controller software. 2. Thermocouple. 3. Glass bowl. 4. Heating mantle. 5. Temperature controller. 6. Temperature controller set at 60°C.

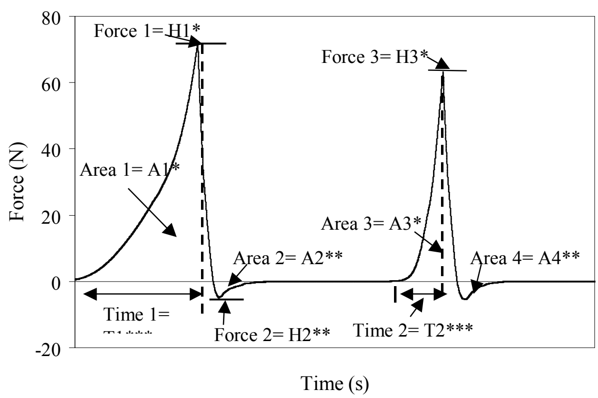

Fig. 2. Typical force-time curve for the double compression test (Test I).
*** parameters used to predict hardness.**
**** Parameters used to predict stickiness.**
***** Parameters used to product both hardness and stickiness.**

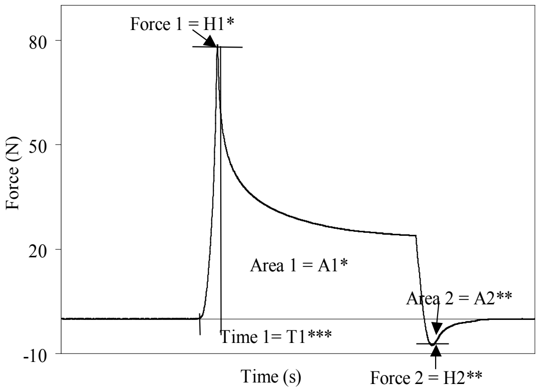

Fig. 3. A typical force-time curve for the single compression test (Tests II and III).
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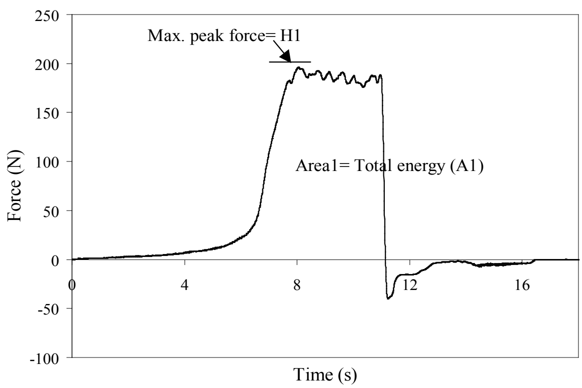

Fig. 4. Typical force-time extrusion curve (Test IV).

Influence of Kernel Thickness on Yellowing of Rough Rice

A.L. Matsler, T.J. Siebenmorgen and A.L.Couch

ABSTRACT

Yellowing is a form of rice deterioration that affects quality, appearance, flavor, and yield. It is unclear as to whether certain kernels in an unfractionated bulk sample are more susceptible to yellowing than others. The objective of this research was to quantify and compare the yellowing of different kernel thickness fractions after exposing rice to conditions known to induce yellowing. Three rice cultivars were harvested from two locations on multiple harvest dates and then separated into three kernel thickness fractions. Rough rice samples from each thickness fraction, as well as from the unfractionated bulk, were heated in covered containers in a 60°C oven for 72 hr to induce yellowing. Samples were milled and the head rice analyzed for head rice yield (HRY) and color.

Kernel thickness did not have a definitive influence on the development of kernel yellowing. However, samples harvested on earlier dates had a greater HRY and developed a more intense yellow color than samples harvested on later dates. This research indicated that factors other than kernel thickness influenced the development of yellowing in rough rice.

INTRODUCTION

Rice kernel yellowing, also known as stack-burn, heat damage, stain, as well as by other terms, is a quality issue affecting not only the rice industry, but other grain industries as well. Although incidents of yellowing have affected the rice industry for many years, the origin of yellowing is still unknown. Yellowing primarily affects the quality of milled rice because discolored kernels influence the rice grade (USDA, 1997). However, yellowing also has various effects on the chemical components of rice. Wang et al. (2002) showed that, compared to non-yellowed kernels, yellowed kernels have a higher protein content, lower starch yield, higher pasting temperature and viscosity, reduced amylose content, increased gel temperature, and an increased amount of reducing sugars.

Rice yellowing usually appears after rough rice has reached high temperatures for extended periods of time (Dillahunty et al., 2001; Phillips et al., 1988; Sahay and Gangopadhyay, 1985). While yellowing occurs in rough rice, the color change is not visible until the rice is dehulled and milled (Phillips et al., 1989). Even though the temperature and duration combination seems necessary for yellowing to occur, it is unclear if there are other factors involved. Factors that have been associated with yellowing include cultivar, moisture content (MC), water activity, microbial activity, heat of respiration, heat of germination, fungal activity, and oxygen and carbon dioxide levels of the surrounding air (Bason et al., 1990; Phillips et al., 1988 and 1989; Swamy et al., 1971; Yap et al., 1990).

Although previous research has investigated the conditions necessary to cause yellowing, and the components of the rice kernels that are affected by yellowing, there is still no clear indication as to whether some kernels in a bulk sample are more susceptible to yellowing than others. Additionally, it is unclear as to why some kernels turn yellow, or become a darker yellow color, than other kernels in a bulk sample as observed by Dillahunty et al. (2001). Could this difference in the response to yellowing by different kernels be due to the difference in kernel thicknesses in the bulk? The objective of this research was to determine if kernels of various thickness fractions were affected differently by conditions known to produce yellowing.

PROCEDURES

Rice Receiving and Handling

Three rice cultivars (*Oryza sativa* L.), ‘Francis’, ‘Wells’, and ‘Clearfield-XL8’ were harvested from two locations: Lodge Corner, Ark., on three harvest dates, and Essex, Mo., on four harvest dates. The harvest dates and corresponding harvest MCs (HMCs) are shown in Table 1. Immediately after harvesting, rough rice samples were separated into three kernel thickness fractions using a precision sizer (Style no. ABF2, Carter-Day Co., Minneapolis, Minn.), beginning with a 2.03 mm screen. Rough rice remaining inside the 2.03 mm screen comprised the “thick” thickness fraction. The rice that passed through the 2.03 mm screen was then passed through a 1.93 mm screen. The rice retained inside the 1.93 mm screen was classified as the “medium” thickness fraction. The rice that passed through the 1.93 mm screen was classified as the “thin” thickness fraction. After sizing, the thin thickness fraction was cleaned with a grain cleaner (Kicker, Mid-Continent Industries, Newton, Kan.) due to the presence of blank kernels and fines in this fraction. Table 1 shows the resulting mass thickness distributions for each cultivar/harvest-date/location combination.

Sample Preparation

After sizing, 400 g of rough rice from each thickness fraction at the harvest MC were placed in aluminum pans (9 x 13 in.) to form a thin layer of approximately two cm depth and covered with aluminum foil. These samples were placed in a 60°C oven for 72 hr, which replicated conditions known to produce yellowing (Dillahunty et al., 2001). After heating, the pans were removed from the oven and equilibrated to room temperature (21°C) for approximately two to three hours before emptying the samples onto screen trays that were placed in a chamber (21°C, 53% RH) until the rice MC reached approximately 12.5%.

After drying, 150 g rough rice samples for each thickness fraction, in duplicate, were dehulled (Rice Machine, type THU, Satake, Tokyo, Japan) and the resulting brown rice was milled for 30 sec in a laboratory mill (McGill #2, RAPSCO, Brookshire, Texas). During milling, a 1.5 kg weight was placed on the lever arm of the mill 15 cm from the centerline of the mill chamber. The milled rice was aspirated for approximately 30 sec (South Dakota Seed Blower, Seedburo Equipment Co., Chicago, Ill.) to remove any loose bran remaining in the samples.

Quality Testing

The head rice yield (HRY) of the rice was measured with a vision analysis system (Graincheck 2312, Foss Tecator, Höganäs, Sweden). Head rice (milled kernels = 75% of the original kernel length) (USDA, 1997) was then separated from broken kernels using a sizing device (Seedburo Equipment Co., Chicago, Ill.). A color meter (Colorflex, HunterLab, Reston, Va.) was used to determine the color of approximately 50 g of head rice from each sample, as expressed by hue angle and chroma.

Statistical Analysis

Statistical software (JMP, version 5.0.1.2, SAS Institute, Cary, N.C.) was used to perform statistical analyses of the data. A one-way analysis of variance of each cultivar and thickness fraction for each location was conducted in the Fit Model platform of JMP. After fitting the model, a Tukey-Kramer HSD test was conducted to identify the means that were statistically different ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Head Rice Yield

As shown in Figure 1, HRY was significantly affected by kernel thickness for samples harvested from both Essex ($p = 0.0001$) and Lodge Corner (data not shown). For all cultivars harvested from both locations, the HRY of the thin-thickness fraction increased with later harvest dates, which also had lower HMC's. This increase can possibly be attributed to the thinner kernels being more immature in the early-harvested rice while the rice samples that were harvested at later harvest dates were more mature, yielding more whole kernels (Matthews et al., 1976).

Color

Figures 2 and 3 illustrate that in all cultivars harvested from both Essex and Lodge Corner, the chroma values, which indicate the color intensity and also relate to discoloration/yellowing trends, were significantly affected by harvest date ($p = 0.0001$). In all cultivars, chroma values decreased with later harvest dates, indicating that the heated rice developed less color, or yellowed less, at the later harvest dates than at the earlier harvest dates independent of rice cultivar. Similar to the results shown by chroma, the hue angle results from rice harvested at a later date had significantly greater hue angle values ($p = 0.0001$), which represent less color development (data not shown). This result could be due to the changing HMC values at different harvest dates.

Although the color development decreased with later harvest dates, there was not a significant difference in chroma among the various thickness fractions from both Essex and Lodge Corner at each harvest date ($p = 0.94$ and 0.91, respectively) (Figs. 2 and 3). Color development, as indicated by hue angle, was also not significantly affected by thickness fraction from either Essex or Lodge Corner ($p = 0.96$ and 0.95, respectively) (data not shown). This indicates that the thickness fractions responded similarly to the yellowing process, whether the rice was heated as an unfractionated bulk, or separated into different thickness fractions before heating.

SIGNIFICANCE OF FINDINGS

This research indicated that the kernel thickness did not influence the development of yellowing in rice kernels. The primary factor influencing yellowing, as determined by chroma and hue angle, was the harvest date. Harvest date also influenced the HRY of some thickness fractions, particularly the small fraction. This is probably due to the increased maturity of the kernels at later harvest dates. Kernels that are more mature will have a greater HRY as compared to less mature kernels. This is an important consideration when deciding when to harvest the rice for later milling. Further analysis is needed to determine if MC, kernel maturity, or other factors were responsible for the yellowing observed in this study.

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Table 1. Harvest moisture content (HMC) and mass percentage for each thickness fraction of each cultivar harvested from two locations.

		Harvest location: Lodge Corner, Ark. Harvest date					
		27 August 2003		4 September 2003		10 September 2003	
Cultivar	Thickness fraction	HMC	% of Bulk	HMC	% of Bulk	HMC	% of Bulk
		(%)		(%)		(%)	
CF-XL8	Unfractionated	24.9	100	18.5	100	14.5	100
	Thick	23.7	30.2	17.9	16.5	14.6	8.3
	Medium	23.2	29.9	17.4	32.6	14.4	43.9
	Thin	27.8	39.9	17.7	50.9	14.6	47.8
Francis	Unfractionated	24.4	100	18.3	100	14.6	100
	Thick	22.5	41.0	17.4	23.3	14.5	12.8
	Medium	22.8	29.5	17.4	31.5	14.5	35.8
	Thin	27.8	29.5	18.4	45.2	14.6	51.4
Wells	Unfractionated	24.8	100	18.2	100	15.9	100
	Thick	22.9	70.3	17.5	67.0	15.4	49.8
	Medium	24.0	14.0	17.6	19.7	15.4	30.8
	Thin	30.5	15.6	19.2	13.3	15.8	19.4

continued

Table 1. Continued.

