B.R. Wells
RICE
Research Studies
2007

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

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

Bobby R. Wells

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

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

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

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

FEATURED RICE COLLEAGUE

Dr. C. Michael (Mike) French

Dr. C. Michael (Mike) French was born August 16, 1951 in Lake Providence, La., and grew up near Lake Providence on a cotton, soybean, and wheat farm. He graduated from Monticello High School in 1969. After high school, he attended the University of Louisiana at Monroe, earning a B.S. degree in agronomy in 1973. During the first two summers of undergraduate school, he operated a road grader scraping parish gravel roads. He also worked for Tennessee Gas Pipeline Company during the next two summers. After graduation he worked for BASF for the summer prior to graduate school. He attended Oklahoma State University completing an M.S. degree in agronomy and Ph.D. degree in crop science – weed science in 1975 and 1978, respectively. He recalls a common practice of taking hoe times on herbicide plots to measure the effectiveness of the herbicide. Dr. French said he was, unfortunately, the best student at this because he had hoed weeds throughout junior and senior high school.

After receiving his Ph.D., he first worked for the University of Georgia Cooperative Extension Service as an Extension Agronomist – Weed Science at Tifton, Ga., where he was responsible for formulating and conducting educational programs in weed science. In 1984 he transferred to Athens, Ga, continuing his extension programs in weed science. In 1989 he was named Head and Professor of the Extension Agronomy Department at the University of Georgia Cooperative Extension Service. In his time at Georgia, he was responsible for developing weed-management information for commodities such as cotton, soybeans, pastures, small grains, Christmas trees, and non-cropland areas. Dr. French was a prolific author of extension publications as well as popular press articles on weed management. He was a strong advocate of the county-based extension system and annually would hold several in-service educational sessions that were designed to improve the weed management expertise of county agents and ag-industry professionals. Similarly he was highly involved with both in-state organizations such as the Georgia Weed Science Society, and regional and professional weed science societies such as the Southern Weed Science Society, the Weed Science Society of America, and the American Christmas Tree Growers Association. He is primarily remembered in Georgia for his overwhelming dedication to the extension service, his enthusiasm for and willingness to help county agents and producers with difficult weed control situations, and his high level of proficiency in weed management.

After 15 years with the University of Georgia Cooperative Extension Service, Dr. French became Associate Director – Agriculture and Natural Resources for the University of Arkansas Division of Agriculture Cooperative Extension Service on May 17, 1993 and became Associate Director – Programs on August 1, 2005. While at the University of Arkansas, he has been responsible for fiscal and programmatic oversight of a diverse agricultural program and successfully secured funding to support extension and experiment station projects including row crops (i.e., corn/sorghum, cotton, rice, soybeans, and wheat); environmental sciences; poultry and livestock; forestry; aquaculture; turf management; and horticulture. More recently, he took on the added responsibility for oversight of all programs, including 4-H and family and consumer sciences. He has responsibility for all county extension programs as well. In addition, he has been a liaison to the Arkansas Farm Bureau and helped develop Arkansas agricultural leaders and sound agricultural policy. During his tenure at the University of Arkansas, he has continued to emphasize the importance of county-based programs and meeting the needs of producers.

Dr. Mike French has had many honors and awards bestowed upon him. In 1981 he was elected chairman of education, regulatory, and environmental aspects of weed control with the Southern Weed Science Society (SWSS); in 1986 he was elected chairman of teaching and extension by the Weed Science Society of America; in 1988 he was appointed to the board of the Agricultural Chemicals Association of Georgia where he served until coming to Arkansas; in 1988 he was presented with an Achievement Award by the National Association of County Agricultural Agents; and in 1989 he was named Outstanding Young Weed Scientist by the SWSS. He has recently received the Outstanding Extension Award from Gamma Sigma Delta. In 2008 Dr. Mike French received the highest honor of his professional career when he was inducted into the Arkansas Agriculture "Hall of Fame."

Dr. French has served the Rice Technical Working Group for much of his tenure at the University of Arkansas and recently received their Distinguished Service Award. He has served as the academic advisor and ex-officio member of the RTWG Executive Committee representing the Cooperative Extension Service for the past 12 years. His guidance and other contributions to the RTWG Executive Committee have been invaluable as the direction of the organization has evolved during the challenging and changing times of the past decade. His commitment and dedication to the success and continuation of the RTWG have been unwavering, and his support of the rice industry in Arkansas and the U.S. is unquestioned.

Dr. French and his wife, Nona, reside in Conway. Their daughters, Mary and Elizabeth, are graduates of the University of Arkansas and reside in New York City and Washington, D.C., respectively. Their son, Austin, is a senior at the University of Arkansas majoring in finance.

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 Agricultural Communication Services, (501) 575-5647.

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Trends In Arkansas Rice Production

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

ABSTRACT

Arkansas is the leading rice-producing state in the U.S., representing 47.9% of the total U.S. production and 48.2% of the total acres planted to rice in 2007. Rice cultural practices vary across the state and across the U.S. However, due to changing political, environmental, and economic times, these practices are dynamic. This survey was initiated in 2002 to monitor how the changing times influence the changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas Rice DD50 Program was included to summarize variety acreage distribution across Arkansas. Other data were obtained from the USDA National Agricultural Statistics Service.

INTRODUCTION

Arkansas is the leading rice-producing state in the U.S., representing 47.9% of the total U.S. production and 48.2% of the total acres planted to rice in 2007. 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 annually since 2002 by polling county extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information was obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice variety distribution was obtained from summaries generated from the University of Arkansas Rice DD50 program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely produced varieties. ‘Wells’ was the most widely planted variety in 2007 at 35.5% of the acreage, followed by ‘Francis’ (11.0%), Clearfield ‘CL 161’ (10.2%), Rice Tec ‘XL 723’ (8.5%), and ‘Bengal’ (7.5%). The acreage planted to Wells in 2007 increased slightly from 31% in 2006 to over 35% in 2007 while the acreage planted to CL 161 increased from less than 7% in 2006 to over 10% in 2007. The biggest changes were the elimination of ‘CL 131’ and ‘Cheniere’, which made up 13.1% and 10.6% of acreage in 2006, respectively. The regulations that were implemented to control Liberty Link rice found in the 2006 crop resulted in shifts in varieties as these two were regulated. The adoption of the Clearfield rice system represents a significant factor that plays a significant role in management of red rice. Clearfield rice (all varieties combined) accounted for over 20% of the total rice acreage in 2007, but was down about 10% from 2006. Clearfield rice varieties have increased in acreage each year since the Clearfield system was launched, except for 2007. However, indications are that Clearfield acreage will again increase in percentage of Arkansas rice in 2008. It provides an opportunity for red rice control that has never been available to rice farmers.

Arkansas’ planted rice acreage represented 48.2% of the total 2007 US rice crop (Table 2). The state-average yield of 7,130 lb/acre (158 bu/acre) was the third highest average in the U.S. behind California and Mississippi. It represents a record yield for Arkansas, exceeding the old record established in 2004 of 6,980 lb/acre. New record yields have been achieved by Arkansas rice producers in 5 of the last 7 years. The total rice produced in Arkansas was 94.5 million hundredweight (cwt). This represents 47.9% of the 197.5 million cwt produced in the U.S. during 2007. Over the past three years, Arkansas has produced 48.1% of all rice produced in the U.S. The five largest rice-producing counties in 2007 included Poinsett, Arkansas, Lawrence, Jackson, and Cross, representing 37.6% of the state’s total rice acreage (Table 1).

Planting began in 2007 much sooner than the 5-year average due to dry weather during the end of March and beginning of April (Fig. 1). Approximately 5% of the crop was planted by 1 April and 35% by 15 April in 2007, compared to a 5-year average of less than 1 and 28%, respectively. Approximately 1% of the rice was emerged by 1 April 2007. This is nearly a week earlier than normal. However, on Easter weekend, three consecutive nights of sub-freezing temperatures and subsequent rain resulted in reduced activity. By 30 April, planting progress was behind the 5-year average. Because of the delays caused by the Easter weekend freeze, harvest progress followed very closely the 5-year average (Fig. 2).

Approximately 55% of the rice produced in Arkansas was planted using conventional tillage methods in 2007 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. This was essentially equal to 2005 and 2006. The most common conservation tillage system utilized by Arkansas rice farmers was stale seedbed planting following fall tillage, representing approximately one third of the state's rice acreage. True no-till rice production was not common but was done in a few select regions of the state. According to the survey, this accounts for approximately 9% of the rice acreage in Arkansas.

The majority of rice was still produced on silt loam soils (Table 3). However, an increasingly important factor was the amount of rice produced on clay or clay loam soils (23% and 16% of the acreage, respectively). This represents unique challenges in rice production issues, such as tillage, seeding rates, fertilizer management, and irrigation. The increase in rice acreage on clay soils has been observed in counties along the Mississippi River, where historically non-irrigated soybeans have dominated. For example rice production in Mississippi County has more than doubled over the last 20 years increasing from approximately 15,000 acres in 1984 to about 37,000 in 2007 (Arkansas Agricultural Statistics, 1984; Table 1). Also, the 2007 acreage was down from the high of 49,000 acres in 2005. Other areas where rice production on clay soils has increased during this timeframe include Crittenden County, and the eastern half of Poinsett, Cross, and St. Francis counties.

As expected, rice most commonly follows soybean in rotation, accounting for almost 80% of the rice acreage (Table 3). Approximately 15% of the acreage in 2007 was planted following rice, with the remaining 6% made up of rotation with other crops including corn, grain sorghum, cotton, wheat, oats, and fallow. Rice following wheat declined dramatically during the 2005 and 2006 seasons, which is a reflection of the significant drop in wheat acreage during the 2005 and 2006 growing seasons. However, the amount of rice planted following wheat during 2007 increased substantially. The majority of the rice in Arkansas was produced in a dry-seeded, delayed-flood system with only approximately 4% using a water-seeded system. Approximately three-fourths of all the Arkansas rice acreage was drill-seeded, with an additional 20% broadcast-seeded in a delayed-flood system.

Irrigation water is one of the most precious resources for rice farmers of Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting and re-using all available water. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Approximately 80% of the rice acreage in Arkansas was irrigated with groundwater, with the remaining 20% irrigated with surfacewater obtained from reservoirs or streams and bayous (Table 3).

During the mid 1990's, the University of Arkansas began educating producers on the use of poly-tubing as a means of irrigating rice to conserve water and labor.

As of 2007, rice farmers have adopted this practice for almost 31% of the state's rice acreage (Table 3). The adoption of multiple-inlet irrigation using poly-tubing has increased from 17% in 2002. Approximately 70% of the rice was still irrigated with conventional levee and gate systems. A small percentage of rice acreage was produced in more upland conditions utilizing furrow-irrigation. A number of producers have increased the amount of rice produced using a furrow-irrigated system which they have found to be particularly efficient in fields that have steep slopes and often contain more area in levees than in paddies. This has increased from less than 1,000 acres in 2002 to more than 8,000 acres in 2007.

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 45% of the 2007 rice acreage in Arkansas was precision leveled, with more than 5% utilizing zero-graded fields (Table 3). Approximately 55% of the rice production still utilizes contour levees.

Stubble management is important for preparing the fields for the next crop, particularly in rice-following-rice systems (Table 3). Several approaches have been utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. In 2007, approximately 23% of the acreage was burned, 30% tilled, 30% rolled, and 22% 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.

SIGNIFICANCE OF FINDINGS

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

ACKNOWLEDGMENTS

The authors would like to extend thanks to all of the county extension agents who participated in this study and the Division of Agriculture, University of Arkansas.

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Table 1. Arkansas harvested

County	Harvested acreage[z] 2005	2006	Medium-grain Bengal	Jupiter	Others[y]	CL161
Arkansas	110,867	105793	4220	1447	124	7516
Ashley	11,536	11182	0	0	0	1543
Chicot	25,228	25051	0	0	68	2230
Clay	79,826	73323	4484	1753	0	3831
Craighead	79,274	78031	6535	5097	319	9711
Crittenden	36,167	36703	2206	0	145	757
Cross	98,038	84918	3129	725	420	26169
Desha	26,536	27528	2202	73	0	0
Drew	11,176	10217	0	0	0	0
Faulkner	2,628	2313	0	0	0	0
Greene	73,078	67450	222	2729	0	9885
Independence	9,607	10364	609	306	0	0
Jackson	89,945	91660	11264	9308	0	11174
Jefferson	56,049	58040	488	241	0	2808
Lafayette	3,966	1971	0	0	0	0
Lawrence	102,712	98234	2657	10176	0	25300
Lee	21,449	17849	586	215	0	397
Lincoln	26,740	26505	0	0	0	2680
Lonoke	76,145	73533	11461	1250	741	5922
Mississippi	39,489	37346	0	0	63	226
Monroe	47,943	46545	3223	47	0	2199
Perry	1,755	1377	0	0	0	809
Phillips	28,077	19857	0	0	0	1847
Poinsett	119,389	117228	27084	4649	40	11319
Prairie	55,721	59743	6378	2688	81	2584
Pulaski	3,243	3379	260	0	0	0
Randolph	33,094	32509	2129	200	0	427
St.Francis	39,126	34157	6218	1858	0	331
White	13,950	12386	602	284	267	423
Woodruff	57,867	56399	3343	1484	0	5168
Others[x]	7,591	3,411	0	0	0	280
Unaccounted[w]	10,497	0				
2007 Total		1,325,000	99,298	44,527	2,267	135,536
2007 Percent		100.00%	7.49%	3.36%	0.17%	10.23%
2006 Total	1,400,000		87,160	11,309	7,046	93,345
2006 Percent	100.00%		6.23%	0.81%	0.50%	6.67%

[z] Source: Arkansas Argicultural Statistics and FSA.

[y] Other varieties: ‘AB647’, ‘Banks’, ‘CL171’, ‘Cybonnet’, ‘Cypress’, ‘Della’, ‘Dellrose’, ‘Drew’, ‘Kaybonnet’, ‘Koshihikari’, ‘Medark’, ‘Nortai’, ‘Pirogue’, ‘Presidio’, ‘Rice Tec CL XL8’, ‘Rice Tec XP716’, ‘Rice Tec XP 744’, ‘Rice Tec CL XP745’, ‘Spring’, and ‘Trenasse’.

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

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

rice acreage 2007 summary.

Long-grain						
CLXL729	CLXL730	Cocodrie	Francis	Wells	XL723	Others[y]
313	2192	12213	29541	32047	8142	8,038
0	0	1018	0	950	5692	1,979
1629	326	7092	0	7818	2155	3,734
3381	3906	901	10968	26895	11269	5,935
3632	3868	8526	1974	27790	6000	4,579
908	2081	492	0	25499	2346	2,270
2395	941	684	12742	30787	3592	3,335
1821	440	4786	1850	7958	4170	4,229
0	1124	419	0	5660	725	2,289
771	771	0	0	0	771	0
15005	14009	4978	0	10951	6329	3,342
6929	1529	0	0	991	0	0
3082	3660	2023	1926	34966	7513	6,743
458	745	5846	3553	26936	4986	11,978
0	389	858	0	655	69	0
11269	2099	6960	1436	20881	8949	8,507
435	0	946	4863	10407	0	0
0	876	663	6553	6314	9419	0
2260	2883	2338	11923	24313	3273	7,169
0	0	0	5358	27056	4641	0
795	2152	4491	11181	19134	889	2,433
0	0	0	0	0	0	568
0	1033	6533	6593	2998	0	854
1368	2115	1493	11693	50999	2488	3,982
1022	2404	4026	8232	17126	4988	10,215
0	0	0	0	2353	0	766
6976	1708	0	1388	4840	5623	9,218
0	298	3078	2913	18634	397	430
0	472	653	0	3362	3918	2,406
3645	1741	4243	10500	21162	3210	1,904
409	0	427	173	855	820	447
						0
68,502	53,762	85,688	145,361	470,339	112,373	107,349
5.17%	4.06%	6.47%	10.97%	35.50%	8.48%	8.10%
556	67,638	61,503	134,413	433,643	26,688	476,699
0.04%	4.83%	4.39%	9.60%	30.97%	1.91%	34.05%

Table 2. Acreage, grain yield, and production of rice in the United States from 2005 to 2007[z].

State	Area planted			Area harvested			Yield			Production		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
	(1,000 acres)						(lb/acre)			(1,000 cwt[y])		
AR	1,643	1,406	1,331	1,635	1,400	1,325	6,650	6,850	7,130	108,792	95,917	94,487
CA	528	526	534	526	523	533	7,380	7,660	8,220	38,836	40,040	43,822
LA	530	350	380	525	345	378	5,900	5,820	6,140	30,983	20,093	23,222
MS	265	190	190	263	189	189	6,400	7,000	7,450	16,832	13,230	14,081
MO	216	216	180	214	214	178	6,600	6,400	6,900	14,124	13,696	12,279
TX	202	150	146	201	150	145	6,800	7,170	6,600	13,668	10,760	9,565
US	3,347	2,838	2,761	3,325	2,821	2,748	6,942	6,868	7,185	230,818	193,736	197,456

[z] Source: USDA-NASS, 2007.
[y] cwt = hundredweight.

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

Cultural practice	2005 Acreage	2005 % of total	2006 Acreage	2006 % of total	2007 Acreage	2007 % of total
Arkansas rice acreage	1,635,000	100.0	1,400,000	100.0	1,350,000	100.0
Soil texture						
Clay	389,176	23.8	309,871	22.1	309,150	22.9
Clay loam	273,576	16.7	231,958	16.6	225,450	16.7
Silt loam	811,125	49.6	734,525	52.5	713,350	52.1
Sandy loam	110,598	6.8	79,915	5.7	70,200	5.2
Sand	50,525	3.1	43,730	3.1	41,850	3.1
Tillage practices						
Conventional	920,897	56.3	782,071	55.9	742,500	55.0
Stale seedbed	565,432	34.6	491,924	35.1	484,650	35.9
No-till	148,671	9.1	126,001	9.0	122,850	9.1
Crop rotations						
Soybean	1,287,726	78.8	1,116,486	79.7	1,061,100	78.6
Rice	238,710	14.6	200,866	14.3	193,860	14.4

continued

Table 3. Continued.

Cultural practice	2005 Acreage	2005 % of total	2006 Acreage	2006 % of total	2007 Acreage	2007 % of total
Crop rotations - continued						
Cotton	25,343	1.6	18,765	1.3	14,850	1.1
Com	36,951	2.3	27,911	2.0	31,050	2.3
Grain Sorghum	14,061	0.9	6,908	0.5	10,800	0.8
Wheat	3,924	0.2	3,700	0.3	21,600	1.2
Fallow	28,122	1.7	25,223	1.8	21,600	1.6
Oats	164	<0.1	140	<0.1	157	<0.1
Seeding methods						
Drill seeded	1,233,935	75.5	1,057,600	75.5	1,031,400	76.4
Broadcast seeded	297,407	18.2	278,344	19.9	261,900	19.4
Water seeded	103,659	6.3	64,056	4.6	56,700	4.2
Irrigation water sources						
Groundwater	1,315,358	80.5	1,121,786	80.1	1,084,050	80.3
Stream, rivers, etc.	150,420	9.2	128,327	9.9	128,250	9.5
Reservoirs	169,223	10.4	139,887	10.0	137,700	10.2
Irrigation methods						
Flood, levees	1,121,610	68.6	1,014,984	72.5	928,800	68.8
Flood, multiple inlet	503,744	30.8	378,396	27.0	413,100	30.6
Furrow	9,042	0.6	6,619	0.5	8,100	0.6
Sprinkler	605	<0.1	0	0.0	0	0.0
Precision-leveled soils						
Contour levees	900,600	55.1	758,240	54.2	738,450	54.7
Precision leveled	734,400	44.9	641,760	45.8	611,550	45.3
Zero grade	82,548	5.0	69,149	4.9	74,250	5.5
Stubble management						
Burned	362,722	22.2	340,400	24.3	313,875	23.3
Tilled	540,751	33.1	375,898	26.8	404,325	30.0
Rolled	461,087	28.2	453,900	32.5	409,725	30.4
Winter flooded	329,672	20.2	300,455	21.5	281,475	20.9

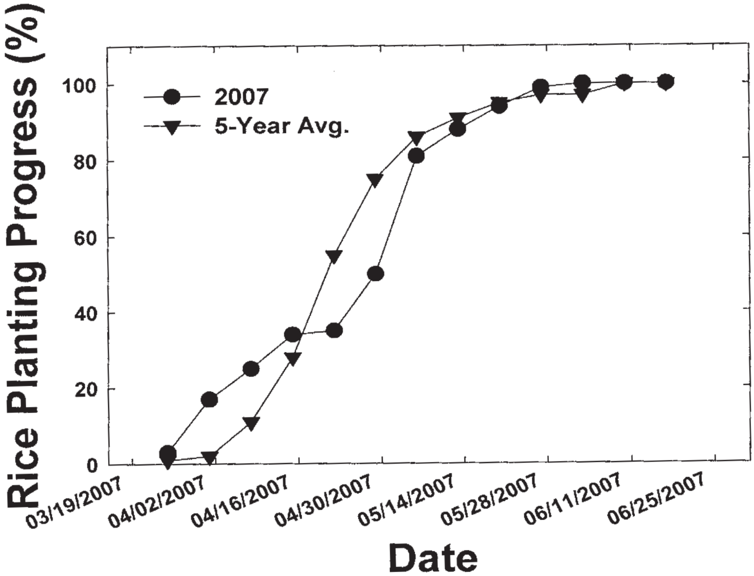

Fig. 1. Arkansas rice planting progress during 2007 compared to the five-year average. (Data obtained from NASS, 2007)

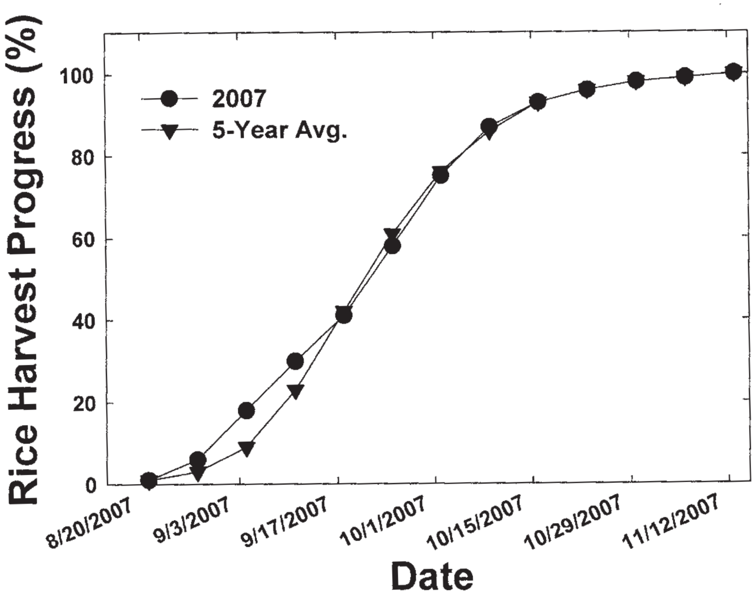

Fig. 2. Rice harvest progress during 2007 compared to the five-year average. (Data obtained from NASS, 2007)

2007 Rice Research Verification Program

S.K. Runsick, R. Mazzanti, C.E. Wilson Jr., J. Hignight, and B. Watkins

ABSTRACT

The 2007 Rice Research Verification Program (RRVP) was conducted on twelve commercial rice fields across the state. Counties participating in the program included Arkansas, Craighead, Independence, Lawrence, Lonoke (2 fields), Mississippi, Pope, Prairie, Randolph, St. Francis, and Woodruff for a total of 645 acres. Grain yield in the 2007 RRVP averaged 189 bu/acre ranging from 148 to 231 bu/acre. The 2007 RRVP average yield was 29 bu/acre greater than the estimated Arkansas state average of 160 bu/acre. The highest yielding field was in Pope County with a grain yield of 231 bu/acre. The lowest yielding field was in Lonoke County, which produced 148 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 58/72 (i.e., head rice/total white rice).

INTRODUCTION

In 1983, the University of Arkansas Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of University of Arkansas recommendations in fields with less than optimal yields or returns.

The goals of the RRVP are to: 1) educate producers on the benefits of utilizing University of Arkansas recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations that contribute to more profitable production, and 5) incorporate data from RRVP into extension educational programs at the county and state level. Since 1983, the RRVP has been conducted on 275 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged about 20 bu/acre better than the state average. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

PROCEDURES

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement university recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents were made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented, and monitor type and level of weed, disease, and insect infestation for possible pesticide applications.

An advisory committee consisting of extension specialists and university researchers with rice responsibility assists in decision-making, development of recommendations, and program direction. Field inspections by committee members were utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2007 included Arkansas, Craighead, Independence, Lawrence, Lonoke (2 fields), Mississippi, Pope, Prairie, Randolph, St. Francis, and Woodruff. The twelve rice fields totaled 645 acres enrolled in the program. Five varieties were seeded (‘Wells’, ‘Cybonnet’, ‘XP 723’, ‘CL XL 729 Brand’, and ‘CL XL 730 Red Tag’) in the 12 fields and University of Arkansas recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. An integrated pest-management philosophy is utilized based on University of Arkansas recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, plant dry-matter accumulation, temperature, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

RESULTS

Yield

The average RRVP yield was 189 bu/acre with a range of 148 to 231 bu/acre (Table 1). The RRVP average yield was 29 bu/acre more than the estimated state yield of 160 bu/acre. This difference has been observed many times since the program began, and can be attributed in part to intensive management practices and utilization of University of Arkansas recommendations. The 2007 RRVP average yield was 17 bu/acre more than the program's highest average yield of 172 bu/acre that was set in 2003. The highest yielding field yielded 231 bu/acre and was seeded with RiceTec hybrid XP 723 in Pope County. Three additional fields, Craighead, Lawrence, and Randolph counties, exceeded 200 bu/acre. The lowest yielding field yielded 148 bu/acre and was seeded with Wells in Lonoke 1 County.

Milling data were recorded on all of the RRVP fields. The average milling yield for the twelve fields was 58/72 (head rice/total white rice) with the highest milling yield of 63/71 occurring in Randolph County (Table 1). The average milling was greater than 55/70, which is considered the standard used by the rice milling industry. The lowest milling field was seeded with Wells in Lonoke 1 County and milled 52/68.

Planting and Emergence

All the fields were planted in the optimal time frame beginning with Craighead County planted 26 March and ending with Independence County planted 23 April (Table 2). An average of 77 lb/acre was seeded in the RRVP fields. Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 16 days was required for emergence. Stand density ranged from 5 to 23 plants/ft^2, with an average of 14 plants/ft^2. The seeding rates in several fields were higher than average due to planting method and soil texture. Broadcast seeding and clay soils require elevated seeding rate.

Irrigation

Well water was used to irrigate nine of the twelve fields in the 2007 RRVP. Lonoke 2, Pope, and Prairie counties were irrigated with surfacewater (Table 2). The Arkansas County field was furrow-irrigated, three fields were zero-graded (Lonoke 2, Pope, and St. Francis), and one field, Craighead County, used multiple-inlet (MI) irrigation. Flow meters were used in nine of the fields to record water usage throughout the growing season, and compare MI to conventional flooding. In fields where flow meters were not utilized, an average of 27 acre-inches was used.

An average of 27 acre-inches of water was pumped across all irrigation methods (Table 2). The field with MI irrigation averaged 21 acre-inches of water. Difference in water used was due in part to rainfall amounts; however, a 25% reduction in water pumped is typically realized when using MI irrigation.

Fertilization

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

Ammonium sulfate was applied at 100 lb/acre and flushed in at 2- to 3-leaf stage in Arkansas County as a management tool to speed development and shorten the time required to get the rice to flood stage (Table 3). Mid-season nitrogen was applied as urea at 100 lb/acre across all varieties in all the counties with the exception of Arkansas, Lawrence, Lonoke 2, Pope, Randolph, and Woodruff counties.

Phosphorus, potassium, and zinc were applied based on soil test results (Table 3). Phosphorus and or potassium and zinc were applied preplant in most of the fields. Phosphorus was applied in Lawrence, Lonoke 2, Pope, and St. Francis counties in the form of diammonium phosphate (DAP; 18-46-0). The DAP was applied preplant in Lawrence County, flushed in at the 2- to 3-leaf stage in Lonoke 2 County and blended with the preflood nitrogen in Pope and St. Francis counties. Zinc was applied as a seed treatment in fields with hybrid rice varieties at a rate of 0.5 lb of zinc/60 lb of seed. The average cost of fertilizer across all fields was $82.65 (Table 4), which was less than the $88.61 spent in 2006.

Weed Control

In 2007, the average herbicide cost was $57.80 (Table 4). Command was utilized in seven of the twelve fields for early-season grass control (Table 5). Command was applied in two of those fields (Lonoke 2 and Prairie counties) early postemergence as a tank mix with a postemergence herbicide and provided season-long grass weed control. Facet was applied in three fields (Arkansas, Craighead, and Woodruff counties) preemergence and in Pope County early postemergence and provided excellent grass weed control. Facet was used in these fields instead of Command because of either recent land leveling or to aid in control of hemp sesbania and/or indigo. All of the fields utilized a herbicide for preemergence weed control. None of the fields required flushing in order to activate the herbicides as rainfall was adequate early in the season. Two fields (Lawrence and Lonoke 2 counties) were seeded in Clearfield varieties and Newpath was applied to control red rice and other weeds. The Pope County field was the only field that did not require a postemergence herbicide application for grass weed control resulting in the least expensive herbicide program at $35.11/acre (Table 4). Lonoke 1 County had the most expensive weed control program at $79.54/acre.

Disease Control

Disease pressure was mild in the verification fields in 2007. Fungicides were applied to just three of the fields in 2007 for control of sheath blight and/or blast (Table 6). The average cost for fungicide was only $5.47/acre (Table 4). Early planting and rapid growth throughout the season allowed the crop to stay ahead of sheath blight. Leaf blast lesions were present in Independence and Lonoke 2 counties, and weather patterns favored the development of the disease at heading. Very little neck or panicle blast was observed in either field after heading. Quadris or Stratego were used to control sheath blight and blast and rates were determined based on variety, growth stage, climate, disease incidence/severity, and disease history (Table 6).

Insect Control

None of the fields required treatment for rice water weevil in 2007 (Table 6). Only the Pope County field was treated for rice stink bug. Rice stink bug pressure was very low in the verification fields across the state. The average cost for insecticides was $0.83/acre (Table 4).

Economic Analysis

This section provides information on the development of estimated production costs for the 2007 RRVP fields (Table 7). Records of operations on each field provided the basis for estimating these costs. The field records were compiled by participating county extension faculty, the coordinator of the RRVP, and the producers for each field. Presented in this analysis are specified direct expenses, specified ownership expenses, and total land costs for each of the fields. Break-even prices for the various cost components and returns above specified expenses at the average 2007 price are also presented.

Specified direct expenses are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application (Table 4 and 7). Actual quantities of all operating inputs were used in this analysis along with input prices collected for use in the Arkansas Cooperative Extension Service 2007 Rice Budgets.

The producers' actual field operations were used as a basis for calculations and actual equipment sizes and types were matched as closely as possible. Fuel and repair costs were calculated by extension models based on the size or horsepower of the equipment. Therefore, the producers' actual machinery costs may vary from the machinery cost estimates that are presented in this report. A diesel price of $2.22/gal was used for 2007 ($2.20 was used for 2006). Specified direct expenses for the 2007 RRVP fields averaged $43/acre less than the 2006 average and ranged from $385/acre for St. Francis County to $512/acre for Lawrence County with an overall average of $439/acre.

Land costs incurred by producers participating in the RRVP varied from land ownership, cash rent, or some form of crop-share arrangement. Therefore, a comparison of these divergent cost structures would contribute little to this analysis. For this reason, a 20% crop-share rent was assumed to provide a consistent standard for comparison. This is not meant to imply that this arrangement is normal or that it should be used in place of existing arrangements. It is simply a consistent measure to be used across all RRVP fields. The average break-even price needed to cover specified direct expenses, including the assumed 20% crop-share rent, was $2.67/bu, which is $0.33/bu less than the $3.00 price required in 2006 (Table 7). Furthermore, break-even prices ranged from $1.99/bu in Pope County up to $3.44/bu in Lonoke 1 County.

Table 7 includes estimated net returns above specified direct expenses and total specified costs. Net land costs and impacts of milling yields on gross returns are also included. Estimated landowner returns or net land costs were calculated assuming the landowner pays 20% of the drying expenses and irrigation-system fixed costs at $25.22/

acre for a typical well or $24.69/acre for a re-lift system. Lonoke 2, Pope, and Prairie counties used a re-lift irrigation system. All costs for risk, overhead, and management were not included.

Crop price was estimated based on a harvest-season average price of $4.57/bu, which was a reported total cash-price average for the period of 13 August 2007 to 5 October 2007. The associated market premium above the loan rate was $1.60/bu based on the $6.59/cwt loan rate for long-grain rice. The 2007 price was higher than the 2006 price of $4.01/bu including a $0.55/bu market premium. Crop prices were calculated based on milling yields for each field and the 2007 USDA loan rates for whole and broken rice kernels. Estimated prices varied from $4.46/bu in Lonoke 1 County to $4.75/bu in Mississippi County, with an average of $4.65/bu.

Net returns above total costs ranged from $125/acre in Lonoke 1 County to a $500/acre profit in Pope County. Much of the difference in net returns across RRVP fields can be attributed to yields and irrigation amounts. For instance, 44 and 40 acre-inches of irrigation were required in Randolph and Arkansas counties, respectively, versus only 13.0 acre-inches of irrigation in Pope County (Table 2).

DISCUSSION

Field Summaries

Furrow-irrigated rice is not a new concept; however, this year was just the second year the management practice was implemented in the RRVP. Arkansas County was the only county in the program that used furrow-irrigation instead of a continuous flood once the rice reached tillering. The field was seeded with the RiceTec hybrid XP723 at 30 lb/acre. Many factors can cause problems in this production system, such as the height of the bed. Last year in this field the beds were a little too high, which led to some of the seed in the middles not getting covered with soil. This year, the beds were about right and an excellent stand was achieved both on top of the beds and in the furrows. Another problem is frequency of irrigation. This year the field was irrigated for one 24-hour period a week during tillering and 48-hours per week during grain fill. A levee was constructed at the bottom of the field to catch and hold the water; however, a flood was never maintained on the field.

Nitrogen utilization can be another challenge in furrow-irrigated rice. At mid-season a noticeable difference in plant color between the beds and furrows could be detected. Plant samples were obtained prior to the last urea application and analyzed for nitrogen content. The resulting analysis showed a 35% decrease in plant nitrogen in the furrows compared to the plants on the top of the beds. The plants in the furrows also headed earlier than the plants on the beds. It appeared that a lot of nitrogen had been lost in the furrows due to leaching through the soil profile.

Insects that are usually not economically important can also present problems in a furrow-irrigated rice system. Bill-bug damage was significant in the field, however, not as bad as the previous year. This insect usually only causes damage on the levees, but without the flood the insect can cause widespread damage. The yield was 179 bu/acre, compared to last year's yield of 155 bu/acre. This year's yield was better than the historical yields for this field. The yield was also achieved without the expense of building levees or the expense of tearing them down.

The Craighead County field was the first field planted on 26 March. The field was broadcast-seeded in the rice variety Wells at a rate of 150 lb/acre. As is typical for broadcast-seeded fields, the stand was much too thick in areas and thin in others resulting in holes in the field especially on the edge of the field where the truck turned around. Researchers did not anticipate that this would be the highest yielding conventional-variety field in the program after seeing the uneven stand and coming through the Easter freeze. The field yielded a surprising 219 bu/acre, which is an all-time program record for the Wells variety. Facet and Prowl were applied delayed preemergence and provided excellent control of the grass weeds. An additional application of propanil and Permit was made mainly for control of broadleaf weeds, some small grasses, and yellow nutsedge.