		Harvest location: Essex, Mo. Harvest date							
	Thickness	11 September 2003		16 September 2003		23 September 2003		2 October 2003	
Cultivar	fraction	HMC	% of Bulk	HMC	% of Bulk	HMC	% of Bulk	HMC	% of Bulk
		(%)		(%)		(%)		(%)	
CF-XL8	Unfractionated	24.3	100	25.1	100	18.6	100	15.6	100
	Thick	21.8	35.1	22.4	38.3	17.2	15.2	15.3	57.0
	Medium	21.4	33.3	22.0	32.7	16.9	35.7	15.1	32.8
	Thin	24.4	31.6	27.4	29.0	18.4	49.1	15.6	10.2
Francis	Unfractionated	26.5	100	21.8	100	20.1	100	17.2	100
	Thick	22.8	43.0	19.2	37.4	17.9	27.0	16.0	16.6
	Medium	23.8	27.1	19.1	33.8	18.2	37.8	16.2	38.3
	Thin	29.2	29.9	23.5	28.8	21.8	35.2	18.7	45.2
Wells	Unfractionated	25.5	100	23.4	100	18.8	100	17.8	100
	Thick	21.9	69.7	20.4	70.3	16.7	61.0	16.2	53.3
	Medium	23.7	13.4	22.3	13.7	17.6	21.4	16.9	25.1
	Thin	30.8	16.9	30.8	16.1	22.1	17.6	22.1	21.6

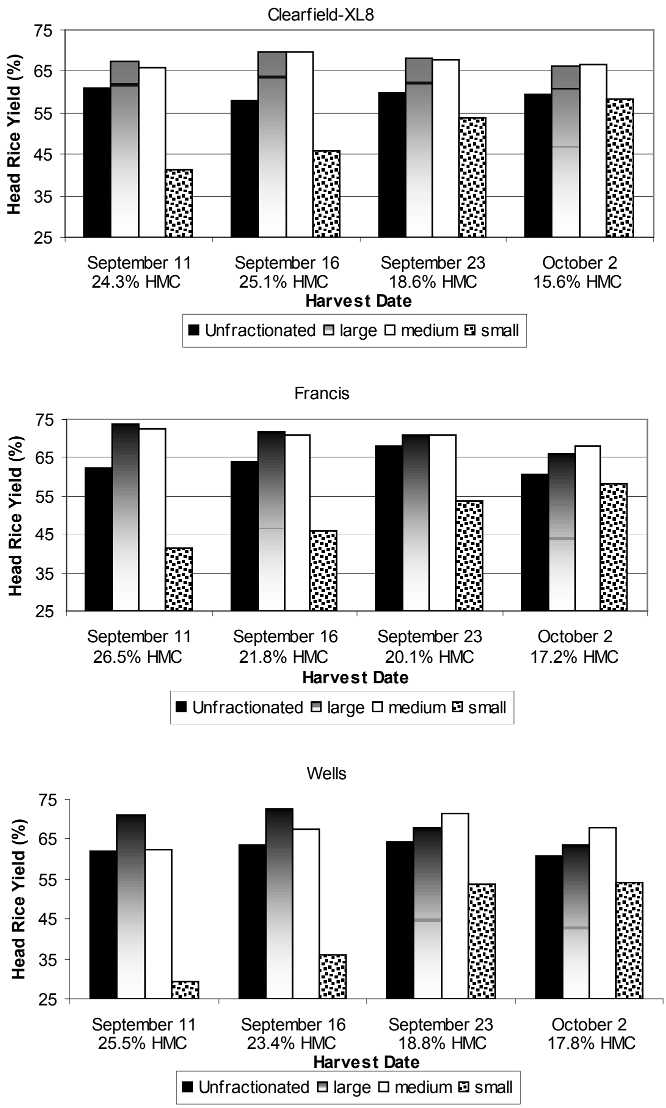

Fig. 1. Head rice yield (HRY) of three cultivars harvested on four dates in 2003 from Essex, Mo. Each data point is the average of two HRY measurements. The harvest moisture content (HMC) below each harvest date is the HMC of the bulk, unfractionated sample.

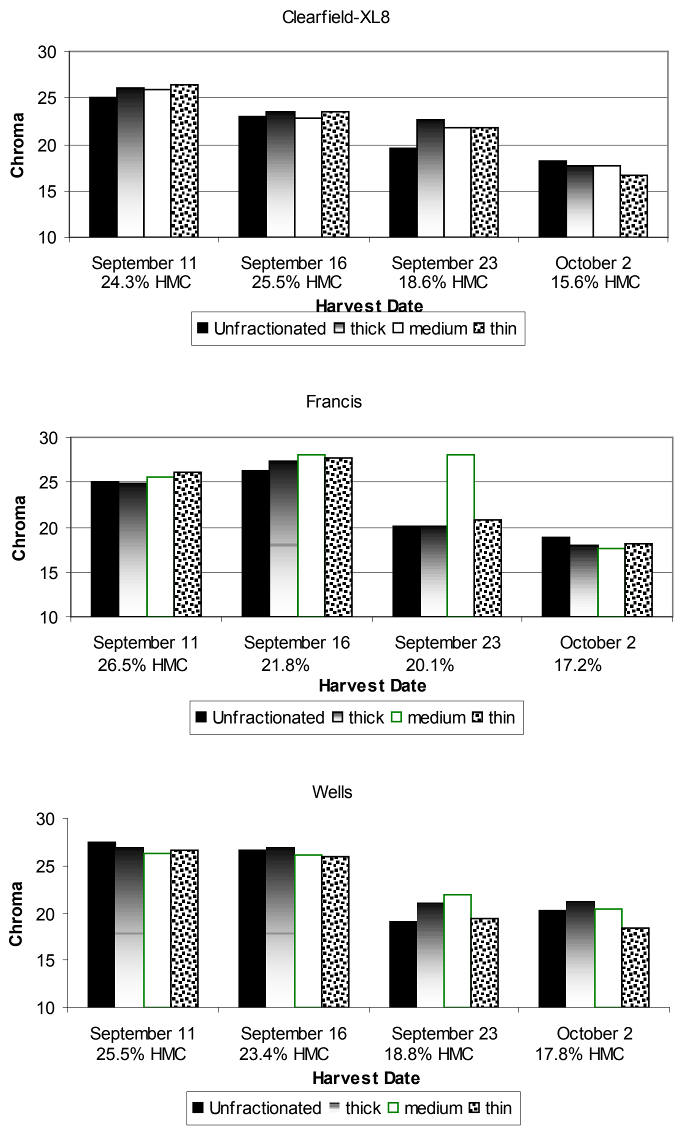

Fig. 2. Chroma of milled rice of three cultivars harvested on four dates from Essex, Mo. Each data point is the average of two color measurements. Greater chroma values indicate greater discoloration. The harvest moisture content (HMC) below each harvest date is the HMC of the bulk, unfractionated sample.

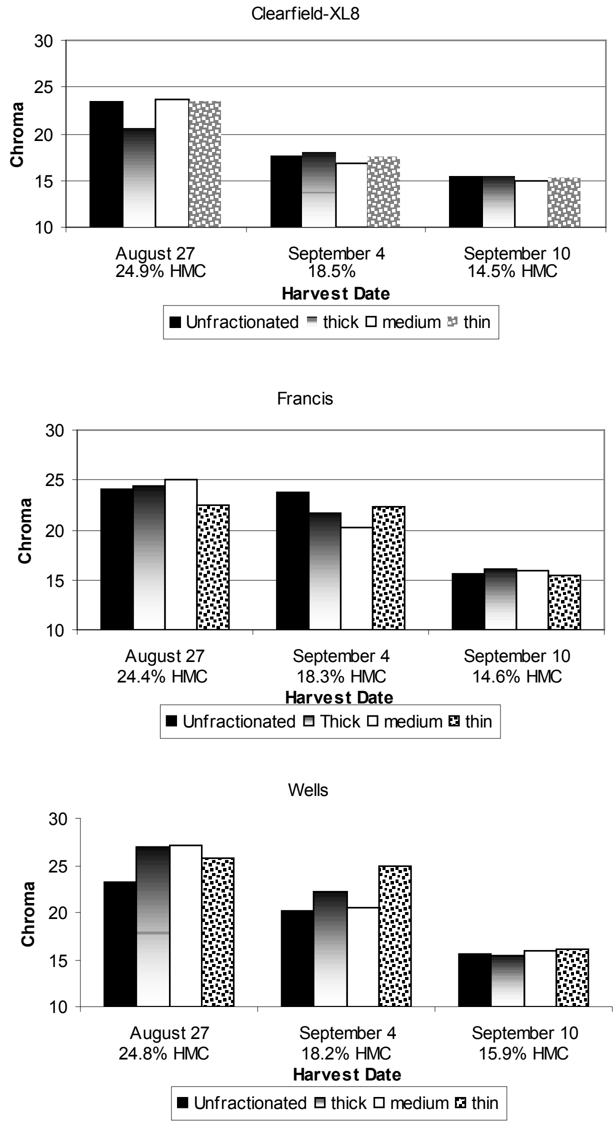

Fig. 3. Chroma of milled rice of three cultivars harvested on three dates from Lodge Corner, Ark. Each data point is the average of two color measurements. Greater chroma values indicate greater discoloration. The harvest moisture content (HMC) below each harvest date is the HMC of the bulk, unfractionated sample.

Changes in Pasting Properties of Rice Constituents During Storage

M. Saleh and J.-F. Meullenet

ABSTRACT

Pasting properties are an important indication of rice flour quality. In addition, rice flour pasting properties change during rough rice storage. However, the reason for these changes is largely unknown.

Rough rice samples of two rice cultivars were stored at 4, 21, and 38°C for up to 36 weeks. A significant increase in peak viscosity of rice flour was observed during storage. Protein removal from rice flour resulted in a decrease in peak viscosity while lipids removal increased peak viscosity. Proteins were found to be responsible for changes occurring in peak viscosity during storage.

INTRODUCTION

Physicochemical changes in rice functional properties after harvest and during storage (rice aging) have been reported to affect rice processing and functionality and also to determine the cooking quality of rice (Itani et al., 2002; Marshall and Wordsworth, 1994). As rice ages, head rice yield (HRY) increases, water absorption during cooking increases, and cooked rice texture becomes fluffier and harder (Marks et al., 2001). However, the changes in rice physicochemical properties are most significant during the first three to four months of storage (Perez and Juliano, 1981). Since changes in rice functionality during storage are associated with changes in rice chemical components, and their interactions during storage, the physical and chemical changes occurring in a rice kernel during storage are considered among the principal factors that determine the quality of rice. In addition to the significant role of rice starch in determining the changes in functionality observed during storage, minor components at the granule surface (i.e.

lipids and proteins) have also been reported to influence rice structural and functional properties (Robards et al., 2003). However, changes in rice flour viscosity during storage of rough rice have shown inconsistent trends. Some researchers have documented an overall increase of rice flour pasting viscosity after short-term storage (Marks et al., 2001) while others have shown dramatic decreases in viscosity for longer term storage (Sowbhagya and Bhattacharyat, 2001). Furthermore, changes in rice constituents have been reported to be most apparent at an elevated storage temperature (Chrastil, 1994). Therefore, the objectives of this study were to investigate the effect of rough-storage temperature on the pasting properties of rice flour and to establish the roles that starches, proteins, and lipids play in determining rice flour pasting properties.

PROCEDURES

Rice Samples

Two rice cultivars, 'Wells' (long-grain) and 'Bengal' (medium-grain), with harvest moisture contents of 18.5% and 17.3%, respectively, were obtained from the 2003 crop of the University of Arkansas Rice Research and Extension Center in Stuttgart, Ark. The dried rough rice samples ~12.5% were placed in plastic bags and samples from each variety were stored at three different temperatures (4°C, 21°C, and 38°C) for 0, 3, 6, 9, 12, 18, 24, and 36 weeks. Rice samples were pulled out periodically for pasting properties measurements.

Rice Milling and Rice Flour

Dried rough rice was hulled using a de-husker (THU-35, Satake, Hiroshima, Japan) and the resulting brown rice was then milled using a continuous mill (Model 91-16839, Satake engineering Co., LTD, Tokyo, Japan) to a constant degree of milling (0.37 – 0.45 % surface lipids). Head rice was then separated, ground, and passed through a 100-mesh sieve rice flour.

Rice Starch Isolation (RS)

Soaked head rice in 0.2% NaOH was wet milled, washed, and centrifuged five times with 0.2% NaOH and then three times with distilled water. The dark tailings layer atop the starch was carefully scraped away and discarded after each centrifugation step. The suspended water and starch was then adjusted to pH 7 and centrifuged, and the starch cake was then dried, milled, and passed through U.S. standard test sieves (number 100) before determining its pasting properties.

Protease Treatment of Rice Flour (RF-P)

Streptomyces griseus protease (Sigma EC 9036 06-0) was used to hydrolyze proteins from rice flour. The protease treatment was conducted for two hours at 37°C after which the flour digest was washed using distilled water and centrifuged; then the tailing solid was scraped carefully and discarded.

Lipids Removal from Rice Flour (RF-L)

Lipids were removed from the rice flour (3.3 g, 12% moisture) by 150 ml of propanol/water (3/1,v/v) at 55°C for 3 hours using a Soxtec apparatus (Robards et al., 2003).

Rheological Measurements

Thereafter a TA AR 2000 Advanced Rheometer in combination with a starch-pasting cell was used for measuring the pasting properties of RF, RS, RF-L, and RF-P. A slurry of 10.4% starch was then mixed at 50°C before being heated from 50°C to 95°C in 4 min. The hot paste was held at 95°C for 5 min and then was cooled to 50°C in 3 min. The TA software was used to extract pasting parameters.

RESULTS AND DISCUSSION

Pasting Properties of Rice Flour Stored at 4, 21, and 38°C for up to 36 Weeks

Figure 1 shows the pasting properties of RF, RF-L, RF-P, and RS for Bengal and Wells stored at 4, 21, and 38°C for up to 36 weeks. Storage of rough rice resulted in a significant increase ($p<0.05$) in peak viscosity of RF for Bengal and Wells (Tables 1 and 2, respectively). Furthermore, storage at 38°C resulted in a higher increase in peak viscosity than samples stored at 4°C. This was explained by the greater rate of S–S protein linkage formation when storing at high temperature that may result in a stronger protein network and consequently a higher peak viscosity. This result is in agreement with Tsugita et al. (1983) who indicated that aging was accelerated at higher storage temperature. During storage, the structure of rice becomes progressively more organized. Changes at the starch granule surface may be influenced by the presence, orientation and nature of rice lipids and proteins. This may result in protecting starch granule integrity, which in addition to the formation of a protein network, may result in increasing the resistance of the rice paste to shear and thus increase the paste viscosity. This probably is the predominant phenomenon responsible for the increase in paste viscosity observed as a function of rough rice storage.

Effect of Protease Treatment on Rice Flour Peak Viscosity

During the pasting viscosity profile formation, denatured proteins may stabilize or strengthen (through protein networks) the continuous matrix between the dispersed and continuous phases. This may provide mechanical support for the gel matrix (mixture of amylose and proteins), inhibit the thixotropic (shear thinning) nature of the starch, and tend to increase the solution viscosity. Rice protein removal and/or disruption resulted in a significant decrease ($p<0.05$) in peak viscosity compared to RF (Fig. 2). The disruption of proteins by proteases may eliminate the formation of protein networks that protect starch granules' integrity from rupture. This may result in more fragile starch granules, increase starch granule susceptibility to be disrupted by shear and therefore decrease RF-P paste viscosity. These results are in accordance with Fitzgerald and Martin (2002) who reported a decrease in pasting properties of rice flour after protein disruption. Rough rice storage at 38°C resulted in slightly higher RF-P peak viscosity than storage at 4°C (Fig. 2) most likely because only 75% of the proteins contained in RF were removed by protease treatment. Chrastil and Zarins (1994) also postulated that the increase in protein molecular weight and the formation of disulfide bonds during storage might affect the degree of protein removal by proteases.

Effect of Lipid Removal on Rice Flour Peak Viscosity

The removal of lipids from rice flour resulted in a significant increase ($P<0.05$) in peak viscosity of the RF-L to a certain point (>12 weeks for both Wells and Bengal) after which it tended to decrease. The removal of lipids from flour could reduce the formation of complexes between rice lipids and amylose molecules (LAM), and may increase the amount of amylose leached in the continuous phase, and change the integrity of the starch granules. This agrees with (Fitzgerald et al., 2003) who reported an increase in peak viscosity after lipid removal from rice flour. The decrease in peak viscosity after storage for more than12 weeks could be due to the greater oxidation of lipids at 38°C than at 4°C. This may explain the decrease in RF-L peak viscosity after storage for ~9 weeks when stored at 38°C and after ~18 weeks when stored at 4°C.

RS Peak Viscosity Stored at 4, 21, and 38°C for up to 36 Weeks

Figure 1 shows the effect of storage on changing RS peak viscosity for Wells and Bengal. A slight change (increase for Wells and a decrease for Bengal) was reported after storage for up to 36 weeks (Tables 1 and 2 for Bengal and Wells, respectively). The overall slight changes in RS peak viscosity prove the important role of other rice constituents in affecting the pasting properties of rice.

SIGNIFICANCE OF FINDINGS

Study results indicated that the minor components of rice (i.e. proteins and lipids) play a major role in determining pasting properties of rice flour. The decrease in peak viscosity in RF-P was attributed to the absence of protein network linkages that maintains starch granule integrity, leading to the rupture of starch granules. On the other hand, the increase in peak viscosity after the removal of lipids was attributed to the absence of the lipid – amylose complexes (LAM) that are formed in the presence of lipids.

Storage at 38°C was reported to increase disulfide bonds and also the average molecular weight of rice proteins (Chrastil, 1990). This, in addition to the formation of a protein network that contributes to protecting starch granule integrity, may result in increasing the resistance of rice paste to shear and thus increase RF paste viscosity during storage.

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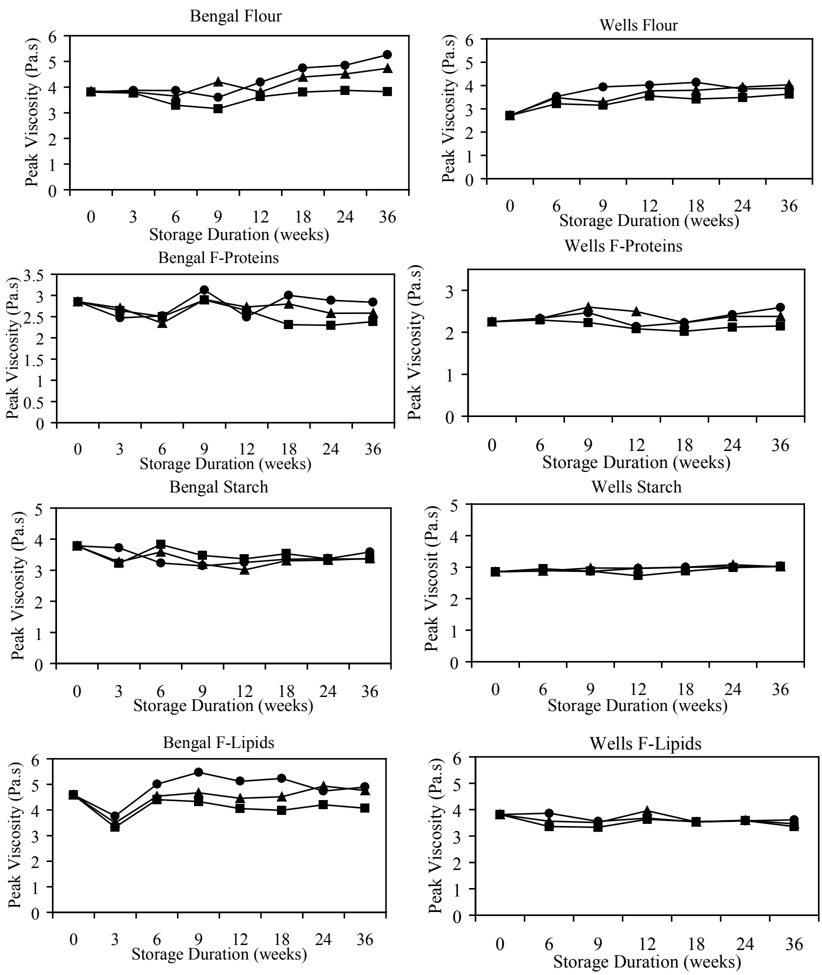

Fig. 1. Peak viscosity of Wells and Bengal RF, RF-L, RF-P, and RS stored at 4 (—■—), 21 (—▲—), and 38 (—●—) °C for up to 36 weeks.

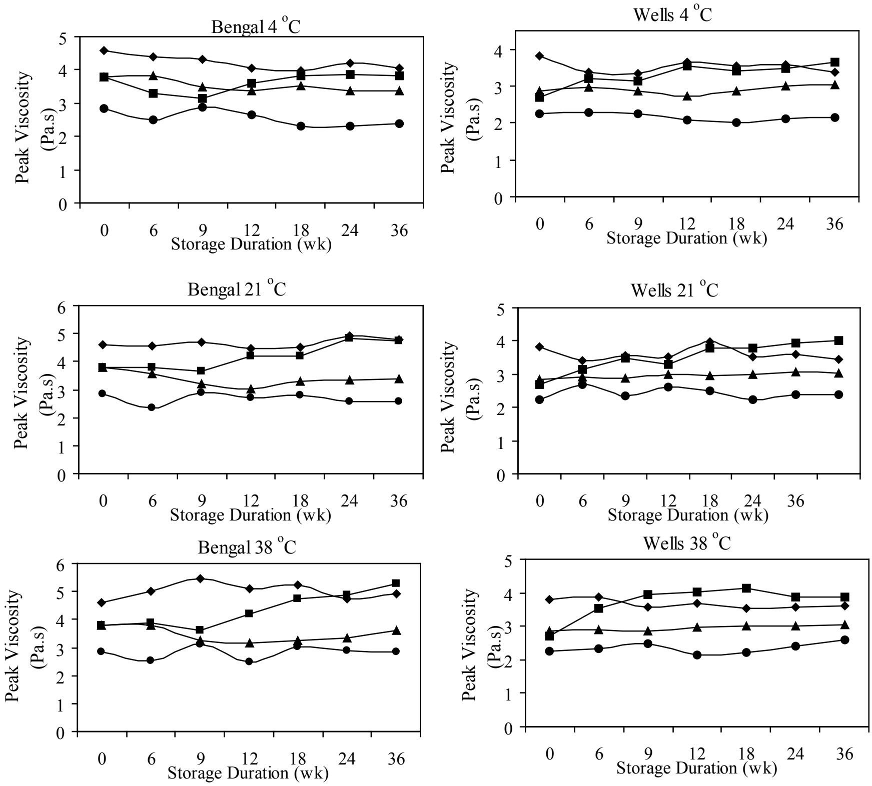

Fig. 2. Changes in RF (—■—), RF-L (—◆—), RF-P (—●—), and RS (—▲—) peak viscosity during storage of Bengal and Wells at 4, 21, and 38°C for up to 36 weeks.

Table 1. Peak viscosities (Pa.s) of rice flour, rice flour without proteins, rice flour without lipids, and rice starch of Bengal rough rice stored at 4, 21, and 38°C for up to 36 weeks.