The Independence County field was one of the last fields planted. Command or Facet could not be used in this field due to its close proximity to the city of Newark. This made weed control somewhat of a challenge. Propanil and Prowl were applied 7 days after emergence. The propanil killed most of the grass, but missed some 3- and 4-leaf signalgrass. RiceStar and Permit were applied 7 days later on wet soil and cleaned up the field. This field was the largest in the program this year at 119 acres. The field was a challenge to keep flooded resulting in a couple of dry spots and a very shallow flood on much of the field. There was also a line of trees on one side. Blast lesions were observed around the edge of the field and on the levees. This was one of only two fields sprayed for blast. The field yielded 191 bu/acre.

Lawrence County was one of two Clearfield rice variety fields in the program. Everything was pretty much by the book and worked just like the Clearfield system is supposed to work. The only change was the use of Clearpath in place of the first Newpath application for control of hemp sesbania and curly indigo. No red rice escapes were found and the field was weed-free all season. Researchers are always impressed with the weed control in this system.

The Lonoke 1 field was a more traditional rice field. It's an 80-acre field on a hillside with lots of levees; the kind of field where you turn the well off and come back the next day to no flood. The biggest challenge in this field was weed control. Command was applied by air after the levees were pulled. The Command did not provide great control of the signalgrass. The decision was made to apply RiceStar following a rain. At that time, there was 3-leaf grass present as mainly broadleaf signalgrass with scattered barnyardgrass. It was thought that perhaps Facet should be applied with the RiceStar, but the field could not be flushed effectively; and if it didn't rain it would be a waste of money, so only RiceStar was applied and it did a good job. The field could have been flooded the following week since the rice was 3- to 4-leaf; however, it turned out to be 2 weeks after the application before the flood was established. What happened was that another flush of grass emerged and it was too big to kill with a flood. There were numerous morningglories and big grass on the levees. In consultation with the agent it was decided to apply Facet ahead of the flood rather than take a chance on propanil alone.

Traditionally the producer uses 2,4-D at mid-season for the morningglories, but a better option was to apply Aim preflood with the Facet and skip an additional application. The field was weed-free after the flood was established. Leaf blast was present in areas of the field and the producer was concerned about kernel smut so Stratego was applied at boot split to 10% heading. The field normally yields 130 to 140 bu/acre. Researchers all thought the field would yield much better than that this year as it appeared to have excellent yield potential. The field yielded a disappointing 148 bu/acre.

The Lonoke 2 field was the other Clearfield variety field in the program. This was a 20-acre zero-grade field. The producer only had enough seed to plant 33 lb/acre. The recommended seeding rate for CL XL730 Red Tag is 46 lb/acre. The initial stand counts indicated 7 plants/ft^2. After the herbicide application, the off-types were killed and the stand was reduced to 5 plants/ft^2. A 100 lb/acre application of 18-46-00 (DAP) was applied prior to a flush irrigation flushed in at the 2- to 3-leaf stage to promote tillering. There were a few thin areas in the field; however, the stand appeared to be adequate. Rice water-weevil adults were present in the field and heavy leaf scarring appeared after the flush. We continued to monitor the insects; however, they never reached treatment level. The roots of the plants were excellent and no root pruning from larvae was evident. The field was drained early, at 50% heading + 2 weeks, and was the first verification field harvested. Researchers usually expect the hybrids to make 200 plus bu/acre, but sometimes they don't. The field yielded 167 bu/acre. I cannot attribute anything specific to the low yield besides the thin stand and possibly draining too early.

The Mississippi County field was seeded in the Wells variety. This area of the state received very little rainfall early in the year. It took over 3 weeks to get a stand in this field and replanting was considered. Weed control was difficult due to the dry conditions. The propanil applied missed some 4-leaf signalgrass. The field required flushing in order to have enough moisture for RiceStar. Ultra Blazer was used for control of hemp sesbania. This was the only field that was treated for sheath blight as the disease was very aggressive. The field yielded a respectable 181 bu/acre.

Pope County was a 40-acre field just zero-grade leveled prior to the 2007 crop. The producer actually had over 600 acres of 40-acre zero-grade fields and this was his first time to grow rice. He applied 3 to 4 tons/acre of chicken litter on the whole farm after leveling. I think the litter was a big contributor to his excellent yields. This field of rice was probably the best field I have ever seen. It was extremely lush and rank and a challenge to walk through later in the season. This field set an all-time program record yield of 231 bu/acre. The field was seeded in RiceTec hybrid XP723 at a rate of 31 lb/acre. Facet and Prowl were applied instead of Command due to the recent leveling and to aid in control of hemp sesbania. Aim was applied for control of smartweed and morningglory. The Facet did allow for some sprangletop to emerge but it was not enough to worry with this year and next year we'll know it's there. These flat, clay fields hold water like a bathtub; that with a lot of rainfall and surfacewater irrigation made this a very cheap field to water.

The Prairie County field was seeded in Cybonnet on 18 April. Propanil plus Command was applied early post-emergence and did an excellent job controlling the weeds. The levees had groundcherry and 2,4-D plus Aim was applied to the entire field at mid-season. The field looked excellent all year and yielded 175 bu/acre which is good for that variety.

Randolph County was seeded in the hybrid XP723 and 1.5 tons/acre of chicken litter were applied. The field came up to an excellent stand and was very uniform. Shortly after the establishment of the permanent flood, the flood was removed in order to construct another levee to aid in irrigating the field. This along with the sandy soil type made this field the highest water-use field in the program. It's been my experience that when the flood is lost for whatever reason, it's difficult to recover from the nitrogen fertilizer lost. An additional 70 lb/acre of urea were applied before the field was flooded back up. It is hard to get good movement of nitrogen into the root zone after the soil has been saturated even if it is dry on the surface. The rice turned yellow at midseason and 100 lb/acre of urea were applied prior to the boot stage. The field still made an excellent yield of 212 bu/acre.

The St. Francis County field was a zero-grade field of 28 acres in size that was broadcast-seeded in the Wells variety. Due to the early planting date, seeding method, and seed quality, 202 lb/acre of seed were sown. Stand counts indicated 23 plants/ft^2 and the stand was thicker in some areas of the field. Command was applied followed by RiceStar. Ultra Blazer was applied at midseason for hemp sesbania control. Sheath blight was present in the field, especially in the thicker areas; however, the disease threshold remained slightly below 50% of the field and below the third leaf. Treatment was not necessary. The field yielded 195 bu/acre.

The Woodruff County field was seeded in the hybrid XP723 at a rate of 30 lb/acre. Part of the field was leveled immediately prior to planting. Even though poultry litter and phosphorus were applied, the plants in the cut area showed signs of phosphorus deficiency. The plants were stunted and did not tiller well. Although the plants in the cut areas seemed to recover by the end of the season, some yield loss occurred in these areas. The remainder of the field was excellent and most likely yielded very high. The whole field yield was 178 bu/acre.

On-Farm Research

Research was conducted in three of the verification fields in 2007. Disease monitoring tests were planted in the Independence and Randolph county fields. The Independence County test was not harvested due to a poor stand. A fungicide trial was conducted in the Craighead County field evaluating milling yield benefits from fungicide when no noticeable disease was present. The results indicated no significant milling yield increase from the application of a fungicide.

SIGNIFICANCE OF FINDINGS

Data collected from the 2007 RRVP reflect the general trend of increasing rice yields and above-average returns in the 2007 growing season. Analysis of these data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

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Table 1. Variety, soil series, previous crop, acreage, grain yield, milling yield, and harvest moisture for the 2007 RRVP by county.

County	Variety	Soil series	Previous crop	Acres	Grain yield	Milling yield[z]	Harvest moisture
					(bu/acre)		(%)
Arkansas	XP 723	Rilla silt loam	Soybean	40	179	52/74	13.8
Craighead	Wells	Roellen silty clay loam	Soybean	50	219	55/73	19.0
Independence	Wells	Amagon silt loam	Soybean	119	191	60/73	14.9
Lawrence	CLXL729 Brand	Jackport silty clay	Rice	38	213	57/69	18.4
Lonoke 1	Wells	Loring silt loam	Soybean	78	148	52/68	15.0
Lonoke 2	CLXL730 Red Tag	Herbert silt loam	Rice	20	167	53/72	15.0
Mississippi	Wells	Tunica silty clay	Soybean	45	181	61/73	14.7
Pope	XP723	Roellen clay	Fallow	40	231	61/71	17
Prairie	Cybonnet	Loring silt loam	Soybean	43	175	61/72	16.2
Randolph	XP723	Bosket fine sandy loam	Soybean	68	212	63/71	15.0
St. Francis	Wells	Dundee silt loam	Rice	26	195	55/72	15.9
Woodruff	XP723	Jackport silty clay loam	Soybean	78	178	60/70	18.3
Average				54	189	58/72	16.0

[z] Head rice / total white rice.

Table 2. Stand density, irrigation, seeding rate, and important dates in the 2007 RRVP season by county.

County	Stand density	Rainfall	Irrigation[z]	Rainfall + Irrigation	Seeding rate	Planting date	Emergence date	Harvest date
	($plants/ft^2$)	(inches)	(acre-in.)	(inches)	(lb/acre)			
Arkansas	14	13	40	53	30	19 Apr	27 Apr	2 Sept
Craighead	16	12	21	33	150	26 Mar	13 Apr	22 Aug
Independence	22	10	27	37	87	23 Apr	4 May	19 Sept
Lawrence	6	11	22	33	49	10 Apr	2 May	1 Sept
Lonoke 1	20	8	27	35	80	19 Apr	29 Apr	12 Sept
Lonoke 2	5	11	16	27	33	10 Apr	23 Apr	17 Aug
Mississippi	15	6	27	33	115	30 Mar	23 Apr	15 Sept
Pope	12	14	13	27	31	20 Apr	3 May	3 Sept
Prairie	15	10	33	43	85	18 Apr	29 Apr	10 Sept
Randolph	12	14	44	58	30	9 Apr	26 Apr	23 Aug
St. Francis	23	8	28	36	202	29 Mar	26 Apr	23 Aug
Woodruff	10	11	25	36	30	9 Apr	28 Apr	26 Aug
Average	14	10.7	27	37.6	76.8			

[z] An average of 30 acre-inches was used for fields not utilizing flow meters.

Table 3. Soil test results from 2007 RRVP fields and fertility recommendations.

County	pH	Soil test[z]			Split application rates	Total-N	Preplant fertility
		P	K	Zn	of urea (45%)[y]	rate	N-P-K-Zn[x]
		(lb/acre)					
Arkansas	5.8	104	297	3.5	100-100-70	143	21-0-0-0.25-24[w]
Craighead	6.3	117	513	14.5	250-100-0	168	10-40-80-0
Independence	5.6	34	180	6.6	230-100-0	149	0-30-90-0
Lawrence	6.3	47	459	7.7	250-0-70	162	18-46-0-0.41
Lonoke 1	5.8	36	170	8.6	250-100-0	158	0-30-90-0
Lonoke 2	6.9	73	588	5.0	250-0-70	162	18-46-0-0.27
Mississippi	7.2	84	476	11.4	300-100-0	180	0-0-0-0
Pope	5.4	54	764	8.8	200-0-70	140	18-46-0-0.26
Prairie	6.6	40	161	17.4	230-100-0	149	0-88-176-0
Randolph	5.8	91	219	8.7	200-70-100	167	0-0-0-0.25
St. Francis	5.6	61	312	8.6	250-100-0	176	18-46-0-0
Woodruff	6.3	94	206	4.8	200-0-75	124	0-23-90-0.25

[z] P= phosphorus, K=potassium, and Zn=zinc.
[y] Preflood-midseason-boot.
[x] N-P_2O_5-K_2O-Zn includes seed treatments.
[w] Ammonium sulfate was applied to 2- to 3-leaf rice and the field flush-irrigated.

Table 4. Selected variable input expenses from 2007 RRVP fields by county.[z]

County	Variety	Seed[y]	Fertilizer[x]	Herbicides[x]	Fungicides[x]	Insecticides[x]	Fuel[w]	Irrigation[v]
		(Input cost /acre)						
Arkansas	XP723	71.70	70.00	61.82	0.00	0.00	21.15	119.11
Craighead	Wells	49.47	95.96	39.34	0.00	0.00	18.42	63.08
Independence	Wells	16.27	90.16	44.98	23.31	0.00	20.38	67.03
Lawrence	CLXL729	115.99	68.21	74.94	0.00	0.00	23.23	55.49
Lonoke 1	Wells	15.02	95.59	79.54	23.31	0.00	19.04	73.18
Lonoke 2	CLXL730	100.65	79.90	51.23	0.00	0.00	12.62	21.28
Mississippi	Wells	20.44	63.20	78.57	19.00	0.00	16.89	67.03
Pope	XP723	74.09	71.45	35.11	0.00	10.01	26.18	36.80
Prairie	Cybonnet	15.91	117.71	57.16	0.00	0.00	19.94	43.89
Randolph	XP723	72.50	79.40	59.66	0.00	0.00	20.47	107.99
St. Francis	Wells	41.00	71.95	45.02	0.00	0.00	14.83	68.72
Woodruff	XP723	72.50	88.26	66.19	0.00	0.00	20.79	68.27
Average	2007	55.46	82.65	57.80	5.47	0.83	19.50	65.99
Average	2006[u]	35.34	88.61	58.23	5.29	5.66	15.38	75.95
Change[t]		20.12	-5.96	-0.43	0.18	-4.83	4.12	-9.96
Hybrid seed average		84.57	76.20	58.16	0.00	1.67	20.74	68.16
Conventional seed average		26.35	89.10	57.44	10.94	0.00	18.25	63.82

[z] Does not include all variable costs, such as drying, hauling, equipment repair, etc.
[y] Includes seed cost and treatments.
[x] Includes the cost of material and application for each input.
[w] Fuel for tractors, combines, and self-propelled equipment ($2.22/gal).
[v] Includes irrigation labor, irrigation supplies (levee gates & poly-pipe), irrigation repair and maintenance, and diesel fuel ($2.22/gal).
[u] Average costs from 2006 RRVP Fields using 2006 costs of production.
[t] Change in average costs from 2006 to 2007.

Table 5. Herbicide rates and timings for 2007 RRVP fields by county.[z]

Arkansas	**PRE[y]:** Facet (0.333 lb) Prowl (2 pt) **POST[x]:** Duet (4 pt) Permit (0.333 oz) Facet (0.25 lb)
Craighead	**PRE:** Facet (0.5 lb) Prowl H20 (1.8 pt) **POST:** Propanil (4 qt) Permit (0.5 oz)
Independence	**POST:** Propanil (4 qt) Prowl (2 pt) fb RiceStar HT (17 oz) Permit (0.333 oz)
Lawrence	**PRE:** Glyphosate (2 pt) Command (1 pt) **POST:** Clearpath (0.5 lb) fb Newpath (4 oz)
Lonoke 1	**PRE:** Glyphosate (1 qt) fb Command (13 oz) **POST:** RiceStar HT(17 oz) fb Facet (0.5 lb) Aim (1 oz)
Lonoke 2	**PRE:** Glyphosate (1 qt) fb Glyphosate (1 qt) **POST:** Command (10 oz)
Mississippi	**PRE:** Command (20 oz) **POST:** Propanil (4 qt) fb RiceStar HT (20 oz)
Pope	**POST:** Facet (0.5 lb) Prowl (2 pt) fb Aim (1 oz)
Prairie	**PRE:** Glyphosate (1.5 pt) **POST:** Propanil (4 qt) Command (12.8 oz)
Randolph	**PRE:** Command (8 oz) **POST:** Propanil (4 qt) Facet (0.25 lb)
St. Francis	**PRE:** Command (12 oz) **POST:** RiceStar HT (17 oz) fb Ultra Blazer (0.5 pt)
Woodruff	**PRE:** Glyphosate (12 oz) Harmony (0.125 oz) fb Facet ((0.25 lb) Prowl H20 (2.0 pt) **POST:** Propanil (3 pt) Facet (0.125 lb)

[z] All rates are on a per-acre basis.
[y] PRE=pre-emergence.
[x] POST=post-emergence.

Table 6. Fungicide and insecticide applications in 2007 RRVP fields by county.

County	Sheath blight	Blast	Rice water weevil	Rice stink bug
Arkansas	------	------	------	------
Craighead	------	------	------	------
Independence	------	Stratego (16 oz)	------	------
Lawrence	------	------	------	------
Lonoke 1	------	Stratego (16 oz)	------	------
Lonoke 2	------	------	------	------
Mississippi	Quadris (7 oz)	------	------	------
Pope	------	------	------	Karate (1.6 oz)
Prairie	------	------	------	------
Randolph	------	------	------	------
St. Francis	------	------	------	------
Woodruff	------	------	------	------

Table 7. Economic analysis of fields from 2007 RRVP by county.[z]

County	Yield	Milling yield	Crop price[y]	Specified direct expenses[x]	Specified ownership expenses[w]	Land costs[v]	Return above direct costs	Return above total costs	BEP[u] to equal operating costs	BEP to equal total costs	Milling yield contributions to gross returns[t]
	(bu/acre)		($/bu)	------------	------------	($/acre)	------------	------------	------($/bu)	------	($/acre)
Arkansas	179	52/74	4.65	490	55	143	223	168	3.17	3.55	13.94
Craighead	219	55/73	4.66	432	47	188	426	379	2.24	2.51	20.13
Independence	191	60/73	4.73	414	55	166	350	295	2.47	2.83	31.78
Lawrence	213	57/69	4.57	512	60	179	307	247	2.78	3.13	-0.18
Lonoke 1	148	52/68	4.46	441	52	120	125	73	3.44	3.87	-15.68
Lonoke 2	167	53/72	4.60	401	38	141	251	212	2.74	3.03	5.26
Mississippi	181	61/73	4.75	409	47	157	318	271	2.57	2.90	32.82
Pope	231	61/71	4.69	407	63	201	500	437	1.99	2.33	27.72
Prairie	175	61/72	4.72	401	50	150	299	249	2.61	2.97	26.37
Randolph	212	63/71	4.72	505	53	182	339	286	2.75	3.06	31.76
St. Francis	195	55/72	4.63	385	41	165	378	337	2.23	2.50	11.95
Woodruff	178	60/70	4.64	469	55	151	231	176	3.04	3.42	13.26
Average 2007	189	58/72	4.65	439	51	162	312	261	2.67	3.01	16.59
Average 2006	164	58/71	4.11	396	44	125	153	109	3.00	3.35	17.67
Change[s]	25	--	0.54	43	7	37	159	152	-0.33	-0.34	-1.08
Hybrid seed average	198	58/71	4.64	464	54	166	309	255	2.74	3.09	15.29
Conventional seed average	183	57/72	4.66	414	49	158	316	267	2.59	2.93	17.89

continued

Table 7. Continued.