Storage duration	RF			RF-P			RF-L			RS		
(weeks)	4°C	21°C	38°C	4°C	21°C	38°C	4°C	21°C	38°C	4°C	21°C	38°C
0	3.802 a[z]	3.802 c	3.802 f	2.856 a	2.856 a	2.856 c	4.590 a	4.590 cd	4.590 f	3.783 a	3.783 a	3.783 a
3	3.769 a	3.845 c	4.388 d	2.644 b	2.706 b	2.471 d	3.322 e	3.493 e	3.765 g	3.218 d	3.271 d	3.721 b
6	3.296 c	3.802 c	3.857 f	2.503 c	2.345 d	2.518 d	4.403 b	4.542 cd	5.009 cd	3.824 a	3.585 b	3.229 e
9	3.160 d	3.649 d	3.584 g	2.896 a	2.903 a	3.128 a	4.333 b	4.671 bc	5.470 a	3.476 b	3.194 e	3.137 f
12	3.596 b	4.193 b	4.197 e	2.649 b	2.726 b	2.496 d	4.051 d	4.455 d	5.119 bc	3.366 c	3.011 f	3.249 e
18	3.824 a	4.205 b	4.749 c	2.311 de	2.802 ab	3.002 b	3.989 d	4.515 cd	5.233 b	3.534 b	3.306 d	3.354 d
24	3.870 a	4.809 a	4.854 b	2.300 e	2.579 c	2.887 c	4.202 c	4.935 a	4.743 e	3.368 c	3.322 cd	3.372 d
36	3.820 a	4.733 a	5.260 a	2.385 d	2.583 c	2.842 c	4.070 d	4.764 b	4.899 d	3.359 c	3.377 c	3.587 c

[z] Means associated with different letters in the same column are significantly different ($p < 0.05$).

Table 2. Peak viscosities (Pa.s) of rice flour, rice flour without proteins, rice flour without lipids, and rice starch of Wells rough rice stored at 4, 21, and 38°C for up to 36 weeks.

Storage duration	RF			RF-P			RF-L			RS		
(weeks)	4°C	21°C	38°C	4°C	21°C	38°C	4°C	21°C	38°C	4°C	21°C	38°C
0	2.707 d[z]	2.707 e	2.707 f	2.253 b	2.253 de	2.253 e	3.814 a	3.814 b	3.814 a	2.855 c	2.855 d	2.855 c
3	3.122 c	3.127 d	3.957 c	2.426 a	2.674 a	2.505 b	3.214 c	3.418 f	3.586 cd	3.006 a	2.933 bcd	3.018 a
6	3.217 bc	3.477 c	3.573 e	2.292 b	2.330 cd	2.333 d	3.361 c	3.562 cd	3.869 a	2.952 ab	2.876 cd	2.888 abc
9	3.148 c	3.287 d	3.940 c	2.234 b	2.599 a	2.472 bc	3.334 c	3.515 de	3.559 cd	2.871 bc	2.975 abc	2.867 bc
12	3.549 a	3.771 b	4.025 b	2.086 d	2.454 b	2.140 f	3.633 ab	3.959 a	3.680 b	2.726 d	2.969 abcd	2.960 abc
18	3.418 ab	3.792	4.139 a	2.024 e	2.229 e	2.232 e	3.551 b	3.532 d	3.537 d	2.870 bc	2.999 ab	3.000 abc
24	3.484 a	3.933 ab	3.855 d	2.125 cd	2.378 bc	2.425 c	3.583 b	3.599 c	3.580 cd	2.987 a	3.073 a	3.013 ab
36	3.634 a	4.029 a	3.886 d	2.152 c	2.377 bc	2.593 a	3.359 c	3.464 ef	3.615 bc	3.021 a	3.017 a	3.028 a

[z] Means associated with different letters in the same column are significantly different ($p < 0.05$).

Predicting Rice Bulk Physicochemical Properties Using Weighted-Average Properties of Thickness Fractions

T.J. Siebenmorgen and R.C. Bautista

ABSTRACT

Long-grain rice varieties, 'Francis' and 'Wells', and hybrid 'XL8 Clearfield', were harvested at three moisture contents (MCs) from two locations in 2003. Rough rice was dried, thickness-fractionated, and milled. The physicochemical properties of unfractionated and fractionated samples were determined. Harvest moisture content (HMC) and growing location affected not only kernel thickness distributions, but also green kernel content, fissured kernel content, and head rice yield (HRY). Most bulk, unfractionated, sample properties were well predicted by the weighted average property values of the thickness fractions.

INTRODUCTION

Rice kernels on panicles do not develop simultaneously or uniformly. For example, at early harvest dates, HMC distributions typically display three kernel MC modes; the distributions transition to lower MC, single modes as the rice matures. The thicknesses of kernels on the same panicles also vary significantly due to non-uniform development (Wadsworth et al., 1982a; Wadsworth and Matthews, 1986). Kernel thickness has been related to many physicochemical properties, including protein content, amylose content, peak viscosity, and palatability (Wadsworth and Matthews, 1986; Matsue and Ogata, 1999; Matsue et al., 2001). Milling properties also vary greatly with kernel thickness (Wadsworth et al, 1982b; Sun and Siebenmorgen, 1993).

Better understanding the role that rice kernel thickness distributions play in determining bulk physicochemical properties could help explain heretofore inexplicable variations in milling and processing behavior. Little is yet known about (1) the effects of HMC and harvest location on rice kernel thickness distributions and (2) how these thickness distributions explain the variations in bulk rice physicochemical properties. As such, the objective of this study was to determine if variation in bulk physicochemical properties could be explained by the weighted-average properties of the constituent thickness fractions.

PROCEDURES

Long-grain varieties, Francis, Wells, and hybrid XL8 Clearfield (XL8CF), were harvested at three HMCs from two locations; Lodge Corner, Ark., and Essex, Mo. Approximate one kg subsample of freshly harvested rough rice from each variety/harvest location/HMC lot was cleaned using a grain cleaner (MCI Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and fractionated into thin, medium, and thick rough rice fractions using a precision sizer (ABF2, Carter-Day International, Inc., Minneapolis, Minn.) with two cylindrical screens that have 1.88 and 2.03 mm rectangular slot widths. The HMC of 1000 randomly selected kernels from each thichness fraction was measured using an individual kernel moisture meter (CTR-800E, Shizouka Seiki Co., Shizouka, Japan). About 60 kg of remaning rough rice from each harvest lot was cleaned, dried to approximately 12.5% MC, and fractionated into thin (<1.88 mm), medium (1.88 to 2.03 mm), and thick (>2.03 mm) rough rice fractions using a precision grader with two screen sizes. Thus, including an unfractionated control, 72 lots were created. To ensure thoroughness, the separation procedure was repeated for each fraction. Two hundred randomly selected rough rice kernels from each lot were hand dehulled, and the green and fissured kernels were counted using an illumination box (Grainscope TX-200, Kett Electric Laboratory, Tokyo, Japan). Replicate sub-samples (150 g) from each of the 72 lots were hulled to produce brown rice and milled in a McGill No. 2 mill (Rapsco, Texas) for 30 s. The milled rice was separated into head rice and brokens using a sizing device (Model 61-115-60, Grainman, Grain Machinery Manufacturing Corp., Miami, Fla.). HRY was calculated as the percentage of the original 150 g of rough rice that remained as head rice. Replicate moisture, protein, amylose, and alpha-amylase contents, and peak viscosities (PVs) of the rice flour from each of the 72 lots were measured according to approved methods (AACC, 2000).

RESULTS AND DISCUSSION

Moisture Content Distributions

Rough rice HMCs of the unfractionated and thickness fractionated samples of Francis, Wells, and XL8CF are summarized in Table 1. Thin kernels had greater MCs than the medium and thick kernels at the early harvest dates, which agrees with Wadsworth et al. (1982b). The HMCs of the different thickness fractions were more uniform at late harvest dates, corresponding to low HMCs; e.g., the HMCs of the thickness fractions of all three varieties harvested on 10 September 2003 at Lodge Corner, Ark., were approximately the same. The weighted-average MCs of the three varieties were at least one percentage point less than the unfractionated MCs at higher HMCs; the moisture loss may have been associated with the fractionation process.

The individual kernel MC distributions of Francis thickness fractions harvested from Lodge Corner, Ark. and Essex, Mo., are shown in Fig. 1. The MC distributions of thin fractions were dramatically different from those of medium and thick fractions, particularly at HMCs greater than 20%. The thin fractions had more high-MC kernels than the medium and thick fractions. The distributions of the thickness fractions narrowed, i.e. the kernel-MC variation decreased, and shifted to lower MCs with harvest date, especially in the thin fractions. At the high HMCs, the medium and thick fractions had lesser MCs than the thin fractions (Table 1), which was due to the medium and thick fractions having relatively few high-MC kernels in those distributions (Fig. 1). Similar trends were noted for the other varieties harvested from both locations.

Thickness Distributions

Kernel thickness distributions are presented in Fig. 2. For Francis and XL8CF from both locations, the medium thickness fractions were dominant, comprising 60 to 80% of the total mass. Wells was generally a thicker-kernel variety in that approximately 45% to 72% of the total mass was represented in the thick fraction, compared to only 7.6% to 22.3% in Francis and XL8CF. The thick-fraction mass percentage of Wells from Lodge Corner, Ark., decreased as the HMC decreased; however, the thick-fraction mass percentage decrease of Wells from Essex, Mo., was not as pronounced, which might have been caused by environmental growing conditions, such as high nighttime air temperatures during kernel filling. The thin-fraction mass percentages of all varieties were less than 17% of the total rough rice mass and generally decreased as the HMC decreased. The increases in the medium thickness fractions with HMC decreases may be due in part to maturation of kernels in the thin fractions, but could also be due to shrinkage of the thicker kernels (Bautista et al., 2000).

Physicochemical Properties

Table 2 shows the green (immature) kernel contents in rice harvested at Lodge Corner, Ark. Most of the green kernels were found in the thin fractions; the content decreased as the HMC decreased. The thin fractions of rice samples harvested from Essex, Mo., had more green kernels than those from Lodge Corner. At the last harvest, the green kernel contents of the thin fractions from Essex were still 13 to 35% (data not shown), while from Lodge Corner the range was 2 to 4%; this difference was possibly due to varying environmental conditions between the two locations, with Essex being further north than Lodge Corner.

The number of fissured kernels increased as HMC decreased (Table 2). At lower HMCs, rice kernels are susceptible to fissuring due to rapid moisture adsorption (Kunze and Prasad, 1978), such as would be caused by rainfall. This was especially true for the thicker fractions, as thick kernels are more vulnerable to fissuring than thin (Jindal and Siebenmorgen, 1994).

HRY, which is negatively impacted by fissured kernels and immature kernels, varied with kernel thickness and HMC (Table 2). The thin fractions had much lower HRYs than the medium and thick fractions. Although the thin fractions had fewer fissured kernels than the medium and thick fractions, there were more weak, immature kernels compared to the medium and thick fractions. The HRYs of the thin fractions of the three varieties were approximately 20 to 40 percentage points less than those of the medium and thick fractions.

The HRYs of the medium and thick fractions generally decreased as the HMC decreased. The thick fractions decreased faster than the medium fractions. This decrease was due primarily to the presence of fissured kernels. Unlike the medium and thick fractions, the HRYs of the thin fractions increased as the HMC decreased, due to increasing maturation and mechanical strength of immature kernels.

The alpha-amylase activity and protein content of the rice flour samples decreased as the kernel thickness increased (Table 2). Normally, immature rice kernels have greater alpha-amylase activity as compared with mature kernels (Del Rosario et al., 1968). The alpha-amylase activity was not affected by variety, HMC, or location; however, the protein content was affected by variety, but not by HMC and location. The average protein contents of unfractionated Francis, Wells, and XL8CF were 7.8, 7.8, and 8.8%, respectively.

The amylose content increased as the kernel thickness increased (Table 2), which agreed with Matthews et al. (1981a) and Matsue et al. (2001). Zhang et al. (2003) reported that the amylose content was positively correlated with the weight of rice kernels on the same panicle, which indicated that mature kernels had greater amylose content than immature kernels. Amylose content was not affected by HMC and location, but was by variety; the average amylose contents of unfractionated Francis, Wells, and XL8CF were 22.4, 23.2, and 25.3%, respectively.

The PVs of milled rice flours were affected by rice variety, location, HMC, and kernel thickness (Table 2). The PVs of rice samples generally increased as the kernel thickness increased, which agreed with the results of Matsue et al. (2001). The greater proportions of starch and the lesser proportions of protein and alpha-amylase in the thicker kernels offers an explanation for the greater PVs of the thick fractions. Protein content was negatively correlated with the overall PVs of the 72 rice sample lots ($r = -0.80$, $p < 0.001$). Generally, the PVs of the rice samples varied with variety and growing location in the following order: Francis>Wells>XL8CF and Lodge Corner>Essex. The PVs generally increased as the HMC decreased; this agreed with Wang et al. (2004).

Comparison of Weighted-average to Unfractionated Physicochemical Property Value

Most physicochemical properties of the unfractionated samples could be predicted by corresponding weighted-average properties of the thin, medium, and thick fractions. Fig. 3 shows the correlations between the unfractionated bulk rice properties and the weighted-averages of thickness fraction properties for alpha-amylase activity, protein content, amylose content, and peak viscosity. The solid lines in Fig. 3 represent trendlines and the dotted lines the theoretically perfect agreement between weighted-averages and unfractionated bulk properties. The slopes of the linear regression trendlines relating weighted-average properties to the unfractionated bulk properties are 0.81 for alpha-amylase activity (R^2=0.75), 0.67 for protein content (R^2=0.72), 0.87 for amylose content (R^2=0.96), and 0.97 for peak viscosity (R^2=0.96).

Similar correlations between unfractionated bulk properties and the weighted-average properties of thickness fractions were observed for HMC (R^2=0.98), 1000-kernel mass (R^2=0.98), and bulk density (R^2=0.41). However, the HRYs of unfractionated bulk rice samples were not well predicted by weighted-averages of thickness fractions (R^2=0.18); the reasons for this are attributed to kernel size uniformity causing differences in milling behavior.

SIGNIFICANCE OF FINDINGS

This study showed that bulk, unfractionated properties could be predicted with good accuracy from the weighted-average properties of the constituent thickness fractions. This was particularly true for the properties of alpha-amylase activity, protein content, amylose content, and peak viscosity. From this, it is garnered that some of the variation in processing performance of bulk lots could be linked to corresponding variation in the thickness distributions of these lots. The thickness variations could be due to environmental conditions occurring during critical stages of kernel development.

ACKNOWLDGMENTS

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Table 1. Harvest moisture contents (% w.b.) of unfractionated control samples and the constituent thickness fractions of rough rice samples harvested on different locations and dates in 2003.

Location	Harvest date	Variety	Thickness fractions: Thin	Medium	Thick	Unfractionated	Weighted[z]
Lodge Corner, Ark.	27 Aug	Francis	27.8	22.7	22.5	24.3	23.5
		Wells	30.5	24.0	22.8	24.8	23.6
		XL8CF	27.8	23.1	23.6	24.9	23.7
	4 Sept	Francis	18.3	17.4	17.3	18.2	17.5
		Wells	19.1	17.5	17.4	18.1	17.5
		XL8CF	17.7	17.3	17.8	18.5	17.4
	10 Sept	Francis	14.5	14.4	14.5	14.5	14.4
		Wells	15.7	15.3	15.4	15.8	15.4
		XL8CF	14.5	14.4	14.5	14.5	14.4
Essex, Mo.	16 Sept	Francis	23.5	19.0	17.2	21.8	19.7
		Wells	30.8	22.3	20.4	23.4	22.0
		XL8CF	27.4	21.4	22.4	25.0	22.5
	23 Sept	Francis	21.8	18.2	17.9	20.0	18.7
		Wells	22.0	17.6	16.6	18.8	17.4
		XL8CF	18.4	16.8	17.2	18.6	17.1
	2 Oct	Francis	18.7	16.1	15.9	17.1	16.5
		Wells	22.0	16.8	16.2	17.8	16.9
		XL8CF	15.6	15.0	15.3	15.5	15.1

[z] Weighted average moisture contents of the constituent thickness fractions.

Table 2. Green and fissured kernels in brown rice samples and physicochemical properties of milled head rice samples harvested from Lodge Corner, Ark., on the indicated dates in 2003[z].

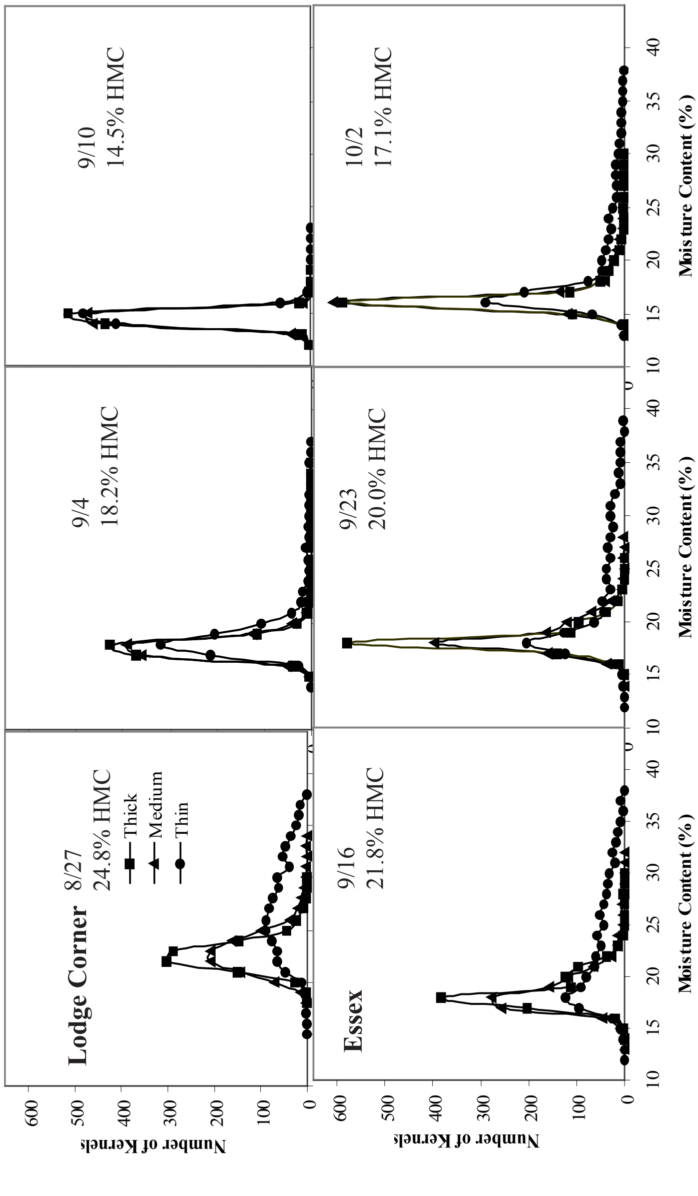
Sample	Green kernels	Fissured kernels	HRY[y]	α-amylase activity	Protein content	Amylose content	Total lipid content	Peak viscosity
	(%)			(unit/100g)	(%)			(RVU)
Francis								
27 Aug								
Thin	48	1	37.9 ij	2.5 c	8.4 ab	20.3 d	0.29 c	243 c
Medium	5	1	69.4 ab	2.0 cd	8.2 ab	22.7 c	0.44 a	242 c
Thick	4	1	70.9 a	1.8 cd	8.0 b	23.1 bc	0.38 ab	263 a
Unfractionated	13	2	63.3 d	1.9 cd	8.0 b	22.5 c	0.33 bc	243 c
4 Sept								
Thin	16	0	45.8 h	2.6 bc	8.2 ab	20.5 d	0.28 c	243 c
Medium	1	0	67.2 b	2.0 cd	7.7 b	22.4 c	0.40 ab	253 b
Thick	0	3	65.6 c	1.6 d	7.7 b	22.6 bc	0.33 bc	263 a
Unfractionated	3	1	63.2 d	2.1 cd	8.0 b	21.9 c	0.33 bc	250 b
10 Sept								
Thin	3	3	48.5 g	4.0 a	7.6 b	21.5 cd	0.34 b	245 bc
Medium	0	5	64.9 cd	2.5 c	7.0 c	21.9 c	0.36 b	254 b
Thick	0	9	61.5 e	2.3 c	7.5 b	23.6 b	0.29 c	264 a
Unfractionated	1	6	61.0 e	2.5 c	7.7 b	22.3 c	0.29 c	251 b
Wells								
27 Aug								
Thin	67	4	28.7 k	2.6 bc	8.3 ab	19.6 d	0.20 d	235 d
Medium	13	1	64.0 cd	2.0 cd	7.6 b	22.0 c	0.34 b	239 c
Thick	5	1	70.6 a	1.7 d	7.7 b	22.9 bc	0.32 bc	251 b
Unfractionated	8	4	64.2 cd	1.8 cd	7.6 b	22.5 c	0.27 c	243 c
4 Sept								
Thin	30	2	39.5 i	2.8 bc	8.7 a	20.1 d	0.24 cd	221 e
Medium	2	3	67.2 b	2.4 c	7.9 b	22.1 c	0.27 c	235 d
Thick	0	3	70.0 a	1.7 d	7.5 b	23.0 bc	0.25 cd	246 bc
Unfractionated	3	2	64.8 cd	1.6 d	7.9 b	23.5 b	0.31 bc	253 b

continued

Table 2. Continued.

Sample	Green kernels	Fissured kernels	HRY[y]	α-amylase activity	Protein content	Amylose content	Total lipid content	Peak viscosity
	(%)			(unit/100g)	(%)			(RVU)
Wells (continued)								
10 Sept								
Thin	4	2	39.8 i	3.3 b	8.8 a	19.8 d	0.23 d	233 d
Medium	1	5	63.3 d	2.4 c	8.5 ab	22.8 bc	0.30 bc	247 b
Thick	0	10	64.4 cd	2.2 c	8.1 ab	23.7 b	0.28 c	251 b
Unfractionated	2	8	58.4 f	2.5 c	8.5 ab	23.3 bc	0.28 c	247 b
XL8CF								
27 Aug								
Thin	30	2	37.0 j	2.3 c	9.3 a	25.1 ab	0.35 b	204 g
Medium	7	1	65.5 c	1.9 cd	9.3 a	25.4 a	0.38 ab	204 g
Thick	3	0	65.9 c	1.6 d	9.1 a	25.9 a	0.28 c	206 fg
Unfractionated	8	2	60.0 ef	1.6 d	8.5 ab	25.9 a	0.39 ab	201 g
4 Sept								
Thin	5	0	40.1 i	2.2 c	8.9 a	23.9 b	0.33 bc	207 fg
Medium	1	1	64.9 cd	1.7 d	8.4 ab	24.2 b	0.28 c	211 f
Thick	0	1	64.5 cd	1.7 d	8.3 ab	25.6 a	0.25 cd	201 g
Unfractionated	2	1	61.1 e	1.8 cd	8.7 a	25.0 ab	0.32 bc	197 g
10 Sept								
Thin	2	8	44.5 hi	4.0 a	8.9 a	24.5 ab	0.29 c	210 f
Medium	0	2	63.0 d	2.4 c	8.4 ab	25.2 ab	0.41 a	211 f
Thick	0	6	63.4 d	1.8 cd	8.1 ab	24.9 ab	0.27 c	220 e
Unfractionated	1	6	60.2 ef	2.5 c	8.5 ab	25.7 a	0.28 c	210 f

[z] Mean values in the same column with different letters are significantly different ($p<0.05$).
[y] HRY=head rice yield.



1. Individual kernel moisture content distributions of Francis thin (<1.88 mm), medium (1.88-2.03 mm), and thick (>2.03 mm) fractions harvested on the indicated dates at the indicated unfractionated harvest moisture contents (HMCs) from Lodge Corner, Ark., and Essex, Mo., in 2003.