[z] 20% crop-share rent was assumed.
[y] Loan rate milling value plus $1.06/bu market premium above standard milling rate loan value.
[x] Includes all variable expenses from Table 6 plus drying, hauling, miscellaneous custom expenses, fuel, repairs, labor for field operations, interest on operating capital, and the Arkansas Rice Checkoff fee.
[w] Excludes ownership expenses of irrigation well, which are assumed to be paid by the landlord.
[v] Gross value of landlords 20% share of crop less drying charges and checkoff fee.
[u] BEP=break-even price.
[t] Impact of milling on gross returns. (Gross returns with milling yields – gross returns at standard milling, i.e. 55/70).
[s] Changes in averages from 2006 to 2007.

Increasing Efficiency of a Marker-Assisted Breeding Program

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

ABSTRACT

Molecular tools such as genotyping and marker-assisted selection (MAS) are being used in the development of improved rice varieties. In this program, DNA markers are used to select progeny of crosses in early generations for desirable agronomic traits, molecularly characterize a working germplasm collection, and track introgression of yield quantitative trait loci (QTL) from a wild rice species. Cooking quality parameters, including amylose content, gelatinization temperature, and aroma, are assessed along with the blast resistance genes *Pi-ta*, *Pi-b*, *Pi-k*, *Pi-I*, and *Pi-z*. As more trait-linked markers are characterized and incorporated into the program and as more parental lines are genetically profiled, then more material enters the molecular pipeline for screening. This reality necessitates increased efficiency of the entire program. This is accomplished by the development of a rapid seed-based DNA extraction method for routine MAS projects, eliminating the need for greenhouse or tissue culture facility production of tissue, and bulking samples instead of performing the analysis on individuals where possible. Over 2,000 lines were analyzed in 2007, yielding the same information as approximately 15,000 individual samples.

INTRODUCTION

MAS is a useful tool to enhance the development process of improved germplasm. By genotyping elite breeding lines using molecular markers linked to important traits, the genes coding for those traits can be identified and the information used to determine future crosses to improve the chances of success in developing lines for commercial release and track introgression of specific genes in the progeny. The information can also be used to decide which populations resulting from crosses made before the DNA marker information was available should be screened for MAS.

A greater number of lines will be screened for MAS as more traits are genetically mapped, more markers become available to public breeding programs, and more germplasm is genetically characterized. To be able to accomplish the analysis of the increased workload in a timely fashion without vastly increasing the cost of the program, it is necessary to revise protocols and develop new strategies.

Developing new methods that enable the marker-assisted breeding program to screen more lines with less investment and ultimately aid in the development of improved cultivars for the rice industry is the objective of this study.

PROCEDURES

Genomic DNA of parental lines is required to be pure enough for even the most recalcitrant markers and stable enough for long-term storage at -20°C. Eventually these DNA samples will be characterized with every available trait-linked marker, and the analysis is performed over a period of years. Leaf tissue samples of parental lines are collected, freeze-dried, and the DNA extracted using a modified PEX/CTAB/organic extraction method (Williams and Ronald, 1994; Fjellstrom, per. commun.).

Projects that need an immediate answer or encompass literally thousands of samples (or both) are processed with a high-throughput DNA extraction method. Leaf tissue samples are collected and stored at -80°C until sampled. Sampling is performed with a single hole-punch, one leaf disk per well of an inexpensive PCR plate, and the DNA is extracted by means of a sodium hydroxide-based method.

Both DNA extraction methods require leaf tissue as their starting material. Generating leaf tissue requires either greenhouse or tissue culture facilities, and a considerable amount of time and labor. To streamline the process and eliminate the need for growth facilities, DNA is now extracted from seeds with a method developed at the UA RREC. The method can be performed on single seed samples successfully, and it is possible to obtain 96 samples of PCR-ready DNA in as little as five hours from rough seed. The method works equally well with a wide range of germplasm and seed types, and the seed does not have to be viable. Amplification products can be analyzed with either gel-based or capillary-based systems, depending on the marker.

PCR was performed with either HEX- or FAM-labeled primers by adding template and enough bovine serum albumin and polyvinylpyrrolidone 40 to have final concentrations of 0.1% and 1%, respectively (Xin et al., 2003), and cycling the reactions in a Mastercycler Gradient S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.). Resulting PCR products were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.), separated on an Applied Biosystems 3730 DNA Analyzer, and analyzed using GeneMapper Software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

Early generations were screened in the past by sampling the DNA of seven different individuals per line, which was a labor-intensive process. For example, the 2006 F_3 project studied 1,291 lines with a SNP marker for *Pi-ta* blast resistance and RM190 for cooking quality. Those 1,291 lines and control samples became 104 96-well DNA template plates totaling almost 10,000 samples and almost 220 PCR plates for the one project. All lines in which the plants were homozygous for the desired trait were selected, along with some heterozygous individuals and heterogeneous lines. A lot of the material that was selected on the basis of the marker analysis was discarded later on a phenotypic basis and no later generations were tested.

Beginning with the 2007 F_3 project, the analysis procedures were changed to be less labor-intensive and more efficient. There were still seven samples of each line, but instead of individual plant sampling, the seven were bulked together in a single well, resulting in 22 DNA template plates representing 1,895 lines. Having fewer template plates to analyze enabled the addition of more markers, so the rice blast-resistance genes *Pi-b* (RM208) and *Pi-z* (AP5659-1) were added to the analysis. Only those lines in which the plants were homozygous for the negative qualities were discarded. Since some materials with a heterogeneous background were kept and still segregating, the decision was made to screen the populations again in at least two subsequent generations. In doing this, the initial screening is a lot faster, and subsequent screenings will take place with only those lines that are also selected on the basis of phenotype, conserving molecular resources for those lines with not only genotypic but also phenotypic potential.

The testing of the new seed-based DNA extraction method determined that the *Pi-ta* SNP in use since 2003 did not identify susceptible alleles in the bulked seed sample. An intentionally mixed plate, which contained combinations of seven seed samples ranging from six resistant and one susceptible to 6 susceptible and one resistant, was used to test the *Pi-ta* SNP, RM208, AP5659-1, and RM190. Results were as expected with all the markers except the *Pi-ta* SNP; with that marker, all wells were scored as homozygous-resistant. A new marker for *Pi-ta*, Pi-indica, was used to detect both resistant and susceptible alleles, and YL183, the susceptible primer of the *Pi-ta* SNP, was used to verify the presence of susceptible alleles. By using both markers, all homozygous-susceptible materials could be identified and discarded.

Results are population-specific. Marker data varied between crosses in a direct correlation with the different breeding parents. In a survey of 1,895 F_3 lines of 57 different crosses, and based on combined data of the Pi-indica, YL 183, RM208, AP5659-1, and RM 190 markers, the percentage of discarded material was from 0% to 100%, depending upon the particular cross. On average 52% of the material from this study was discarded in the early generation, thereby allowing for phenotypic selection of only those lines with desirable cooking quality and blast disease resistance (Tables 1 through 6).

SIGNIFICANCE OF FINDINGS

Molecular marker data can be a useful tool for increasing the efficiency and accuracy of variety development, giving the breeders more confidence at each stage of the selection process. By using a seed-based DNA extraction method and bulking samples wherever possible, valuable time, labor, and resources can be saved. This allows for the use of even more markers to identify and eliminate undesirable material in early development stages, making the program more productive.

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Table 1. Screening of seventeen F_3 populations for *Pi-ta, Waxy*.

Cross no.	Lines	Keep	Discard	% Discard
050642	7	2	5	71
050648	5	1	4	80
050702	11	10	1	9
050715	12	0	12	100
050716	54	20	34	63
050721	5	1	4	80
050731	60	42	18	30
050732	18	10	8	44
050733	9	4	5	56
050736	4	3	1	25
050738	2	1	1	50
050742	5	0	5	100
050743	10	9	1	10
050744	47	32	15	32
050745	4	2	2	50
050747	46	35	11	24
050748	29	17	12	41
Totals	**328**	**189**	**139**	**42%**

Table 2. Screening of eight F_3 populations for *Pi-ta, Pi-z, Waxy.*

Cross no.	Lines	Keep	Discard	% Discard
050647	149	70	79	53
050649	137	71	66	48
050652	172	60	112	65
050690	10	2	8	80
050693	45	9	36	80
050701	11	9	2	18
050709	8	1	7	88
050711	18	4	14	78
Totals	**550**	**226**	**324**	**59%**

Table 3. Screening of nine F_3 populations for *Pi-ta, Pi-b, Waxy.*

Cross no.	Lines	Keep	Discard	% Discard
050656	8	3	5	63
050660	21	6	15	71
050661	39	6	33	85
050670	6	1	5	83
050671	10	0	10	100
050687	12	8	4	33
050699	11	2	9	82
050714	12	3	9	75
050730	5	2	3	60
Totals	**124**	**31**	**93**	**75%**

Table 4. Screening of four F_3 populations for *Pi-ta, Pi-b, Pi-z.*

Cross no.	Lines	Keep	Discard	% Discard
050655	47	3	44	94
050662	6	1	5	83
050698	18	0	18	100
050713	11	5	6	55
Totals	**82**	**9**	**73**	**89%**

Table 5. Screening of six F_3 populations for *Pi-z, Waxy.*

Cross no.	Lines	Keep	Discard	% Discard
050658	9	9	0	0
050659	11	11	0	0
050691	24	20	4	17
050692	8	8	0	0
050735	14	14	0	0
050746	14	14	0	0
Totals	**80**	**76**	**4**	**5%**

Table 6. Screening of thirteen F_3 populations for *Pi-z.*

Cross no.	Lines	Keep	Discard	% Discard
050650	17	11	6	35
050651	51	37	14	27
050653	86	6	80	93
050654	22	9	13	59
050674	48	48	0	0
050675	21	16	5	24
050676	18	0	18	100
050677	8	4	4	50
050678	36	36	0	0
050694	178	127	51	29
050700	81	67	14	17
050708	122	39	83	68
050710	16	12	4	25
Totals	**704**	**412**	**292**	**42%**

Development Of Semidwarf Long- And Medium-Grain Cultivars

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ABSTRACT

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

INTRODUCTION

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

Lee et al. (1998) have characterized several recently introduced USDA germplasm accessions as tolerant to both rice sheath blight and blast. Most of these introductions belong to the indica subtribe of cultivated rice. Indicas have been suggested as sources for yield potential and disease resistance for domestic breeding programs (Eizenga et al., 2006). Our objective is to develop genetically diverse, semidwarf long- and medium-grain cultivars that are high-yielding with excellent grain, milling, and processing quality and that tolerate the common stresses and pests found in Arkansas rice fields.

PROCEDURES

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

RESULTS AND DISCUSSION

About 112 cross combinations were made in 2007. Emphasis was placed on triple crosses with parents selected for tolerance to straighthead disorder, blast and panicle blight disease as well as yield and grain quality. Over 200 F_1 single plants from triple crosses were selected in 2006 and will be space-planted at Stuttgart in 2007 (Table 1) as well as 30 populations from single crosses. Rodent damage in our greenhouse in 2007 severely reduced our triple cross F_1 populations. Over 1900 F_2 single plants were selected during the year. Several of these crosses were programmed with cold-tolerant parents and the populations were exposed to freezing temperatures in the field this year. Panicles from these plants were sent to the winter nursery for generation advancement. About 1800 single panicles from early-flowering lines were harvested and replanted at Puerto Rico so that 2 generations will be gained from the winter nursery in 2006. Plants with known sources of blast genes *Pi-ta*, *Pi-z, Pi-b,* and *Pi-9,* and diverse cooking quality alleles were evaluated using molecular aided selection (MAS), allowing for significant increase in efficiency of selection at Puerto Rico. At Stuttgart, panicles from over 207 F_4 rows were selected to advance to F_5 in 2007. From over 7500 rows planted, about 690 F_4 and F_5 lines were selected based on plant type, grain quality, earliness, and disease reaction to advance to preliminary yield trials.

Yields of selected semidwarf lines from the preliminary yield trial (PYT) are shown in Table 2. The experimental line 1134 from the cross RU9901133/PI 560239// Cybonnet was the highest yielding at the RREC while the check medium-grain Bengal recorded the highest yield at the SEREC. RU9901133 and Cybonnet are Arkansas-developed semidwarf long-grains while PI 560239 is a cold-tolerant accession from South America. The line 1134 and a sister line 1138 show similar blast and straighthead reaction to Cybonnet with improved sheath-blight tolerance while milling yields are an improvement over the check cultivar Wells. Both have large kernel size. Milling yields of all entries in the PYT were generally low this year due to fall rains prior to harvest. The medium-grain line 1137 showed improved blast resistance and vigor to Bengal, but had reduced milling quality and yield at the SEREC. Entry 1020 shows resistant reaction to straighthead and is from the cross RU9901133/'Drew'//'Spring'. Several lines from this cross were resistant to straighthead and selected lines will be incorporated in the crossing program for 2008. Superior selected lines from the PYT will be advanced to the 2008 SIT. Long-grain entries 1122 and 1295 yielded more than Wells and were superior in either blast reaction or milling quality. The entry 1295 is from the cross Cocodrie/'ZHE733'//WC 285. Cocodrie is a popular Louisiana semi-dwarf, japonica type while ZHE733 and WC 285 are indica introductions from China and South America, respectively. These lines will be further advanced to replicated trials for 2007. All the experimental lines are semidwarf but variation in plant height was observed. The use of blast spreader rows at Pine Tree to simultaneously evaluate for disease and agronomic traits continues to be successful. Plant growth was very good under the disease system and blast disease pressure was good enough to identify susceptible lines. In 2007 more experimental lines, including F2 populations, will be tested under similar conditions at Pine Tree.

Data for 8 semidwarf experimental lines and check cultivars from the semidwarf SIT are shown in Table 3. These entries varied in grain yield with the experimental lines 1081, 1085, 1106, 1111, and 1024 averaging 228, 207, 200, 200, and 195 bu/ac, respectively. Medium-grain Bengal and long-grain checks Wells and Cybonnet yielded 210, 198, and 172 bu/ac, respectively. Blast ratings varied but were equal or superior to the checks. Milling yields were good in 2007 and varied from 63:71 (Head Rice: Total Rice) for entry 1081 to 48:68 for entry 1111. We are testing our material for this "delayed harvest" effect and have identified sources for tolerance (data not shown). Identification and incorporation of parents with disease tolerance and diverse genetic backgrounds, while maintaining grain quality and yield in the progeny, will continue to be a priority. The continued exchange and use of new germplasm is an important component of this project. The lines 1111 and 1024 originate from a cross between either introduced indica long-grain rices (1111) or introduced cold-tolerant japonicas (1024). These lines will be advanced to multi-location yield trials in 2008.

SIGNIFICANCE OF FINDINGS

Promising semidwarf experimental lines with diverse genetic backgrounds have been identified that have good disease resistance, high yields, and good milling quality. Semidwarf long- and medium-grain rice varieties offer producers options in their choice of cultivar and management systems for Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

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Table 1. Number of early-generation lines selected in project ARK02030 during 2006.

	Number of lines	
Evaluation phase	Planted	Selected
F_1 Transplants	3064	206
F_2 Space plants	168,000	1907
F_4 Panicle rows	1780	207
F_5 & F_6 Panicle rows	1791	694

Table 2. Data from the 2007 Semidwarf Preliminary Yield Trial (PYT) for selected experimental lines and check cultivars.

Entry	Grain type	Yield[z] RREC	SEREC	avg.	Disease[y] NB	SH	ShB	50% HD[x]	Height	Vigor	Kernel wt.	Milling[w] HR:TOT
		-----------	(bu/acre)	---------					(in.)	(1-4)	(mg)	
Bengal	M	192	261	226	7	6	5	86	37	3	2.17	56:70
1134[v]	L	215	181	198	2	5	4	83	41	3	2.00	42:67
1138	L	202	192	197	4	4	5	86	36	3	2.20	44:66
1020	L	157	236	196	7	3	6	77	36	3	1.90	43:69
1030	L	135	250	192	7	5	6	81	34	3	2.00	46:68
1137	M	189	191	190	4	5	7	86	34	4	1.80	47:66
Cybonnet	L	152	210	181	2	5	7	91	36	3	1.80	51:68
Wells	L	165	174	170	7	5	7	91	39	3	1.80	32:67

[z] The 2007 PYT consisted of one replication at two locations: the Southeast Research and Extension Center, Rowher division (SEREC), Rowher, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark.

[y] Disease scores from field evaluation: neck blast (NB) at Pine Tree Experiment Station where 0 = no blast and 9 = plants dead, Straighthead (SH) from RREC where 0=no straighthead and 9=complete sterility, and sheath blight (ShB) at RREC where 0 = no infection and 9 = plants dead.

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

[w] Milling is expressed as Head Rice/Total Rice.

[x] Entries1134 and 1138 are from the cross RU9901133/PI 560239//Cybonnet, entry 1020 is from RU9901133/Drew//Spring, 1030 is from Drew/OL5//RU9901133, and 1137 is from STG02P-02-067/STG02AC-03-096.