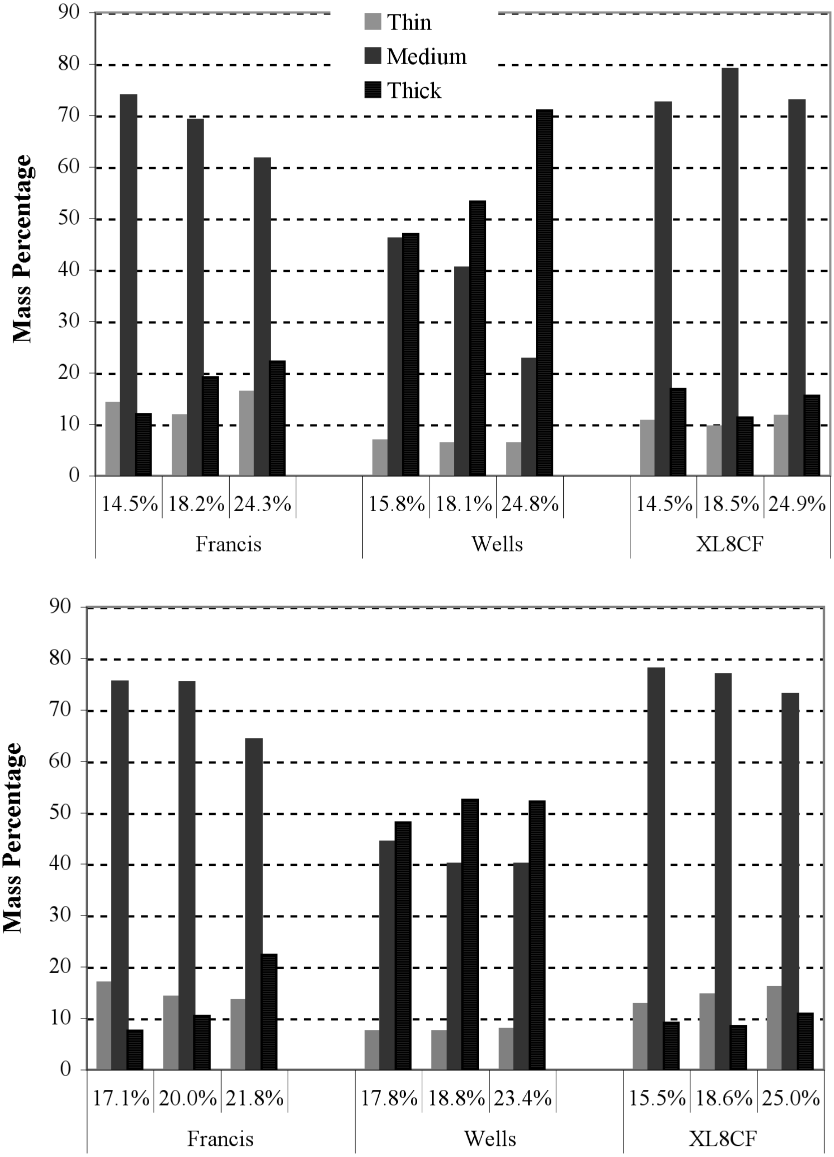


Fig. 2. Mass percentages of rough rice harvested at the indicated MCs from Lodge Corner, Ark., and Essex, Mo., in 2003 and dried to approximately 12.5% before thickness fractionating into thin (<1.88 mm), medium (1.88-2.03 mm), and thick (>2.03 mm) kernel thickness fractions.

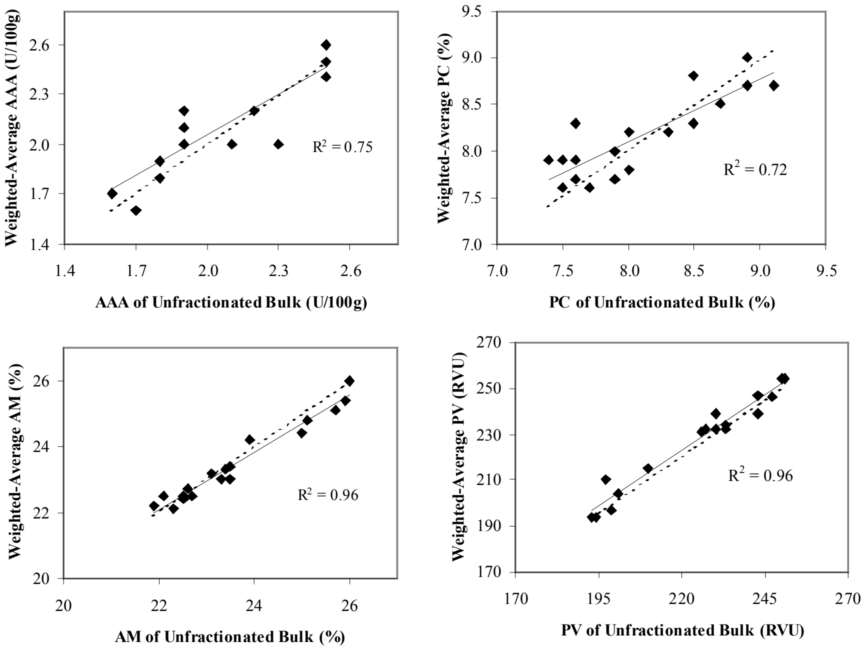


Fig. 3. Relationships between the weighted-average thickness fraction properties and the unfractionated bulk properties: alpha-amylase activity (AAA), protein content (PC), amylose content (AM), and peak viscosity (PV). Solid and dotted lines represent the trendlines and the theoretically perfect prediction lines by the weighted-averages, respectively.

Explaining Head Rice Yield Variation Using Historical Weather Data

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ABSTRACT

Rice quality, specifically head rice yield (HRY), can inexplicably vary from one lot of rice to another, which can lead to uncertainty in profit margins for producers as well as plant/product losses for rice processors. Historical weather and quality data were investigated to possibly correlate fluctuations in HRY to temperature trends during various stages of kernel development. Interpolation techniques using DD50 staging data were applied to a set of 17-year historical data for two long-grain cultivars, Newbonnet and Lemont, which included HRY, days to 50% heading, and temperatures. The analysis revealed that the average daily low temperature (or nighttime temperatures) from the R6 through R8 developmental stages had significant ($P>0.01$) influence on the HRY of Newbonnet but not of Lemont. The average daily high temperatures and the average daily mean temperatures did not significantly correlate to HRY trends. This historical analysis indicated that the nighttime temperatures during the reproductive stage of rice development could contribute to the variation in rice quality observed between rice lots and from year to year.

INTRODUCTION

Rice quality is largely measured by head rice yield (HRY), which is determined in part by production practices but can also 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 minimize waste and to maintain a consistent end product.

Historical data sets have proven useful in relating environmental temperature to rice yield. Downey and Wells (1975), in a six-year analysis, indicated that higher rice yields in Arkansas were associated with years in which the environmental temperatures during the growing season were neither above 88°F nor below 70°F. In particular, Downey and Wells found that the occurrence of long durations of high nighttime temperatures contributed to reduced yield. More recently, Peng et al. (2004) found that over a 24-year period, there was a clear relationship between rice yield and average low temperature during the entire dry-cropping season. However, there have not been many studies that relate historical environmental temperature to rice quality.

It has been shown that high temperatures, particularly during the early reproductive stages of rice plant development, have been linked to kernel quality and chemical composition of the kernel, including decreased kernel weight, decreased kernel dimensions, and an increased number of chalky kernels (Yoshida and Hara, 1977; Tashiro and Wardlaw, 1991). Thus, it would be useful to be able to target these growth stages within a set of historical data in order to evaluate the effects of weather patterns on the rice quality-determining stages of the plant. Yet historical data sets rarely contain information on specific rice developmental stages. The staging system of Counce et al. (2000) provides a means of interpolating the onset of the reproductive period from temperature data, possibly allowing trends in historical yield and quality data to be explained and possibly making the data trends more meaningful and understandable.

The Counce et al. (2000) staging system separates the vegetative (V) and reproductive (R) physiological stages of the rice plant based on the status of the plant mainstem, providing a uniform language in stage identification. For example, the stage at which the panicle exerts from the stem is termed "booting" or "50% heading", which is termed R3 in the Counce system, the third reproductive stage. Anthesis, or "flowering", is R4. Stage R5 occurs when at least one rice kernel on the main stem starts to fill with starch. The "grain-filling" stage is termed R6, which starts when at least one rice kernel on the main stem panicle has completely lengthened to the end of the hull. The appearance of one yellow hull and subsequently the appearance of one brown hull on the mainstem panicle are termed R7 and R8, respectively. The end of maturation is R9, when all of the kernels that have reached R6 have a brown hull.

The objectives of this study were, through analysis of a set of historical weather and quality data, to 1) interpolate the timing of the reproductive growth stages according to Counce et al. (2000) and 2) determine whether the average daily low, average daily high, and daily average temperatures at different reproductive growth stages were related to HRY.

PROCEDURES

Yield and Head Rice Yield Data

The Rice Research and Extension Center in Stuttgart, Ark., provided a set of 17-year historical data (1983 to 1999), which included HRY and number of days to 50% heading for two long-grain rice cultivars, Newbonnet and Lemont. Rice was harvested and processed at the Rice Research and Extension Center (Stuttgart, Ark.), following consistent protocols from year to year.

Weather Data and Degree-Day Determination

Weather data from 1983 to 1999 was obtained from the USDA weather station at Stuttgart, Ark., which included daily high and low temperatures in °F (Fig. 1). The DD50 uses equation [1] to calculate a day's thermal growing capacity based on air temperature with a base temperature of 50°F (Slaton and Norman, 1999).

$$DD50 = \left\{ \frac{\text{(Daily Maximum Temperature (°F) + Daily Minimum Temperature (°F)) -50}}{2} \right\} \text{ X 1 day}$$

Where: Daily Maximum Temperature = 94°F if maximum temperature is >94°F
Daily Minimum Temperature = 70°F if minimum temperature is >70°F

Interpolation of Developmental Stages

The 50% heading date, or R3 stage, was included in the data set, from which point the DD50 daily values were accumulated. Using staging data of the cultivar Lemont (Counce, unpublished data), which was expressed in terms of accumulated °F-days, the date at which each subsequent developmental stage occurred was determined. The average daily low temperature, the average daily high temperature, and the average daily temperature were then calculated for the duration of each growth stage for each year and were plotted against HRY for both cultivars. Regression curves were applied to the data to determine adequacy of fit.

RESULTS AND DISCUSSION

Regression Analysis

The F and R^2 values for the fitted quadratic regression curves relating HRY to daily high, daily low, and average daily temperatures for Newbonnet and Lemont are found in Table 1. The daily low temperature (or nighttime temperature) averaged over the R6 through R8 stages of rice development accounted for 56.7% (R^2) of the variability in HRY observed in Newbonnet rice, which was significant at the 0.01 probability level (Table 1, Fig. 2). The R^2 values correlating the average daily low temperature with HRY during Newbonnet's individual reproductive stages (R6, R7, and R8) were also relatively strong, being 0.344, 0.302, and 0.401, respectively, and were all significant at the 0.1 probability level. The daily average temperature during R6 to R8 accounted for 38.2% of the variation in Newbonnet HRYs, the regression of which was significant at the 0.05 probability level. However, since the daily high temperature during R6 to R8 showed weaker correlation with Newbonnet's HRY (R^2 value of 0.228 and insignificant F-value), the strong correlation between daily average temperature and HRY can be attributed to the strong correlation between daily low temperature and HRY as a co-linearity exists between the daily average and the daily low temperatures. It should be noted that the Newbonnet data set contained HRY values of 70.1% and 69.5%, results that are abnormally high and are generally not observed in rice grading. However in laboratory milling, these numbers can possibly be observed and thus the values were included in the data analyses.

The correlations between temperatures and Lemont HRYs resulted in low R^2 values and insignificant F-values for the daily high, daily low, and daily average temperatures (Fig. 3), for all rice reproductive stages. Lemont is a thicker kernel than Newbonnet, which makes it particularly susceptible to fissuring due to water absorption in the field and thus decreased HRYs, a phenomenon described by Jindal and Siebenmorgen (1994) and Siebenmorgen et al. (1992). It is possible that moisture absorption was responsible for the lower Lemont HRYs, the effect of which may have obscured the effect of temperature during kernel development on HRY.

SIGNIFICANCE OF FINDINGS

The application of the rice growth staging system of Counce et al. (2000) introduces a new method of targeting developmental stages within historical data if the data set contains a benchmark like the 50% heading date. The results of this analysis indicate that the nighttime, or daily average low, temperatures during kernel filling could have a significant effect on HRY values. Alternatively, the average daily high temperatures and the average daily temperatures did not explain a significant amount of the variation in HRY of either cultivar. The significant correlation of nighttime temperatures during kernel filling to HRYs warrants further, more detailed studies relating these environmental effects to rice milling and functional properties.

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Table 1. R^2 and F values for the quadratic correlations between HRY and temperature averaged over the inidicated developmental stages (Counce et al., 2000) for Newbonnet and Lemont.

	Developmental	Newbonnet		Lemont	
Temperature	stage	Pr>F	R^2	Pr>F	R^2
Daily average	R5	0.6264	0.065	0.3689	0.133
	R6	0.1037	0.028	0.1953	0.208
	R7	0.2104	0.200	0.9723	0.004
	R8	0.1132	0.268	0.2618	0.174
	R6-R8	0.0316*	0.382	0.5641	0.079
Daily high	R5	0.7956	0.032	0.5330	0.086
	R6	0.1762	0.220	0.1946	0.209
	R7	0.5515	0.082	0.8091	0.030
	R8	0.6270	0.065	0.8240	0.027
	R6-R8	0.1637	0.228	0.9033	0.014
Daily low	R5	0.3755	0.131	0.4261	0.115
	R6	0.0523*	0.344	0.3175	0.151
	R7	0.0809*	0.302	0.0840*	0.003
	R8	0.0265**	0.405	0.9797	0.298
	R6-R8	0.0029***	0.567	0.4105	0.119

*, **, *** significant at the 0.1, 0.05 and 0.01 probability levels, respectively.

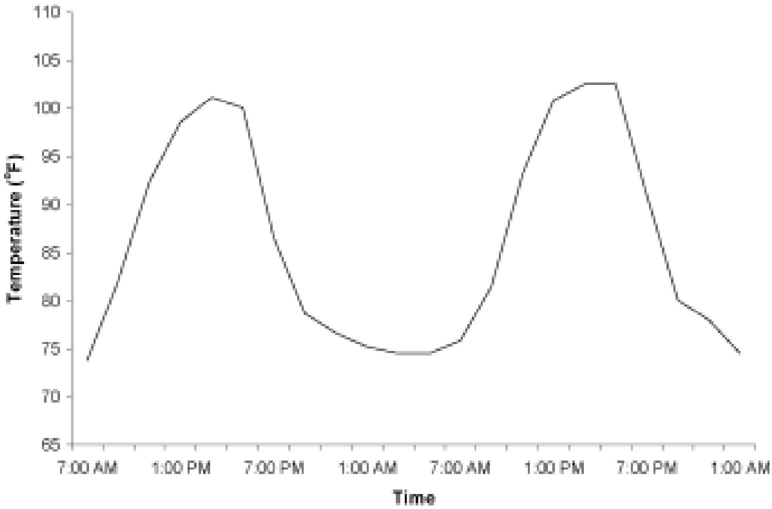

Fig. 1. An example of a diurnal temperature profile showing tested parameters. The daily average temperature is the average of the daily high and the daily low temperatures.

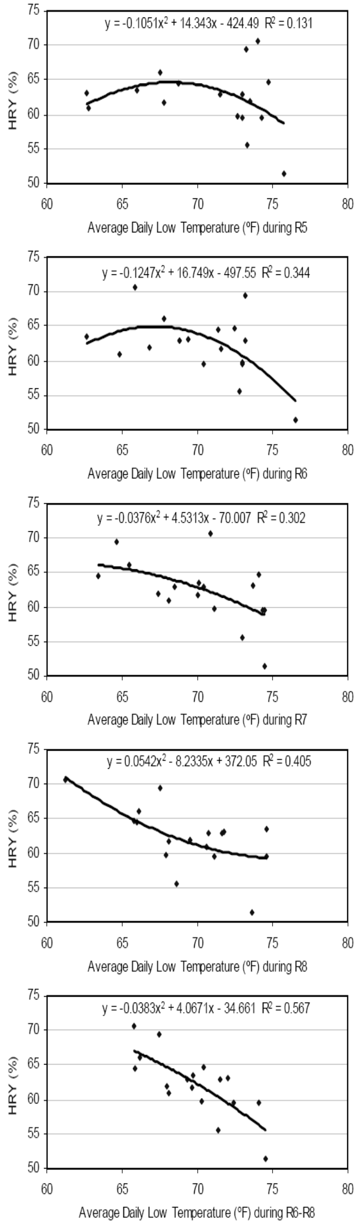

Fig. 2. Historical head rice yield (HRY) of Newbonnet rice from Stuttgart, Ark., 1983-1999, related to the average low (or nighttime) temperatures at the indicated stages of rice development.

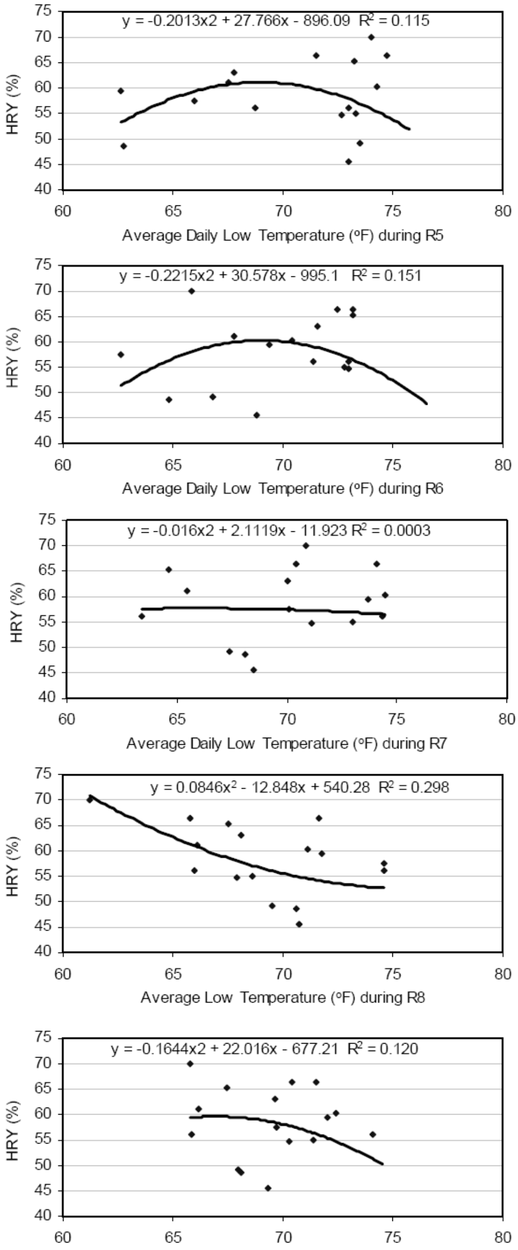

Fig. 3. Historical head rice yield (HRY) of Lemont rice from Stuttgart, Ark., 1983-1999, related to the average low (or nighttime) temperatures at the indicated stages of rice development,

Impacts of Farm Size and Tenure on the Profitability of No-Till Rice Production in Arkansas

K.B. Watkins, J.L. Hill, M.M. Anders, and T.E. Windham

ABSTRACT

Rice in Arkansas is typically produced using intensive tillage. No-till rice has been studied, but the research focus has been limited to impacts on yields and per acre net returns. Impacts of farm size and tenure on no-till profitability could not be evaluated in these studies. This analysis evaluates the profitability of no-till rice at the whole-farm level using both enterprise budget analysis and linear programming. The results indicate that no-till management can be profitable for Arkansas rice production due to savings in machinery ownership expenses resulting from less dependence on land preparation equipment prior to planting. Large operations may benefit more from no-till than smaller operations due to a combination of size economies that arise from spreading machinery inputs over more acres and lower machinery ownership expenses for no-till relative to conventional till management. No-till economic benefits may be greater on rented land than on owned land due to the nature of current rental arrangements used in Arkansas rice production. Greater economic benefits of no-till on rented land appears to be due to a combination of lower ownership expenses from less land-preparation equipment in the machinery complement and lower irrigation-ownership expenses due to use of irrigation wells that are supplied and maintained by the landlord.

INTRODUCTION

Most rice production in Arkansas involves intensive cultivation. Fields are “cut-to-grade” every few years and disked and “floated” (land planed) annually in early spring to ensure smooth water movement across the field. Conventional tillage accounts for nearly two-thirds of all planted rice acres, while stale seedbed (seedbed preparation in fall followed by burn-down herbicides prior to planting in the spring) accounts for over a quarter of all planted rice acres. True no-till (rice planted directly into the previous crop residue without tillage at any time) accounts for 10 percent of planted rice acres in Arkansas (Wilson and Branson, 2004).

Siltation is the primary pollutant identified for most eastern Arkansas waterways (ADEQ, 2002), and conservation practices like no-till will likely be recommended as remedial mechanisms. The economics of no-till management in rice have not been fully explored. Economic studies of the subject (Pearce et al., 1999; Smith and Baltazar, 1992; Watkins et al., 2004) have been limited to enterprise budget analyses based on experimental plots and have produced mixed findings. A shortcoming of such studies is that production costs from plot research often poorly reflect true machinery costs observed for typical commercial farms. Also, operation size and tenure are ignored in these studies. The objectives of this study were to evaluate the profitability of no-till relative to conventional till rice and determine the impacts of farm size and tenure on no-till rice profitability at the whole farm level.

PROCEDURES

This study compares the profitability of no-till to conventional till rice management for a medium rice farm (1200 acres) and a large rice farm (2400 acres) growing both rice and soybeans in a two-year rotation. Machinery complements were developed for both operation sizes under conventional till (CT) and no-till (NT). The machinery complements were constructed based on actual equipment observed in Arkansas rice production and closely tied to timing for completion of land preparation, planting, and harvesting operations.

Ownership expenses (depreciation, interest, taxes, insurance, and housing) for machinery-complement items were calculated based on American Society of Agricultural Engineers machinery standards formulas (ASAE, 2003a,b). Depreciation in particular was estimated for each item based on current list prices and remaining value equations that account for both machinery age and annual usage. Operating expenses for each rice and soybean enterprise were calculated using the Mississippi State Budget Generator (MSBG). The machinery labor, fuel, and repairs and maintenance expenses used in the MSBG corresponded with the timing of operations, annual use hours, and performance rates (hours/acre) of items in each machinery complement. Other operating expenses (seeds, fertilizer, pesticide, custom application) were based on production inputs obtained from an ongoing long-term rice-based cropping systems study at Stuttgart, Ark. (Watkins et al., 2004).

Net returns were calculated as gross returns (price x yield) less operating and ownership expenses. Five-year season average market prices for rice ($2.37/bu) and soybeans ($5.60/bu) for the period 1999 to 2003 were used as expected prices in the study. A five-year average loan deficiency payment of $1.25/bu was added to the rice market price to obtain a total cash price of $3.62/bu for rice. Hauling and drying expenses of $0.42/bu rice and $0.15/bu soybean were subtracted from expected prices to account for per unit custom charges. Average yields for the period 2000 to 2003 were obtained from the long-term cropping systems study to represent expected yields for rice and soybeans under conventional till and no-till management using standard fertility treatments.

Per-acre net returns were calculated for both owned and rented cropland under no-till and conventional till management. Net returns to rented cropland were calculated using the typical 25 percent straight-share arrangement (Parsch and Danforth, 1994). In this arrangement, the landlord receives 25 percent of the crop, pays 25 percent of the custom hauling and drying charges associated with the crop, and pays 100 percent of all belowground irrigation expenses (well, pump, and gearhead). The farm operator receives 75 percent of the crop, pays 75 percent of the custom drying and hauling expenses related to the crop, pays 100 percent of all aboveground irrigation expenses (power unit, fuel), and pays 100 percent of all other production expenses.