Table 3. Data from the 2007 Semidwarf Stuttgart Initial Test (SIT) for selected experimental lines and check cultivars.

	Grain	Yield[z]			Disease[y]			50%				Milling[w]
Entry	type	RREC	SEREC	avg.	NB	SH	ShB	HD[x]	Height	Vigor	Kernel wt.	HR:TOT
		----------- (bu/acre) ---------							(in.)	(1-4)	(mg)	
1081[v]	M	209	247	228	7	5	5	94	38	3	2.12	63:71
Bengal	M	191	229	210	7	6	6	92	37	3	2.13	62:72
1085	L	194	219	207	7	6	6	92	36	3	2.06	54:69
1106	L	188	213	200	8	4	6	89	36	3	1.99	54:69
1111	L	210	190	200	2	7	7	90	38	3	2.02	48:68
Wells	L	202	194	198	7	5	6	91	40	3	2.00	52:71
1024	M	202	189	195	4	6	6	87	33	3	2.11	63:68
Cybonnet	L	191	152	172	3	4	7	89	38	3	1.87	61:70
$LSD_{0.05}$		38	64									
cv		11	19									

[z] The 2007 SIT consisted of two replications at two locations, the Southeast Research and Extension Center, Rowher division (SEREC), Rowher, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark.

[y] Disease scores from field evaluation: neck blast (NB) at Pine Tree Experiment Station where 0 = no blast and 9 = plants dead, straighthead (SH) from RREC where 0=no straighthead and 9=complete sterility, and sheath blight (ShB) at RREC where 0 = no infection and 9 = plants dead.

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

[w] Milling is expressed as Head Rice:Total Rice.

[v] Entry 1081 is from the cross VSNTLM//L201/9NRZ/3/MARS/TBNT//9827/4/VSTNLM//L201, Entries 1085 and 1106 are from RU9901133/JEFF, 1111 is from YACU 9/ZHE 733//WC 292, and 1024 is from 97Y229/PI 560265//STG97F5-01-004.

Breeding And Evaluation For Improved Rice Varieties – The Arkansas Rice Breeding And Development Program

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ABSTRACT

The Arkansas rice breeding program has as an ongoing goal to develop new long- and medium- grain cultivars as well as specialty cultivars such as Japanese-quality short-grains and aromatics. Cultivars are evaluated and selected for desirable characteristics. Those that require further improvement are utilized as parents in future crosses. Important components of this program include: high-yield potential; excellent milling yields; pest and disease resistance; improved plant type (i.e., short stature, semidwarf, earliness, erect leaves); cold tolerance; and superior grain quality (i.e., cooking, processing and eating). New varieties are continually being released to rice producers for the traditional southern U.S. markets as well as for the emerging specialty markets. This report entails a part of the overall rice breeding effort dealing with long-grain cultivar development in Project ARK01860.

INTRODUCTION

The rice breeding and genetics program at the University of Arkansas Rice Research and Extension Center (RREC) is by nature a continuing project with the goal of producing new, improved rice cultivars for rice producers in Arkansas and the southern U.S. rice growing region. The Arkansas rice breeding program is a dynamic team effort involving breeders, geneticists, molecular geneticists, pathologists, soil scientists, physiologists, entomologists, economists, systems agronomists, weed scientists, cereal chemists, extension specialists, and in some cases a statistician. We also encourage input from producers, industry, and consumers. As breeders, we integrate information from all of the disciplines to make selections. We are always looking for ways to enable the producer to become more economically viable. This team changes through time as breeding objectives shift.

Breeding objectives for improved long-grain cultivars include standard cooking quality, excellent milling and grain yields, improved plant type, disease resistance, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal. Blast resistance has been addressed through research by visiting scholars, graduate students, and by the development and release of 'Katy', 'Kaybonnet','Drew', and 'Ahrent'. 'Banks' was also released from this program with blast resistance, but because it was derived from backcrossing, it did not contain the minor genes needed to protect it from *IE-1k* in the field. These cultivars are among the first to have resistance to all of the common southern U.S. rice blast races. Sheath blight tolerance also has been an ongoing concern and the cultivars from this program have also had the best sheath blight tolerance of any in the U.S. One of the recent releases from the program, 'Spring', is a very early long-grain cultivar with cold tolerance, some blast resistance, and kernel smut resistance similar to Ahrent. Significant yield increases have been realized with the release of the long-grain cultivars 'LaGrue', 'Wells', 'Francis', and Banks.

PROCEDURES

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

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

RESULTS AND DISCUSSION

Rice blast (*Pyricularia grisea*) can be a devastating disease in Arkansas. Races *IB-49* and *IC-17* are currently the major races in Arkansas, but as demonstrated in 2004 and 2005 race *IE-1k* may become more of a problem. Race *IE-1k* has been isolated from Banks fields in both years. The potential release 41182 has the high yield potential of Wells and Francis, the major gene *Pi-ta,* which confers resistance to the common blast races in Arkansas, and the minor genes necessary to have moderate resistance to the race *IE-1k*. The line 41182 will be grown as foundation seed in 2008 for potential release to seed growers in 2009. It originated from the cross Drew/5/'Newbonnet'/3/ 'Dawn'/CI9695//'Starbonnet'/4/Katy/Starbonnet (cross no.19981441), made at the Rice Research and Extension Center, Stuttgart, Ark., in 1998. This line had an average yield of 197 bu/acre in the ARPT 2005 to 2007, which compares favorably with Francis and Wells at 202 and 199 bu/acre, respectively (Table1). Milling yields of this line are better than Wells (Table 1).

The long-grain line, 61188, originating from the cross LaGrue//Katy/Starbonnet/5/LaGrue//'Lemont'/Radiated Bonnet 73/3/LaGrue/4/LaGrue (cross no. 20001657), has the longer and larger kernel size desired by the industry and will also be grown as foundation seed in 2008 as a potential release to Arkansas seed growers in 2009. It has high yield potential, yielding 198 bushels/acre which compares favorably with Wells and Francis (Table 1). Head rows will be grown in 2008 of the line 81076, originating from the cross LaGrue//Katy/Starbonnet/5/Newbonnet/Katy//Radiated Bonnet73/ Lemont/4/'Lebonnet'/CI9902/3/Dawn/CI9695//Starbonnet (cross no. 20001692). This line yielded 215 bu/acre in the 2007 ARPT compared to Wells and Francis, which each yielded 185 bu/acre (Table 2). There are also two Clearfield lines in the breeding program that will also be considered for potential head row in 2008 (Table 2 and 3). One line has very good yield potential and is a little taller and the other has good yield, especially in the Clearfield test (Table 3), but tends to be short. These lines will be evaluated further in the ARPT and ARPT Clearfield tests this year along with several other Clearfield lines.

Twenty-three extremely early lines from the cross RU9101001/ 'Raminade Strain 3' were evaluated in the Stuttgart Initial Trials (SIT) at the Rice Research and Extension Center and the Southeast Research and Extension Center-Rohwer Division during the 2007 growing season. Raminad Stain 3 is an international rice blast differential that has resistance to all of the southern U.S. races. These lines have maturities of about 100 to 110 days as well as blast resistance. Twelve of these lines will be in the SIT tests again in 2008 and eight of them were used as parents in the crossing program in 2007. Other crosses are also being made to further improve the blast resistance in Arkansas varieties.

Cooperative work with Tim Croughan (retired professor from the LSU Rice Station at Crowley, La.) resulted in the release of ‘CL171-AR’, which will be available as certified seed for the first time in 2008. It has resistance to the Newpath herbicide. Rough rice grain yields of CL171-AR are very similar to ‘CL161’ in the ARPT (Tables 1, 2, and 3).

Work is continuing with crosses between IMI lines that were selected from the initial crosses that Dr. Croughan made in Louisiana and crosses made at the RREC, Stuttgart, Ark. Lines from these crosses will be screened for tolerance to the IMI herbicides again this year.

Data from the Arkansas Rice Performance Trials (ARPT) conducted in Arkansas (Stuttgart, Keiser, Rohwer, Clay County, and Jackson County) in 2007 are available in the University of Arkansas Cooperative Extension Service Information Sheet "Arkansas Rice Performance Trials, 2005-2007", and on line at:http://www.uaex.edu www.uaex.edu Agriculture; Agronomy; Rice.

Marker-assisted selection has been utilized in this program to select the lines that have the *Pi-ta* gene for blast resistance and the CT classes to predict cooking quality (see Boyett et al., 2005). This has helped to streamline the selection process through fast, easy, and efficient elimination of material that has poor cooking quality and blast susceptibility.

Table 4 shows the number of lines that were in the different phases of this breeding project for the 2007 growing season. There were 76 new cross combinations made in 2007, these are growing in the greenhouse to produce F_2 seed for 2008 space plants. There were 2,448 F_3 rows planted in the winter nursery in Puerto Rico this winter for generation advance. Panicles from these rows will be harvested this spring and then grown in the 2008 P panicle rows.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum-yielding cultivars with good levels of disease resistance for release to Arkansas rice producers. The release of Wells, Francis, Banks, Spring, CL171-AR, and the potential release of 41182 (a high-yielding line with improved blast resistance) and 61188 (a high-yielding line with the larger kernel) demonstrate that continued improvement in rice varieties for the producers of Arkansas can be realized through this program. The line 81076 with the highly stable grain yield could be the replacement for Wells. Improved lines will continue to be released from this program in the future. They will have the characteristics of improved rough rice grain and milling yields, disease resistance, plant type, and kernel size. In the future, new rice varieties will be released not only for the traditional southern U.S. long- and medium-grain markets but also for specialty markets as they arise.

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Table 1. Data from the 2005-2007 Arkansas Rice Performance Trials for promising experimental lines and check cultivars.

Cultivar	Grain type[z]	Yield[y] 2005	2006	2007	Mean	Height	50% Heading	Kernel wt.	Milling HR:TOT[x]
		------------ (bu/acre)			-------------	(in.)	(days)	(mg)	
Francis	L	210	208	185	202	40	89	16.9	58:70
Wells	L	211	198	185	199	41	90	18.8	53:71
Cybonnet	L	202	186	171	187	37	90	17.6	60:71
Cocodrie	L	195	162	163	174	37	88	17.7	62:71
41182[w]	L	211	197	179	197	41	92	16.3	57:71
61188[w]	L	---	204	190	198	44	93	19.7	55:71
CL171-AR[v]	L	194	173	167	178	39	90	17.0	60:72
CL161	L	187	176	155	173	39	89	16.4	62:70

[z] Grain type L = long-grain.
[y] Yield trials in 2005 and 2006 consisted of six locations: Rice Research and Extension Center (RREC), Stuttgart Ark.; Pine Tree Experiment Station (PTES), Colt, Ark.; Southeast Branch Experiment Station (SEBES); Rowher, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Jackson Co. Farmer Field, Newport, Ark. (JC); and Clay County Farmer Field, Corning, Ark. (CC); yield trials in 2007 were conducted at five locations: RREC, SEBES, NEREC, JC, and CC.
[x] Milling figures are head rice : total milled rice.
[w] Experimental lines not for sale
[v] CL stands for Clearfield lines

Table 2. Data from the 2007 Arkansas Rice Performance Trials.

Cultivar	Grain type[z]	Yield[y] CC	JC	NEREC	RREC	SEBES	Mean	Height	50% Heading	Kernel wt.	Milling HR:TOT[x]
		(bu/acre)						(in.)	(days)	(mg)	
Francis	L	218	249	93	199	163	185	38	87	17.2	53:70
Wells	L	203	230	168	172	150	185	41	88	18.7	48:70
Cybonnet	L	190	207	190	163	103	171	35	90	17.8	58:71
STG04L-37-098[w]	L	232	239	226	182	195	215	43	93	18.3	54:70
CL171-AR[v]	L	197	210	180	142	105	167	39	90	16.7	57:71
CL161	L	189	212	122	140	113	155	38	89	16.7	61:70
STG05IMI-01-113[w]	L	204	251	182	171	150	191	44	89	19.7	45:70
STG05IMI-04-091[w]	L	187	218	183	142	82	162	32	89	18.1	55:69

[z] Grain type L = long-grain.

[y] Yield trials in 2007 were conducted at five locations: Rice Research and Extension Center (RREC), Stuttgart Ark.; Southeast Branch Experiment Station (SEBES), Rohwer, Ark; Northeast Research and Extension Center (NEREC), Keiser, Ark; Jackson Co. Farmer Field, Newport, Ark. (JC); and Clay County Farmer Field, Corning, Ark. (CC).

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

[w] Experimental lines not for sale.

[v] CL and IMI are Clearfield lines.

Table 3. Data from the 2007 Clearfield Arkansas Rice Performance Trials.

Cultivar	Grain type[z]	Yield[y] NEREC	RREC	Mean	Height	50% Heading	Kernel wt.	Milling HR:TOT[x]
		(bu/acre)			(in.)	(day)	(mg)	
CL171-AR[w]	L	177	130	153	41	90	15.5	58:72
CL161	L	101	99	100	40	89	14.7	61:70
STG05IMI-01-113[v]	L	165	122	143	46	88	19.2	42:71
STG05IMI-04-091[v]	L	210	155	182	37	87	17.0	59:70

[z] Grain type L = long-grain.
[y] Yield trials in 2007 were conducted at two locations: Rice Research and Extension Center (RREC), Stuttgart Ark.; and Northeast Research and Extension Center (NEREC), Keiser, Ark.
[x] Milling figures are head rice : total milled rice.
[w] CL and IMI are Clearfield lines.
[v] Experimental lines not for sale.

Table 4. Number of lines in each phase for project ARK01860 in 2007.

Evaluation phase	Number of lines
Crosses	76
F_2 Space plants	29,700
F_3 Panicle rows Puerto Rico	2,448
F_4 P Panicle rows	3,036
L & M Panicle rows	7,920
IMI Panicle rows	396
Preliminary trials	532
Stuttgart Initial Test and Quality Test	266
IMI Test	186
Arkansas Rice Performance Trials[z]	104
Uniform Regional Rice Nursery[z]	200
Breeder head rows	5

[z] ARPT and URRN are shared tests with Project ARK02030.

Pythium Species Associated with Rice Stand Establishment Problems in Arkansas

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

ABSTRACT

The role of seedling disease pathogens in stand-establishment problems of rice was examined in field and controlled environmental studies using selective fungicides and pathogens isolated from seedlings. *Pythium* spp. were the most common group of seedling disease pathogens isolated in these studies. The *Pythium* spp. recovered from over 20 producers' fields from these studies in Arkansas in 2006 and 2007 were identified and characterized. *Pythium* isolates were evaluated for pathogenicity (stand loss) and selected isolates were identified molecularly using the mitochondrially encoded cytochrome oxidase II gene (mtDNA *cox* II). Pathogenic *Pythium* species were found to be *P. arrhenomanes* and *P. irregulare.* Non- or less-pathogenic *Pythium* species included *P. catenulatum*, *P. torulosum,* and *P. diclinum*. Virulence studies using isolates of different *Pythium* species in artificially infested, pasteurized soil confirmed that *P. arrhenomanes* and *P. irregulare* caused greater stand losses than the other species, as well as reduced plant weight and development of the surviving seedlings. *Pythium arrhenomanes* was the most frequently isolated and most virulent of the *Pythium* species in Arkansas rice fields and also has been reported as an important pathogen in other rice-production areas.

INTRODUCTION

Stand problems consistently cause significant production losses and management problems in Arkansas rice fields. *Pythium* species play an important role in stand establishment, especially under cool soil temperatures (Rothrock et al., 2004). Previous research, funded by the Arkansas Rice Research and Promotion Board, has identified cold-tolerant *Pythium*-resistant rice genotypes that hold the promise for more reliable stand establishment for rice in Arkansas under marginal planting environments (Rothrock et al., 2005; Rothrock et al., 2006).). These studies were designed to clarify the role of field history, soil characteristics, and environmental conditions shortly after planting on stand establishment and to identify and characterize important *Pythium* spp. and other seedling pathogens. The objective of this portion of the study was to identify the different *Pythium* spp. associated with seedling diseases of rice and characterize their virulence on rice under different environmental conditions.

PROCEDURES

Pythium Isolates

Pythium isolates were isolated from rice seedlings from studies using 21 producers' fields in 13 counties. These studies included 9 field experiments and controlled studies using 12 soils and two environments.

Fungicide seed treatment trials in 2006 and 2007 were conducted in producers' fields using the cultivar 'Wells'. After 4 to 5 weeks, three 1-meter stand counts were taken for each plot and approximately 25 seedlings were dug from the nontreated plots for disease assessment and isolation of pathogens.

Soils were collected from six producers' fields in 2006 and 2007 for the controlled environmental studies. Two environments were used; cool/wet and warm/dry. Three cultivars were used ('Francis', Wells, and 'Cheniere') and four fungicide seed treatments were used. Stand counts were taken and seedlings were removed from all containers after 21 days in the warm environment and 28 days in the cool environment.

Rice seedlings were washed for 20 minutes in running tap water and roots and coleoptiles were assessed for disease from all studies. Roots from seed not treated with fungicides were disinfested in 0.5% NaOCl, blotted dry, and plated on water agar (WArad). After 3 to 5 days, unique colony growth was transferred to potato dextrose agar (PDArad) and identified to genus.

Identification of *Pythium* Species

Identification of *Pythium* spp. was done using PCR-RFLP of the mitochondrially encoded cytochrome oxidase II (cox II) gene. A total of 77 isolates was chosen for identification. Each isolate was grown in V8 Juice®-broth and the mycelium was lyophilized and ground in liquid nitrogen. The mitochondrial DNA was extracted by a procedure previously described by Correll et al. (1993).

The mitochondrially encoded cytochrome oxidase II gene (mtDNA *cox* II) was amplified using *Pythium*-specific primers developed by Dr. Frank Martin (USDA-ARS, Salinas, Calif.). The primers, PyRFLP-1 and PyRFLP-2, amplify the *cox* II gene and the spacer of the mitochondrially encoded *cox* I and II gene clusters (Martin, 2000). Each mtDNA *cox* II gene fragment that was amplified was digested with three restriction enzymes: *Alu*I , *Nla*III, and *Rsa*I. RFLP analyses were conducted following the procedure of Martin and Tooley (2004). The *Pythium* isolates were grouped according to banding patterns for identification against known banding patterns (Fig. 1). In addition, selected isolates for a group were sent for sequencing of the ITS region to assist in molecular identification.

Pathogenicity Tests

Pathogenicity of *Pythium* isolates was evaluated initially in sterilized vermiculite. Pathogenicity was determined using stand counts from infested pots compared to a noninfested control, after analysis of stands by the GLM procedure using SAS.

Identified isolates of *Pythium* were evaluated for virulence under two environments by infesting a pasteurized soil from the Rice Research and Extension Center, Stuttgart. The warm-environment experiments were in a greenhouse at 22.4°C day and 17.1°C night and soil water content was maintained between -30 Joules/kg and saturation. The cool-environment experiments were in growth chambers; two weeks at 15°C and three weeks at 20°C. The soil moisture content was monitored gravimetrically and maintained between -10 Joules/kg and saturation. Surviving rice seedlings were harvested and evaluated for root disease severity and plant development. Each experiment was a randomized complete block design with four replications. Data were analyzed using the GLM in SAS.

RESULTS AND DISCUSSION

Pythium spp. were the most frequently isolated organisms from rice seedlings. Isolation of *Pythium* spp. from field studies ranged from 44% of the seedlings in Faulkner Co. to 100% of the seedlings in 4 of the 9 field studies (Table 1). Isolation was consistently high for both the cold- and warm-environmental studies (Table 2). Results from these studies conducted in 2006 and 2007 were in general agreement with previous results that *Pythium* spp. play a large role in stand establishment.

Initial pathogenicity experiments divided isolates into three groups: virulent (little or no stand), semi-virulent (moderate stand loss), and avirulent (no stand loss) relative to the noninfested control. Isolates were taken from each group for identification of species, emphasizing isolates in the virulent group.

Molecular techniques were used to identify the different *Pythium* species isolated from rice seedlings. Treatment of the DNA fragments of the mtDNA *cox* II gene with the three enzymes allowed the differentiation and identification of the different isolates to corresponding species. From the isolates identified, five different species have been found. *Pythium arrhenomanes* and *Pythium irregulare* were found to be the most virulent and common species. Semi-virulent to avirulent species or less common species included *Pythium torulosum*, *Pythium catenulatum*, *Pythium arrhenomanes*, and *Pythium diclinum.*

The number of surviving plants was greater in the warm environment compared to the cool environment, indicating that disease caused by these *Pythium* species is favored by a cooler environment (Fig. 2). In addition to affecting stand, these isolates also decreased root growth compared to the control (Fig. 3). Root weight decreased drastically in the cool environment, including the control, showing that the environment also has an effect on rice development. Environment did not have much effect on root discoloration, but species did (Fig. 4). Even species that did not have a large impact on plant stand or seedling growth compared to the noninfested control caused substantial root discoloration.

These studies demonstrated that *Pythium* spp. are a major part of the seedling disease complex on rice. Rice planted and emerging under cooler and wetter environments is likely to suffer greater losses from *Pythium* spp. These studies also indicate that these pathogens reduce root growth and plant development even at warmer soil temperatures. *P. arrhenomanes,* one of the most important and common species found in producers' fields in Arkansas, has been reported to be an important seedling rice pathogen in other states and countries. This research also indicated that a number of other *Pythium* spp. may be important seedling disease pathogens in Arkansas.

SIGNIFICANCE OF FINDINGS

Field and controlled environmental studies examined soils from 21 producers' fields in 2006 and 2007. The importance of different seedling pathogens in stand losses is being identified by examining stand response to specific fungicides and isolation of pathogens in these studies. Five different *Pythium* species have been identified and their importance characterized: *Pythium arrhenomanes, P. irregulare, P. torulosum*, *P. catenulatum*, and *P. diclinum.*

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Table 1. Isolation frequency of *Pythium* species from field studies.

Year	County	*Pythium* isolation
		(%)
2006	Faulkner	44
2006	Clark	70
2006	Desha	63
2006	Prairie	58
2006	Poinsett	100
2006	Mississippi	100
2007	Poinsett	61
2007	Jackson	100
2007	Crittenden	100

Table 2. Isolation frequency of *Pythium* species from soils used in controlled environmental studies.

		Pythium isolation	
Year	County	Cold	Warm
		-----------(%)------------	
2006	Clark	95	85
2006	Prairie	85	94
2006	Desha	92	90
2006	Poinsett	87	90
2006	Lonoke	83	83
2006	Lafayette	68	98
2007	Independence	98	97
2007	Lonoke	97	99
2007	Jackson	89	94
2007	Poinsett	84	86
2007	Cross	81	60
2007	Jefferson	80	97

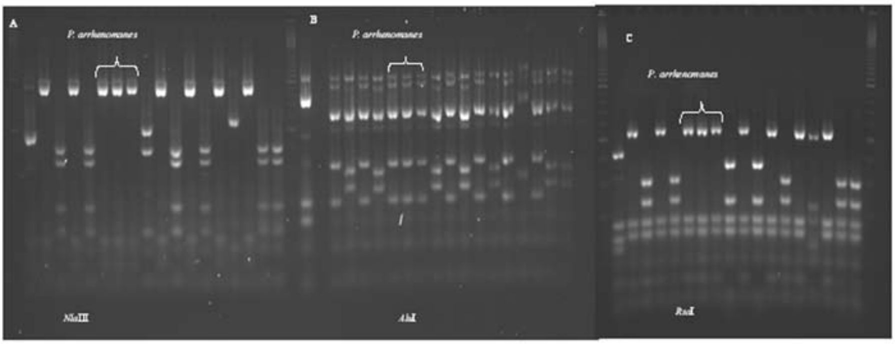

Fig. 1. RFLP banding pattern for *Pythium* species using three enzymes: A = *Nla*III, B = *Alu*I, and C = *Rsa*I. Banding patterns for *Pythium arrhenomanes* are indicated.

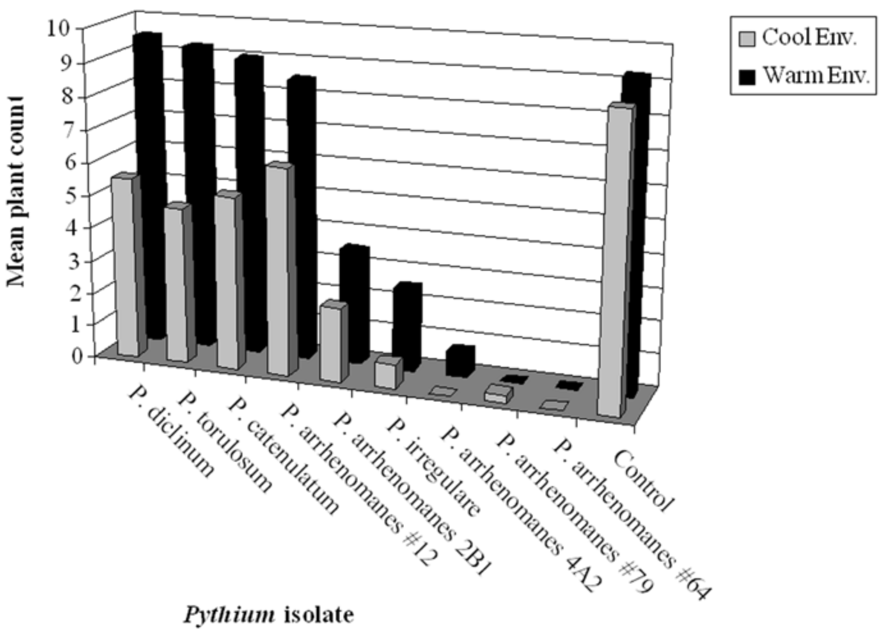

Fig. 2. Rice plant stand in soil infested with selected *Pythium* species under two environments.

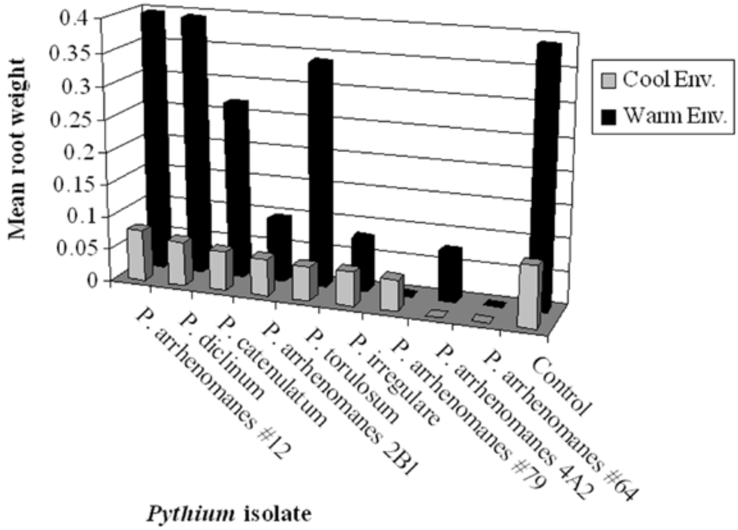

Fig. 3. Root weight of rice seedlings in soil infested with selected *Pythium* species under two environments.

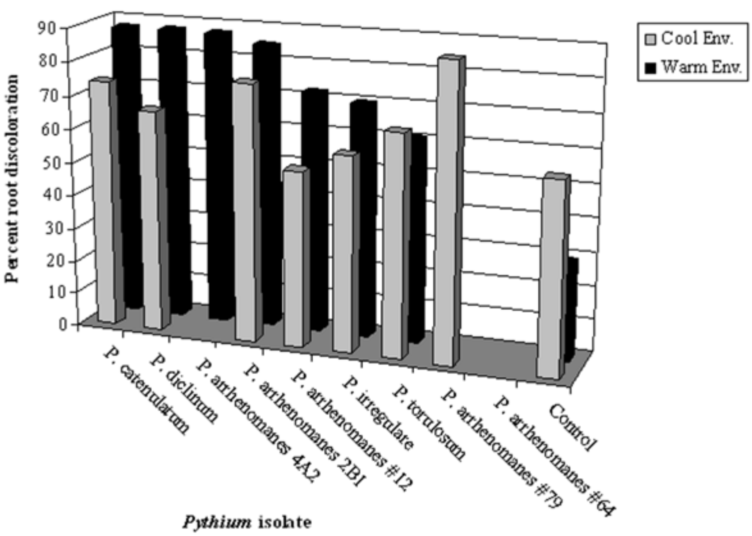

Fig. 4. Root discoloration (%) of rice seedlings in soil infested with selected *Pythium* species under two environments.

Rice Blast Evaluation of Newly Introduced Rice Germplasm

F.N. Lee, W.G. Yan and S.B. Belmar

ABSTRACT

Genetic resistance to the rice blast fungus, *Magnaporthe oryzae* (anamorph *Pyricularia oryzae*) was identified in newly introduced rice germplasm through quarantine when tested in artificially inoculated greenhouse and field nursery tests during the 2007 growing season. Of 229 entries, 31 were rated very resistant to rice panicle blast in field tests and to *M. grisea* races IB-1, IB-49, IC-17, IE-1, IE-1K, IG-1, and IH-1 in greenhouse tests. Of these 31 entries, six also rated zero to race IB-33. In addition to these outstanding entries, more than 40 additional entries also scored as resistant in both tests. Several entries were tentatively rated susceptible to a natural infection of Big Eye Leaf Spot caused by *Drechslera gigantea*.

INTRODUCTION

The Arkansas Rice Research and Promotion Board-funded research project, 'Discovery, Definition, and Utilization of Resistance Genes for Arkansas Rice Disease Control', has the overall objective of developing rice disease-control strategies including discovering and defining new resistance genes for use in rice cultivars. To this end, 229 new rice germplasm entries recently processed through quarantine were evaluated in an inoculated blast field nursery at the University of Arkansas Pine Tree Branch Experiment Station (UA-PTBES) located near Colt, Ark., and in greenhouse tests in the Rice Research and Extension Center (UA-RREC), Stuttgart, Ark.

PROCEDURES

Greenhouse Tests

Greenhouse tests at the UA-RREC used standardized greenhouse procedures to test disease reaction to specific pathogen strains under controlled environmental conditions. Replicated entries at the 4-leaf growth stage were inoculated using an atomized spore suspension (2 x10^5 spores/ml) of defined *P. grisea* races IB-1, IB-33, IB-49, IC-17, IE-1, IE-1K, IG-1, and IH-1. For enhanced susceptibility, well-fertilized plants were grown upland and moderately drought stressed at the time of inoculation. Plants were immediately moved to a 100% humidity chamber for 24 hours then transferred to greenhouse benches. After 7 days, leaf blast severity was scored using the standard visual 0 to 9 rating scale where 0 = no disease, 5 = lesions with well developed centers and borders, and 9 = large susceptible type lesions.

Blast Field Nursery

Rice entries were planted in hill-drop plots with a 12-inch by 16-inch spacing in the blast field nursery at the UA-PTBES. A intermittent shallow flood and selective application rate of nitrogen fertilizer favored blast development within the nursery. Large overhead sprinklers supplied occasional simulated rain. When plants neared the 4-leaf growth stage, artificial inoculations were made with rye grass seed and cracked corn colonized with *P. grisea* races IB-1, IB-49, IC-17, IE-1, IG-1 and IH-1. Leaf lesions were scored using the standard 0 to 9 visual rating scale. Panicle blast evaluations were on a on a visual rating scale where 0 = no symptoms and 9 = very severe symptoms with the panicle completely blanked. Intermediate ratings are: 3 to 4 = limited lesion symptoms on one or more flag leaf collars, exposed nodes or panicles; 5 to 6 better lesion development on susceptible tissue. Entries were also scored for a normally minor leaf disease, tentatively identified as Big Eye Leaf Spot caused by *Drechslera gigantean* using a visual rating scale where 0 = no symptoms and 9 = severe leaf and/or panicle symptoms.

RESULTS AND DISCUSSION

Data presented are preliminary and must be confirmed with further testing over years and locations. Of 229 entries, 31 were rated very resistant to rice panicle blast in field tests and to *P. grisea* races IB-1, IB-49, IC-17, IE-1, IE-1K, IG-1, and IH-1 in greenhouse tests (Table 1). Of these 31 entries, six also rated zero to race IB-33. In addition to these outstanding entries, more than 40 additional entries also scored as highly resistant in both tests.

Big Eye Leaf Spot (BELS) scores of 5 or higher were recorded for 206 entries. The importance of BELS and its relative severity is undetermined since the disease very rarely occurs in the UA-PTBES blast nursery and in Arkansas production fields.

However, the introduction of foreign germplasm always carries the liability of increased susceptibility to endemic diseases normally considered benign.

Most plots received a rating that varied +/- one unit because of normal variation in field conditions and skill of individual evaluators. Numerical ratings can be converted to letter symbols where 0 to 3 = R (resistant), 3 to 4 = MR (moderately resistant), 5 to 6 = MS (moderately susceptible), 7 = S (susceptible), and 8 to 9 = VS (very susceptible). Depending on the disease at hand and test conditions, a rating of 5 to 6 is usually considered to have sufficient disease tolerance for use under typical field conditions.

SIGNIFICANCE OF FINDINGS

Utilization and manipulation of resistance genes is a basic component of rice disease-control strategies. Defining the disease liabilities of newly introduced rice germplasm and the identification of unique germplasm resistant to common rice diseases provide plant breeders necessary tools required to improve the yield and quality characteristics of new rice varieties. These data will be entered into the Germplasm Resources Information Network and be available along with other descriptors at www.ars-grin.gov.

ACKNOWLEDGMENTS

Funding for this research was provided in part by rice grower check-off funds through the Arkansas Rice Research and Promotion Board. The expertise and contributions of Hazel Mullins, Josh Lawson, and Greg Jones are much appreciated.

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Table 1. Rice blast severity scores for new rice acces-

Acp	Acno	Entry name	Heading (days)	Plant height (cm)	% Amylose	IB-49[z]
PI	637232	CT11072-2-4-1T-1P-2P-2	116	104	24.8	0.0
PI	637404	P 2182F5-49-3	116	96	23.3	0.0
PI	637418	LINEA 4440	119	102	23.0	0.0
PI	637453	P 3081-F4-58-3	110	104	24.2	0.0
PI	637454	P 3059-F4-25-3	108	102	24.6	0.0
PI	637687	Tox 3867-9-3-2-1-2-2-2	110	118	24.1	0.0
PI	637072	CT8008-16-10-3P-1X	114	96	23.9	0.0
PI	637071	CT8008-16-3-11P-1X	118	102	23.8	0.0
PI	637355	3835	119	102	23.7	0.0
PI	637510	ACC 1257	115	108	25.6	0.0
PI	637607	Tox 3093-35-2-3-3-1	110	102	23.9	0.0
PI	637669	Tox 3753-29-3-1-2-3-2-1	114	112	24.6	0.0
PI	637670	Tox 3770-17-2-2-1	115	90	23.8	0.0
PI	637518	EPAGRI 108	114	106	23.0	0.0
PI	637594	ITA 252	119	116	23.8	0.0
PI	637674	Tox 3772-40-3-2-2	111	98	24.3	0.0
PI	637708	Tox 4136-41-3	119	110	24.1	0.0
PI	637519	EPAGRI 109	115	100	24.8	0.0
PI	637613	Tox 3241-21-2-2-3-2	112	110	24.0	0.0
PI	637615	Tox 3241-31-2-1-3-1	111	104	24.4	0.0
PI	637741	UPR 254-85-tc-a3	85	98	24.3	0.0
PI	637693	Tox 3880-5-1-1-3	117	106	24.1	0.0
PI	637721	Tox 4251-397-2	109	104	24.1	0.0
PI	637724	Tox 4251-449-3	107	102	24.2	0.0
PI	637348	2135	117	114	25.2	0.0
PI	637421	P 1036-9-3-1-3-2M	111	92	24.4	0.0
PI	637439	P 3059-F4-87-2-2	110	100	23.4	0.0
PI	637671	Tox 3771-144-2-1-1	117	106	24.3	0.0
PI	637662	Tox 3717-25-3-1-3	108	108	24.6	0.0
PI	637664	Tox 3717-25-3-3-2	109	104	25.3	0.0
PI	637716	Tox 4251-270-2	104	100	24.5	0.0
PI	637614	Tox 3241-22-3-3-3	112	104	23.9	0.0
PI	637183	CT9748-3-1-1P-2-M	116	94	24.4	0.0
PI	637061	WC 265	118	94	24.6	0.0
PI	637370	ALTAMIRA 7	111	90	22.5	0.0
PI	636931	P 3055-F4-3-3P-2P-1B	120	108	24.7	0.0
PI	637208	CT9506-18-7-1T-2	118	106	17.2	0.3
PI	637686	Tox 3867-19-1-1-3-1-1-1	112	102	24.8	0.3
PI	637360	ITA 212	118	112	24.4	0.0
PI	637663	Tox 3717-25-3-3-1	110	98	24.9	0.0
PI	637675	Tox 3772-94-1-1-1	112	110	24.3	0.0
PI	637357	5209	118	110	24.8	0.0
PI	637366	1843	119	118	24.1	0.0
PI	637685	Tox 3857-34-3-3-1-3-2-1	118	108	24.9	0.3
PI	637668	Tox3749-71-1-1-3-2-2	117	112	24.2	0.0
PI	637350	S7-17	118	108	24.7	0.0
PI	637762	Redi Anaisa	98	96	22.9	0.0

sions from the national rice quarantine system.