Linear programming models were constructed for each farm size to evaluate the whole-farm profitability of no-till relative to conventional till management for typical Arkansas rice farms growing both rice and soybeans in a two-year rotation. The objective functions of each LP model maximized whole farm returns to CT and NT subject to constraints on total cropland available, owned cropland, and rented cropland. Buying activities for labor and diesel fuel were incorporated into each LP model to evaluate the impact of different wage rates and fuel costs on whole-farm profitability.

RESULTS AND DISCUSSION

Returns and Expenses by Operation Size and Tenure

Per-acre returns and expenses by operation size and crop for owned and rented cropland are presented in Table 1. Gross returns are lower for NT compared with CT due to lower expected rice and soybean yields for no-till relative to conventional till at Stuttgart, Ark., over the 2000 to 2003 period (184 bu/acre conventional till rice vs. 173 bu/acre no-till rice; 46 bu/acre conventional till soybeans vs. 42 bu/acre soybeans). Operating (variable) expenses for rice and soybeans are slightly lower for NT compared with CT due to lower diesel fuel costs, repairs and maintenance costs, and labor costs resulting from fewer machinery operations devoted to land preparation under no-till management. However, much of these cost savings are offset by higher herbicide application costs for no-till relative to conventional till management.

Operating expenses vary little across operation size and remain invariant for owned and rented cropland since the farm operator pays virtually all of the operating expenses in a typical straight-share arrangement. However, ownership (fixed) expenses vary considerably by operation size, tillage, and tenure. Per-acre ownership expenses decline in every case when going from 1200 acres to 2400 acres due to size economies resulting from spreading machinery inputs over more acres. Per-acre ownership expenses also decline when going from CT to NT due to less land preparation equipment in the machinery complement for NT. Finally, ownership expenses decline when going from owned to rented land due to all belowground irrigation expenses being paid by the landlord rather than the farm operator in a straight-share arrangement.

Net returns to the farm operator tend to vary most by operation size. Per-acre net returns to rice, soybeans, and the farm increase when going from 1200 acres to 2400 acres due to size economies resulting from spreading machinery across more acres. Net returns to the farm operator are also impacted by tenure. Per-acre net returns to the farm are nearly the same across tillage treatments on owned land. However, per-acre net returns to NT are larger than those to CT on rented land. This is due in large part to a combination of lower ownership expenses for NT resulting from less land preparation equipment in the machinery complement and lower irrigation ownership expenses resulting from the farm operator's use of irrigation wells supplied and maintained by the landlord.

Per-acre net returns to the landlord for a typical 25 percent straight-share rental arrangement are reported for comparison purposes in the last column in Table 1. Net returns to the landlord are invariant by operation size since these returns are derived primarily from the share of the crop and therefore are driven primarily by crop yields. Since expected crop yields in this study are lower for no-till than for conventional till management, per-acre net returns to the landlord for NT are smaller than those for CT.

Linear Programming Results

Optimal LP net-return solutions for a 1200-acre rice operation under CT and NT are presented in Table 2. Solutions are reported for four scenarios: 1) the "Base Solution," in which the price of diesel and the labor wage are held at levels reported in 2004 Arkansas crop budgets ($0.90/gal diesel; $6.70/hour labor); 2) a "High Fuel Cost" scenario, in which the price of off-road diesel is raised to levels observed in Arkansas during the latter part of 2004 ($1.63/gal); a "High Labor Cost" scenario, in which the per-hour labor wage rate is raised to the level reported by the Arkansas Agricultural Statistics Service for Arkansas field workers in 2004 ($8.12/hour); and 4) a "High Fuel and Labor Cost" scenario where the price of diesel and the wage rate are the same as those in scenarios 2 and 3 above. Optimal solutions for each scenario were generated assuming 32 percent of total cropland acres are owned and 68 percent rented. These percentages were calculated using tenure data from the 2002 Census of Agriculture for counties comprising the Arkansas Grand Prairie region (Arkansas, Lonoke, Monroe, and Prairie Counties).

The optimal solutions for the 1200-acre operation are similar across tillage practices under the Base scenario. The NT strategy is slightly more profitable than CT under the Base scenario (+$3,333). The larger return for NT is totally attributable to higher returns on rented cropland, where NT nets $4,127 more return than CT. The NT strategy earns $794 less return on owned acres relative to CT under the Base scenario.

An increase in wage rate from $6.70/hour to $8.12/hour produces similar results relative to the Base Scenario. Under the High Labor Cost scenario, the NT strategy earns slightly more return for the 1200-acre operation when compared to the CT strategy (+$5,165). Again, the larger return for NT is attributed exclusively to higher returns on rented cropland, where NT nets $5,372 more return than CT. The NT strategy earns $208 less return on owned acres relative to CT under the High Labor Cost scenario.

Return differences between NT and CT are much larger for the 1200-acre operation under the High Fuel Cost scenario and the High Fuel and Labor Cost scenario. Under the former scenario NT earns $7,358 more return than CT, while under the latter scenario NT earns $9,190 more return than CT. In both cases, NT earns more return than CT on both owned and rented cropland, with the largest share of the return difference attributable to rented cropland.

Optimal LP net-return solutions for a 2400-acre rice operation under CT and NT are presented in Table 3. The optimal solution for NT is larger than that for CT in all four scenarios, with return differences ranging from +$18,603 under the Base scenario to +$31,551 under the High Fuel and Labor Cost scenario. The greater profitability of NT for the 2400-acre operation relative to the 1200-acre operation is due primarily to greater size economies for the larger farm operation. In all instances, NT earns more return than CT on both owned and rented cropland. However, as in the case of the 1200-acre operation, the largest share of the return difference is attributable to returns from rented cropland.

SIGNIFICANCE OF FINDINGS

The results of this study indicate that because of cost savings, no-till management can be profitable for Arkansas rice production. The primary cost savings of no-till are attributable to reduced ownership expenses resulting from less dependence on land preparation equipment. Operating-expense savings are also evident for no-till in the form of lower fuel, repair and maintenance, and labor expenses resulting from fewer land preparation operations prior to planting. However, a large portion of these cost savings is offset by higher herbicide application costs for no-till compared with conventional till management.

Operation size has a large impact on the profitability of no-till rice management. Larger operations may benefit more from no-till than smaller operations due to greater size economies resulting from more efficient use of machinery. No-till management may magnify size economics that are already present in large operations by further lowering per-acre ownership costs. Tenure also has a major impact on the profitability of no-till management in Arkansas rice production. The economic benefits from no-till management may be greater on rented land than on owned land given the structure of rental arrangements used in Arkansas rice production. On rented land, the farm operator benefits from use of irrigation wells that are supplied and maintained by the landlord. The landlord pays these “belowground” expenses. Thus, the farm operator’s ownership expenses are lower on rented acres than on owned acres. No-till further magnifies ownership cost savings on rented acres by further reducing ownership costs associated with land preparation.

The current structure of rental arrangements in Arkansas rice production may act as a deterrent to no-till adoption. Crop-share arrangements are the primary rental strategies used in Arkansas rice production, and the landlord's return is driven primarily by crop yields. Since cost savings from no-till accrue exclusively to the farm operator in these arrangements, the landlord benefits only if crop yields increase. Ancillary evidence from agronomic studies suggests that no-till crop yields are generally lower or not significantly different from conventional-till crop yields in rice production, at least in the short run (Bollich, 1991; Cartwright et al., 1998; Pearce et al., 1999; Smith and Baltazar, 1992). Crop yields in this study were slightly lower for no-till than for conventional till, and corresponding per-acre net returns to the landlord were also slightly lower. Thus adjustment may be required in current rental arrangements to allow landlords to receive some of the economic benefits of no-till management.

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Table 1. Per-acre returns and expenses for 1200- and 2400-acre Arkansas rice farms producing rice and soybeans in a two-year rotation.

		Owned				Rented				
Enterprise	Tillage	Gross return	Operating expenses	Ownership expenses	Net return	Gross return	Operating expenses	Ownership expenses	Net return	Landlord's net return
1200-acre operation		($/acre)								
Rice	CT[z]	588.80	196.38[y]	83.17	309.25	441.60	193.26	73.88	174.46	134.79
	NT	553.60	192.49	62.47	298.64	415.20	189.37	53.18	172.65	125.99
Soybean	CT	250.70	141.39	73.41	35.90	188.03	140.46	64.12	-16.55	52.45
	NT	228.90	133.41	53.12	42.37	171.68	132.47	43.83	-4.63	47.00
Farm[x]	CT	419.75	168.88	78.29	172.58	314.81	166.86	69.00	78.96	93.62
	NT	391.25	162.95	57.80	170.51	293.44	160.92	48.50	84.01	86.50
2400-acre operation		($/acre)								
Rice	CT	588.80	194.48	67.88	326.44	441.60	191.36	58.59	191.65	134.79
	NT	553.60	187.13	46.16	320.31	415.20	184.01	36.87	194.32	125.99
Soybean	CT	250.70	140.92	64.00	45.78	188.03	139.98	54.71	-6.67	52.45
	NT	228.90	130.04	42.33	56.53	171.68	129.10	33.04	9.53	47.00
Farm	CT	419.75	167.70	65.94	186.11	314.81	165.67	56.65	92.49	93.62
	NT	391.25	158.58	44.25	188.42	293.44	156.56	34.95	101.93	86.50

[z] CT = Conventional Till; NT = No-Till.
[y] Owned and rented operating expenses calculated assuming a labor wage of $6.70/hour and a diesel price of $0.90/gal.
[x] Per-acre farm returns and expenses are calculated as one-half acre rice plus one-half acre soybean.

Table 2. Linear programming net-return optimal solutions for 1200-acre Arkansas rice farm producing rice and soybeans in a two-year rotation.

Optimal solution	CT[z]	NT	Difference
Diesel price = $0.90/gal, Labor = $6.70/hour (Base solution)			
Farm[y]	130,699	134,032	3,333
Owned return	66,270	65,476	-794
Rented return	64,429	68,556	4,127
Diesel price = $1.63/gal, Labor = $6.70/hour (High fuel cost)			
Farm	104,498	111,856	7,358
Owned return	57,885	58,379	494
Rented return	46,613	53,476	6,864
Diesel price = $0.90/gal, Labor = $8.12/hour (High labor cost)			
Farm	125,263	130,428	5,165
Owned return	64,530	64,322	-208
Rented return	60,733	66,105	5,372
Diesel price = $1.63/gal, Labor = $8.12/hour (High fuel and labor costs)			
Farm	99,062	108,252	9,190
Owned return	56,146	57,226	1,080
Rented return	42,916	51,026	8,109

[z] CT = Conventional Till; NT = No-Till.
[y] Assumes 32 percent of total cropland acres are owned and 68 percent are rented.

Table 3. Linear programming net-return optimal solutions for 2400-acre Arkansas rice farm producing rice and soybeans in a two-year rotation.

Optimal solution	CT[z]	NT	Difference
Diesel price = $0.90/gal, Labor = $6.70/hour (Base solution)			
Farm[y]	292,448	311,051	18,603
Owned return	142,935	144,708	1,773
Rented return	149,513	166,344	16,830
Diesel price = $1.63/gal, Labor = $6.70/hour (High fuel cost)			
Farm	238,233	266,699	28,467
Owned return	125,586	130,515	4,929
Rented return	112,647	136,184	23,538
Diesel price = $0.90/gal, Labor = $8.12/hour (High labor cost)			
Farm	282,173	303,860	21,687
Owned return	139,647	142,406	2,760
Rented return	142,526	161,454	18,928
Diesel price = $1.63/gal, Labor = $8.12/hour (High fuel and labor costs)			
Farm	227,957	259,508	31,551
Owned return	122,298	128,214	5,916
Rented return	105,660	131,295	25,635

[z] CT = Conventional Till; NT = No-Till.
[y] Assumes 32 percent of total cropland acres are owned and 68 percent are rented.