Blast race							UA-PTBES		
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	Leaf blast	Panicle blast	Big Eye Leaf Spot[x]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	9
0.0	0.0	0.0	0.0	0.0	0.0	5.3	1.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	5.7	1.0	0.0	6
0.0	0.0	0.0	0.0	0.0	0.0	6.0	2.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.7	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.3	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.3	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.7	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.7	2.7	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.7	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.0	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.7	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.0	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.0	2.0	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.3	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	7.3	1.0	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	7.3	1.0	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.3	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.3	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.7	0.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.7	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.0	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.7	0.0	5
0.0	0.0	0.0	0.0	0.0	0.7	7.3	0.3	0.0	5
0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.7	0.0	8
0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	7
0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.0	.
0.0	0.0	0.3	0.0	0.0	0.0	6.0	1.0	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.0	0.0	8
0.0	0.0	0.3	0.0	0.0	0.0	7.3	0.7	0.0	7
0.0	0.0	0.3	0.0	0.0	0.0	7.7	0.3	0.0	8
0.0	0.0	0.3	0.0	0.0	0.0	7.7	1.3	0.0	7
0.0	0.0	0.3	0.0	0.0	0.0	8.0	1.7	0.0	7
0.0	0.3	0.0	0.0	0.0	0.0	8.0	1.0	0.0	5
0.0	0.3	0.0	0.0	0.0	0.0	1.3	0.7	0.0	.
0.0	0.0	0.0	0.7	0.0	0.0	7.3	0.7	0.0	8
0.0	0.0	0.7	0.0	0.0	0.0	7.7	1.3	0.0	7
0.0	1.0	0.0	0.0	0.0	0.0	0.3	1.3	0.0	.

continued

Table 1. Continued.

Acp	Acno	Entry name	Heading (days)	Plant height (cm)	% Amylose	IB-49[z]
PI	637227	CT11361-17-F4-11P-1P	110	104	24.1	0.7
PI	637480	PNA 314-F4-202-1	114	100	25.2	0.0
PI	637587	CHINNE SHAKAR	112	102	24.2	0.0
PI	637688	Tox 3872-61-3-3-3-2-1	119	112	24.8	6.0
PI	637727	Tox 4251-493-1	95	102	24.5	0.0
PI	637361	1313	112	118	24.8	0.3
PI	636939	P 3082-F4-18	106	90	24.7	0.0
PI	636955	P 3844-F3-18-5-1B-1X	119	100	23.8	0.0
PI	637006	2476	112	90	24.6	0.0
PI	637007	S7-17	117	92	24.0	0.0
PI	637033	CT6096-7-4-4-3-M	107	88	24.0	0.0
PI	637206	CT10325-29-4-1-1T	99	110	25.2	0.0
PI	637234	CT8837-1-17-1P-4-M	111	106	24.5	0.0
PI	637413	P 2786F4-19-7-4	112	104	23.1	0.0
PI	637448	CA810023	112	100	25.0	0.0
PI	637490	J 282-17-1-7	111	116	18.9	0.0
PI	637593	ITA 230	112	114	23.9	0.0
PI	637636	Tox 3440-16-3-1-1-3	108	108	24.6	0.0
PI	636943	P 3293-F4-27-1P-1B	110	104	24.8	0.0
PI	637354	S13-3	118	106	24.8	0.0
PI	637245	CT13737-5-5-3P-M	95	92	19.7	0.3
PI	637740	Tox 894-28-201-1-2	115	98	23.8	0.0
PI	637197	CT10323-8-2-2P-1-1T-4P	108	96	24.8	0.0
PI	637352	2698	115	106	24.7	0.0
PI	637212	CT8285-8-8-2P-M-1P-12	112	114	24.4	0.0
PI	637738	Tox 728-1	89	104	24.7	7.3
PI	637200	CT10175-4-6-2P-2-2	105	104	23.1	6.3
PI	637000	1845	108	102	24.1	0.0
PI	637481	PNA 314-F4-140-1	119	96	24.7	0.0
PI	637416	P 2189F4-64-5	119	116	23.6	0.0
PI	637462	P 3081-F4-31	96	95	22.5	0.0
PI	637732	Tox 4251-635-3	101	104	24.3	0.0
PI	636923	P 2786-F4-19-7-4	114	98	23.3	5.7
PI	637712	Tox 4251-117-2	105	108	24.5	0.0
PI	636870	IR10781-75-3-2-2	115	92	24.9	0.0
PI	636871	IR10791-75-3-2-2	116	104	25.2	0.0
PI	636883	IR25586-45-1-2	116	98	24.5	0.0
PI	636884	IR31916-9-2-2-2	114	114	23.9	0.0
PI	636895	NGOVIE-A	97	94	25.1	0.0
PI	636957	P 3844-F3-22-1-1X	116	100	24.4	0.0
PI	637021	P 5746-18-11-4-1-3X	107	108	24.5	0.0
PI	637027	ITA 306	120	102	24.2	0.0
PI	637030	P 4729-F2-5-1	112	112	24.8	0.0
PI	637087	CT8249-2-7-3-1X	98	104	15.6	0.0
PI	637100	CT8452-2-10-11P-1X	112	98	15.3	0.0
PI	637101	CT8452-2-27-4P-1X	100	96	15.3	0.0
PI	637114	CT10004-4-3-1P-1-2	110	90	17.3	0.0

Blast race							UA-PTBES		
							Leaf	Panicle	Big Eye
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	blast	blast	Leaf Spot[x]
0.0	0.0	0.0	0.3	0.0	0.0	6.3	1.7	0.0	5
0.0	3.3	0.0	0.0	0.0	5.7	8.0	2.7	0.0	5
0.0	3.7	0.0	0.0	0.0	6.3	7.3	0.7	0.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	8
0.0	3.7	0.3	6.0	0.0	7.3	8.0	1.0	0.0	5
0.0	6.7	3.7	2.3	0.0	6.7	7.7	1.7	0.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	5
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.3	1.0	8
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.3	1.0	5
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	1.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.3	1.0	6
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.0	1.0	5
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	1.0	6
0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.7	1.0	8
0.3	0.0	0.0	0.0	0.0	0.0	8.0	1.0	1.0	5
0.3	0.0	0.0	0.0	0.0	0.0	6.7	1.0	1.0	6
0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.7	1.0	5
0.0	0.7	0.0	0.0	0.0	0.0	7.0	0.5	1.0	8
0.0	1.0	0.0	0.0	0.0	0.0	1.3	1.0	1.0	7
0.0	2.0	0.0	0.3	0.0	0.0	7.7	1.7	1.0	7
0.0	2.7	0.0	0.0	0.0	5.7	0.0	1.7	1.0	7
0.0	0.0	0.0	6.0	0.0	2.0	7.0	1.0	1.0	.
1.7	0.0	0.0	1.0	5.3	4.3	5.0	3.0	1.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.3	1.3	9
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.3	1.3	8
0.0	0.0	0.0	0.0	0.0	7.7	7.3	0.7	1.3	8
0.0	0.3	0.0	0.0	0.0	0.0	1.0	1.7	1.3	7
0.0	0.0	0.0	0.3	0.0	7.3	8.0	1.0	1.5	6
0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.7	1.5	.
0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	1.7	8
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.0	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	5.7	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.7	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.0	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.7	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	2.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	2.0	6
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.0	2.0	5
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	2.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.0	5

continued

Table 1. Continued.

Acp	Acno	Entry name	Heading	Plant height	% Amylose	IB-49[z]
			(days)	(cm)		
PI	637119	CT10323-29-4-1-1-1T-2P	111	102	24.3	0.0
PI	637122	CT9809-7-1-M-1-1	115	92	16.3	0.0
PI	637126	CT10335-01-8-1P-4-3P	117	100	22.1	0.0
PI	637127	CT9162-12-6-2-2-1	111	94	18.3	0.0
PI	637193	CT11030-1-2-2T-1P-1P-3	101	106	17.3	0.0
PI	637233	CT9992-2-7-2T-2P-3P-3	109	100	24.5	0.0
PI	637695	Tox 3894-41-2-1-3	95	100	22.0	0.0
PI	637696	Tox 3894-41-2-3-1	94	98	22.5	0.0
PI	637487	P 3081-F3-5C-2M-1BC	96	94	23.5	0.0
PI	637110	IA CUBA 19	114	94	21.9	0.0
PI	637112	IA CUBA 17	117	92	21.6	0.0
PI	637113	IA CUBA 23	111	96	20.4	0.0
PI	637204	CT10175-5-10-3P-5-3	95	118	24.5	0.0
PI	637105	CT8470-26-9-1P-1X	117	102	23.7	0.0
PI	636958	P 3902-F3-15-2-1B-1X	115	106	24.5	0.0
PI	636899	P 1377-1-15M-1-2M-3	117	96	24.6	0.0
PI	636956	P 3844-F3-19-1-1B-1X	106	96	24.5	0.0
PI	637734	Tox 4251-641-1	106	84	23.6	0.0
PI	637312	TAICHUNG SEN YU 195	95	82	16.7	0.3
PI	637120	FB0007-3-1-6-1	114	100	23.9	0.0
PI	636874	IR13257-46-1E-P1	116	96	24.8	0.0
PI	637186	CT8008-16-10-10P-M	114	100	24.3	0.0
PI	637220	CT12908-1-4-9-2-M	99	92	15.3	0.0
PI	636862	ECIA 31-21-1-1	113	90	17.9	0.7
PI	637243	IR63872-8-3-1-2-1	99	84	22.0	0.7
PI	636909	P 2189-F4-64-5	118	94	23.8	0.0
PI	636908	P 2186-F4-2-2	114	112	24.0	1.0
PI	636975	P 4743-F2-85-6-1X	111	102	25.4	0.0
PI	636952	P 3817-F4-6-1	119	108	24.2	0.0
PI	637004	1884	118	102	23.8	2.0
PI	636929	P 2945-F4-41-1	108	110	24.6	0.7
PI	636999	1170	118	102	24.6	0.0
PI	637096	CT8447-5-6-4P-1X	105	92	23.3	0.0
PI	637080	CT8220-2-15-7P-1X	115	98	23.4	0.0
PI	637081	CT8220-2-15-7P-2X	114	100	23.0	0.0
PI	636972	P 4725-F2-43-1B-1X	114	94	24.1	0.3
PI	636971	P 4725-F2-16-7-1x	118	104	24.8	8.0
PI	636967	P 4711-F2-51-5-1X	97	98	24.5	0.0
PI	637017	P 4743-F2-14-1	102	106	24.3	0.0
PI	637590	FKR 14	118	102	23.5	0.0
PI	636927	P 2887-F4-9-4	119	110	23.8	0.0
PI	637471	PNA 343-F4-446-2-4	91	100	16.7	0.0
PI	637647	Tox 3553-34-3-2-3-2-2	105	98	24.1	0.0
PI	637739	Tox 85a-c2-455-2	119	112	24.0	0.0
PI	636946	ICTA MOTAGUA	97	88	24.7	0.0
PI	636855	B 2850B SI-2-3	113	98	23.8	0.0
PI	636866	IG2035	97	104	24.5	0.0

Blast race							UA-PTBES		
							Leaf	Panicle	Big Eye
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	blast	blast	Leaf Spot[x]
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.0	5
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	5.7	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.0	2.0	.
0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.7	2.0	7
0.0	0.0	0.0	0.0	0.0	0.3	6.0	2.0	2.0	8
0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.0	2.0	5
0.0	0.0	0.0	0.0	0.0	1.0	0.3	2.0	2.0	7
0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.3	2.0	5
0.0	0.0	0.0	0.0	0.0	3.0	4.0	1.7	2.0	8
0.0	0.0	0.0	0.0	0.0	3.3	6.7	0.7	2.0	5
0.0	0.0	0.0	0.0	0.0	4.0	7.7	1.3	2.0	8
0.0	0.0	0.0	0.0	0.0	6.3	0.0	1.3	2.0	8
0.3	0.0	0.0	0.0	0.0	0.0	1.0	1.7	2.0	8
0.3	0.0	0.0	0.0	0.0	0.0	8.0	0.5	2.0	6
0.0	0.0	0.0	0.0	0.0	0.0	7.3	2.0	2.0	7
0.3	0.0	0.0	0.0	0.0	3.7	0.0	0.3	2.0	8
0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	6
0.0	0.0	0.7	0.0	0.0	0.0	2.0	1.0	2.0	7
0.0	0.7	0.0	0.0	0.0	0.0	8.0	0.7	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.3	2.0	9
0.0	0.0	0.0	0.0	0.0	0.0	7.3	1.0	2.0	8
0.7	0.0	0.0	0.0	0.0	6.7	7.3	1.3	2.0	9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	6
0.0	0.0	1.0	0.0	0.0	7.0	0.0	2.7	2.0	8
0.7	0.0	1.0	0.0	0.0	0.7	6.0	0.7	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.0	2.0	8
0.7	0.7	0.0	0.0	0.0	7.0	6.7	1.7	2.0	8
0.0	5.7	0.0	0.0	0.0	7.3	8.0	2.7	2.0	5
0.0	0.0	0.7	0.0	5.3	0.0	7.0	1.0	2.0	7
0.0	0.0	0.0	0.0	7.0	0.0	0.0	2.0	2.0	8
0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.3	2.0	7
7.0	0.0	0.0	0.0	0.0	6.3	7.0	2.0	2.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	2.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.3	7
0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.3	5
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.7	2.3	7
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.3	2.7	8
0.0	0.0	0.0	0.0	0.0	0.0	8.0	1.0	2.7	5
0.0	0.0	0.7	0.0	0.0	0.0	5.7	1.0	2.7	5
0.0	1.7	0.0	0.0	0.0	0.0	6.0	1.0	2.7	5
0.0	0.0	0.0	0.0	4.0	0.0	4.7	1.3	2.7	5
0.0	0.0	0.0	0.0	0.0	0.0	4.7	3.0	3.0	8
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.7	3.0	8

continued

Table 1. Continued.

Acp	Acno	Entry name	Heading	Plant height	% Amylose	IB-49[z]
			(days)	(cm)		
PI	637060	C 48CU76-3-2-1-4-5M	98	72	24.3	0.0
PI	637086	CT8248-1-12-2P-1X	105	104	17.9	0.0
PI	637216	CT9157-3-2-6-2	96	92	24.2	0.0
PI	637230	CT10491-12-4-2T-3P-2P-1	98	92	20.8	0.0
PI	637255	TOX 1010-24-6-1-1B	94	92	16.1	0.0
PI	637676	Tox 3779-51-2-2-2	106	98	24.6	0.0
PI	637085	CT8240-1-5-2P-1X	100	90	13.9	0.0
PI	637129	CT9506-28-3-3P-M-1-M	94	96	23.7	0.0
PI	637184	CT11008-12-3-1M-1P-4P	104	104	23.9	0.0
PI	636921	P 2359-F4-9	105	92	23.0	0.0
PI	637718	Tox 4251-313-3	98	96	24.6	0.0
PI	637768	Yom Ju #14	68	82	15.2	7.5
PI	637125	CT9159-18-2-3-1	98	98	23.6	0.0
PI	637149	CT10554-4-4-2-2-M	91	92	18.5	0.0
PI	637152	CT10825-1-2-1-3-M	82	106	19.2	0.0
PI	637190	CT9841-5-2-1P-2I-2I-M	82	88	24.8	0.0
PI	637191	CT9748-13-2-1-M-M-1-1	90	98	24.6	0.0
PI	637217	CNARR4949-8B-BM85-15-2P	94	88	25.6	0.0
PI	637347	1862	107	108	24.2	0.0
PI	637160	IRGA 369-31-2-3F-A1-1	87	92	25.4	0.0
PI	637150	CT10166-16-1-2P-1-3	87	88	23.7	0.0
PI	637226	CT9145-4-21-5P-1-MI-F8-3P	100	96	23.9	0.0
PI	637180	IR62061-89-1-3-2	85	82	22.7	6.0
PI	637521	EMBRAPA 7 TAIM	91	84	25.1	0.0
PI	637722	Tox 4251-413-2	101	100	24.6	0.0
PI	637677	Tox 3779-51-2-2-2	98	96	24.7	0.0
PI	636945	P 3299-F4-1B-1X	113	104	24.8	0.7
PI	637205	CT10244-1-1-1-1T-2-1	99	108	24.7	0.0
PI	637223	CT10166-1-1E-3P-6-2-2P-5P	89	88	24.5	0.0
PI	637458	P 2867-F4-31-5	112	116	24.0	0.7
PI	637156	IRGA 660-3-13-5-3	83	104	18.8	0.0
PI	637128	CT9509-28-3-3P-M-1	95	94	16.7	0.0
PI	637192	CT10491-12-4-2T-3P-1P	94	96	18.3	0.7
PI	637148	CT9682-2-M-14-1-M-1-3P-M-1	99	90	23.5	0.0
PI	637035	CT7201-16-5P	98	108	22.8	7.7
PI	637058	CT7363-8-2-2	85	92	23.9	0.0
PI	637151	CT9509-17-3-1-1-M-1-3P-M-1	89	92	24.7	0.0
PI	637203	CT10166-2-1-1T-1C	91	94	24.8	0.0
PI	637215	CR 2515	98	110	24.7	0.0
PI	637132	CT9155-2-3-1-2M-4-1P	89	98	23.4	0.0
PI	636864	GZ864-2-3-1	93	72	16.7	7.0
PI	637381	IR5929-12-2	94	112	22.1	0.0
PI	637236	CT9852-3-2-1-2-F7	89	96	19.5	0.0
PI	637157	IRGA 659-1-2-2-2	79	96	16.4	0.0
PI	637092	CT8250-21-12-2P-1X	86	104	13.4	0.0
PI	636961	P 4277-F2-2-9-1X	90	88	23.8	0.3
PI	637032	CT6129-12-7-2P	82	94	14.8	5.3

Blast race							UA-PTBES		
							Leaf	Panicle	Big Eye
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	blast	blast	Leaf Spot[x]
0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.0	3.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	3.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.0	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.0	8
0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	3.0	6
0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0	3.0	7
0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	3.0	7
0.0	0.0	0.0	0.0	0.0	5.3	6.7	2.3	3.0	7
0.0	0.0	0.0	0.0	0.0	5.7	0.0	2.0	3.0	8
0.3	0.0	0.0	0.0	0.0	0.0	7.0	1.0	3.0	6
0.0	0.3	0.3	0.0	0.0	0.0	0.0	1.0	3.0	5
8.0	6.0	0.7	8.0	8.0	8.0	7.3	2.7	3.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.3	7
0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3	3.3	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	3.3	8
0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.7	3.3	7
0.0	0.0	0.0	0.0	0.0	0.0	7.3	1.0	3.3	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.3	8
0.0	0.0	0.0	0.0	0.0	0.0	7.0	1.3	3.3	7
0.0	0.0	0.0	0.0	0.0	0.3	4.7	0.3	3.3	7
0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.7	3.3	6
0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.7	3.3	.
1.0	0.0	0.0	0.7	0.0	5.3	5.7	1.0	3.3	7
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.3	3.5	8
0.0	0.0	0.0	0.0	0.0	5.3	8.0	1.0	3.7	8
0.0	0.3	0.0	0.0	0.0	0.0	1.7	0.7	3.7	8
2.3	0.0	0.0	0.0	0.0	0.0	5.3	1.7	3.7	8
0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.7	4.0	5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	4.0	6
0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.3	4.0	.
0.0	0.0	0.7	0.0	0.0	1.0	5.0	1.0	4.0	7
0.7	0.0	0.0	0.0	0.0	0.0	7.3	1.0	4.3	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.3	7
0.0	0.0	0.0	0.0	7.3	4.7	0.0	1.0	4.3	8
0.0	0.7	0.0	0.0	0.0	7.0	7.7	2.0	4.6	5
0.0	0.0	0.0	0.0	0.0	0.0	4.3	1.0	4.7	6
0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	4.7	8
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.0	4.7	8
0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.7	7
0.0	0.0	0.0	0.0	0.0	5.3	0.0	1.0	4.7	7
0.0	1.3	0.0	0.0	0.0	5.7	7.0	0.7	4.7	6
0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.7	5.0	.
0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.7	5.0	7
0.0	0.0	0.0	0.0	0.0	3.7	0.7	1.3	5.0	7
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	5.3	8
0.0	0.7	0.0	0.0	0.0	0.0	4.0	2.0	5.3	7
5.7	0.0	1.3	0.0	0.0	0.5	6.7	1.0	5.6	5

continued

Table 1. Continued.

Acp	Acno	Entry name	Heading	Plant height	% Amylose	IB-49[z]
			(days)	(cm)		
PI	637162	CNAX 5011-9-1-6-4-B	88	96	19.0	0.0
PI	637169	CT8285-13-4-1P-M	110	92	22.8	0.0
PI	637040	CT7363-13-5-3	82	92	23.7	0.0
PI	637187	CT8008-3-5-8P-M-2P	90	88	24.5	0.0
PI	637178	CT11280-2-F4-12P-5	91	104	23.9	0.0
PI	637057	CT7363-5-3-10	81	88	23.6	0.0
PI	636970	P 4725-F2-9-6-1X	112	104	24.1	0.7
PI	636863	FLOTANTE 36 MUTANTE 3	76	102	14.1	0.0
PI	636795	MILYANG 142	93	86	17.8	5.0
PI	637363	HAIKONGPAU	76	114	24.0	1.0
PI	637769	Pyong Buk #3	70	76	16.0	7.0
PI	637042	IR32429-122-3-1-2	80	82	22.6	0.0
PI	637108	CT8240-1-3-4P-4	91	90	16.0	0.0
PI	637166	CT8665-1-1-1P-4	95	104	18.3	0.0
PI	637189	PR 23613-1-4	81	88	25.0	0.0
PI	637509	ACC 1256	107	100	12.8	7.3
PI	637442	TOX 1780-2-1-1P-3	90	100	19.0	0.7
PI	636812	CAIAPO	82	110	17.5	5.7
PI	636775	ODAEBYEO	68	88	18.5	6.5
PI	637041	CT7363-13-5-4	83	98	24.3	0.0
PI	637118	CT10175-5-1-3P-1-3-2P	85	96	23.9	0.0
PI	637174	CT8240-1-5-2P-M-1P	100	78	13.7	0.0
PI	637489	P 3061-F4-5C-1M-1BC	110	84	23.3	4.3
PI	637135	CT10588-CA-1-M	84	92	16.5	7.7
PI	637507	TOX 1177-13B-2CN-1JU	98	108	22.6	7.3
PI	636780	SANGJUBYEO	68	82	18.5	1.0
PI	637213	RCN-B-93-083	99	94	23.1	0.7
PI	636807	CAN 8061	77	112	23.4	1.0
PI	636813	CARAJAS	79	110	17.6	0.0
PI	636808	CAN 8070	76	118	22.9	0.3
PI	637452	P 2859-F4-97-6	97	96	22.5	7.0
PI	636779	SHINUNBONGBYEO	67	88	18.2	8.0
PI	636925	P 2859-F4-99-1	104	94	22.9	0.0
PI	636783	KUMOBYEO	68	84	17.7	6.7
PI	636865	IG2018	88	112	22.9	0.0
PI	637778	IRGA 284-18-2-2-2	81	100	24.7	0.0
PI	637777	Si Jung #10	68	92	17.8	7.0
PI	637776	Yon An #12	79	92	17.8	5.0
PI	637773	Ryong Song #15	68	102	17.7	7.3
PI	637767	Yom Ju #1	68	90	17.9	7.0
PI	637774	Ryong Song #25	79	118	17.3	7.0
.	.	Ahrent	.	.	.	0.0
.	.	Banks	.	.	.	0.0
.	.	Bengal	.	.	.	7.0
.	.	Cocodrie	.	.	.	6.3
.	.	Cypress	.	.	.	6.7
.	.	Cybonnet	.	.	.	.

Blast race							UA-PTBES		
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	Leaf blast	Panicle blast	Big Eye Leaf Spot[x]
0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.0	5.7	6
0.0	0.0	0.0	0.0	0.0	6.7	0.0	1.0	5.7	6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.0	8
0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.3	6.0	7
0.0	0.0	0.0	0.0	0.0	4.7	0.0	1.3	6.0	8
0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.7	6.0	8
0.0	0.0	0.0	0.0	0.3	0.0	6.7	0.7	6.0	8
0.0	0.0	0.0	0.0	4.7	0.0	7.0	1.0	6.0	8
6.0	1.0	1.3	0.0	0.0	0.0	8.0	2.3	6.0	8
0.0	6.0	0.3	7.7	5.0	6.0	7.3	2.7	6.0	5
8.0	5.7	0.0	8.0	0.0	7.3	7.3	3.0	6.0	8
0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.7	6.3	5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	6.3	7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	6.3	7
0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.7	6.3	7
0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.7	6.3	.
7.0	0.0	1.3	0.0	0.0	6.7	7.0	0.7	6.3	5
1.0	0.0	0.0	0.0	5.0	0.0	7.0	1.7	6.3	8
7.3	0.0	0.7	0.0	3.7	4.3	7.3	2.3	6.3	8
0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.3	6.7	7
0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.3	6.7	7
0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.3	6.7	7
0.0	3.3	0.0	1.0	0.0	6.3	5.0	3.3	6.7	5
0.0	0.0	2.0	0.0	0.0	0.0	7.3	2.3	6.7	7
7.0	0.0	1.3	7.3	0.0	6.3	7.0	1.0	6.7	.
0.0	0.0	0.0	0.0	0.0	0.3	7.7	1.3	7.0	8
0.0	0.0	0.7	0.0	0.0	5.7	6.3	1.7	7.0	7
2.0	0.0	1.0	0.0	0.0	5.7	5.3	1.0	7.0	8
2.7	1.3	0.0	0.3	0.0	6.0	6.0	3.0	7.0	8
0.7	0.0	0.0	0.0	5.7	0.0	7.3	0.7	7.3	8
1.0	0.0	0.0	0.7	0.0	0.0	6.7	1.3	7.3	8
7.7	0.0	0.0	0.0	0.0	7.0	7.3	2.7	7.3	7
0.0	0.0	0.7	0.0	0.0	0.0	7.0	1.0	7.7	.
8.0	0.3	0.7	0.0	0.0	6.0	7.0	2.3	7.7	8
6.7	4.7	7.3	3.7	0.0	8.0	7.7	7.0	7.7	8
0.0	1.0	0.0	0.0	0.0	5.0	0.0	1.0	.	.
7.7	4.3	3.3	3.0	.	6.3	6.3	3.7	.	8
8.0	7.3	4.0	8.0	4.0	8.0	7.0	4.0	.	.
7.0	6.7	0.0	8.0	8.0	7.3	7.3	3.0	.	8
7.3	5.0	5.3	7.3	8.0	7.3	8.0	2.3	.	6
7.3	7.0	4.7	8.0	7.3	8.0	6.7	1.0	.	8
0.0	0.0	0.3	0.0	0.0	8.0	7.3	.	.	.
0.0	0.0	0.0	0.3	0.0	7.7	6.7	.	.	.
8.0	2.7	.	1.3	0.0	6.0	8.0	.	.	.
7.3	6.0	4.3	7.7	0.0	3.3	8.0	.	.	.
7.0	7.3	4.0	0.0	0.0	8.3	7.0	3.3	8.0	9
.	.	.	.	.	.	.	1.0	7.5	6

Table 1. Continued.

Acp	Acno	Entry name	Heading	Plant height	% Amylose	IB-49[z]
			(days)	(cm)		
.	.	Drew	.	.	.	0.0
.	.	Dular	.	.	.	8.0
.	.	Francis	.	.	.	7.7
.	.	Jeff	.	.	.	.
.	.	Kanto 51	.	.	.	.
.	.	Katy	.	.	.	0.0
.	.	Kaybonnet	.	.	.	0.3
.	.	LaGrue	.	.	.	8.0
.	.	Lemont	.	.	.	7.7
.	.	M201	.	.	.	8.0
.	.	Mars	.	.	.	8.0
.	.	Medark	.	.	.	7.7
.	.	Newbonnet	.	.	.	8.0
.	.	Saber	.	.	.	0.0
.	.	Spring	.	.	.	0.0
.	.	Starbonnet	.	.	.	8.0
.	.	Usen	.	.	.	7.7
.	.	Wells	.	.	.	8.0
.	.	ZHE 733	.	.	.	0.0
.	.	Zenith	.	.	.	6.3

[z] Greenhouse rice leaf blast evaluation visual rating scale: 0 = none to 9 = maximum.

[y] Field blast was evaluated in the Pine Tree Brach Experiment Station: planted 22 May 2007; inoculated 21 June and 25 July 2007. Leaf evaluation was rated 26 July 2007. Panicle evaluations were rated 13 - 14 September and 23 - 24 October 2007 in the disease visual rating scale: 0 = none to 9 = maximum.

[x] Natural field infestation of Big Eye Leaf Spot. Leaf evaluation 23-24 October 2007: visual rating scale: 0 = none to 9 = maximum.

							UA-PTBES		
Blast race							Leaf	Panicle	Big Eye
IB-1	IC-17	IE-1	IG-1	IH-1	IE-1k	IB-33	blast	blast	Leaf Spot[x]
0.0	0.0	0.0	0.0	0.0	7.5	8.0	0.3	7.7	5
7.0	7.7	4.7	4.7	0.0	7.7	8.0	.	.	.
7.3	7.7	7.0	8.0	0.0	8.0	8.0	.	.	.
0.0	0.7	0.0	0.0	0.0	0.0	.	.	.	.
.	7.0	.	8.0	8.0	.	8.0	.	.	.
0.0	0.0	0.0	0.3	0.0	8.0	7.3	.	.	.
0.0	0.0	0.0	0.0	0.0	7.7	7.7	.	.	.
8.0	7.3	7.0	8.0	8.0	7.3	8.0	.	.	.
6.7	6.0	5.0	0.0	0.0	8.0	7.7	.	.	.
8.0	7.7	7.0	8.0	8.0	8.0	8.0	.	.	.
7.3	0.0	0.3	0.0	0.0	5.7	7.7	4.7	8.7	7
7.0	3.0	3.3	0.3	0.0	6.0	8.0	.	.	.
6.7	8.0	6.3	0.0	0.0	8.0	7.7	.	.	.
0.0	0.7	0.0	0.0	0.0	0.3	7.0	.	.	.
0.0	0.7	0.0	0.0	0.0	8.0	8.0	.	.	.
6.3	7.7	7.0	7.0	0.0	8.3	7.7	.	.	.
1.0	0.0	0.0	5.0	6.0	4.7	8.0	.	.	.
6.0	7.3	6.0	0.0	0.0	8.3	7.7	5.7	8.0	6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	
6.7	0.0	2.0	0.0	0.0	0.0	8.0	.	.	.

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

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ABSTRACT

Sheath blight remains the most important disease in Arkansas rice production and accounts for most of the rice fungicide use in the state. Since the introduction of azoxystrobin in 1997, total usage of fungicides in rice has increased from 10% of planted rice area treated to more than 70%. Usage patterns have also shifted, from scouting and decision-making systems based on disease intensity to preventative applications. While strong monogenic resistance in rice to sheath blight is not known, current cultivars vary greatly in reaction to the disease. There are many new rice cultivars available to Arkansas producers, including hybrids, but the yield response of individual cultivars to preventative fungicide applications is not well documented, yet would be helpful in understanding their value to rice growers considering this approach.

In 2006, 15 cultivars were assessed while 20 were tested in 2007. In the first year, 9 of 14 cultivars had significantly higher yield in treated plots while 12 of 20 cultivars did in 2007. Sheath blight severity and yield loss varied greatly among cultivars in both years. Yield loss varied from 1.9 to 37.4 % in 2006, and -1.5 to 24.4% in 2007, depending on cultivar, and averaged 17% across cultivars under 2006 conditions and 8.5% in 2007. Factors that may have influenced the results between years likely included weather patterns, with 2006 having milder and wetter conditions than 2007; slight location differences; the presence of stem rot at the 2006 site; and fertilizer differences in 2007.

Grain quality was influenced by fungicide treatment both years, but inconsistently. Fungicide treatment increased head rice yield in 5 of 15 cultivars in 2006 and 5 of 20 cultivars in 2007. Total milled rice was increased for 7 of 15 cultivars in 2006 but only for 3 of 20 cultivars in 2007.

INTRODUCTION

The use of foliar fungicides in Arkansas rice production has increased since 1997 with the introduction of azoxystrobin (Quadris®), a highly effective sheath blight fungicide. After a statewide kernel smut epidemic in Arkansas during 1998, extension specialists started recommending the use of propiconazole during the booting stage to prevent kernel smut in highly susceptible cultivars. Beginning in 1999, mixtures of Quadris® + Tilt® during the booting stage provided control of both sheath blight and kernel smut for many cultivars. In 2002, Stratego® fungicide was introduced. This mixture of trifloxystrobin + propiconazole provided a single formulation that controlled both diseases at a lower cost per acre than Quadris® + Tilt®. Shortly afterwards, a premix product containing azoxystrobin + propiconazole (Quilt®) was introduced by Syngenta to compete with Stratego®. With increasing use of effective fungicides, more growers adopted preventative use of these products, with less regard for scouting or disease pressure. All these developments resulted in an overall increase of fungicide use in the state from less than 200,000 acres treated prior to 1997 to over 900,000 acres treated in 2007.

Rice diseases limit production and profit in the South but do not cause measurable loss in every field. While scouting continues to be encouraged as an important part of the fungicide decision-making process, a growing number of producers routinely treat all fields regardless of cultivar or other factors, assuming fungicides always “at least pay for themselves.” Fungicide applications for rice routinely cost $20 to $30/acre, and while environment plays a huge role in the need for and effectiveness of foliar fungicides, cultivar resistance is also important. Since strong resistance in rice cultivars to sheath blight is limited, fungicides have become a major control method. However, modern cultivars do vary in susceptibility to sheath blight damage, and susceptibility should be a consideration before fungicide use.

Given the rapid change in cultivars in the South and limited knowledge about the resistance of current cultivars to sheath blight and crop loss to this disease, this study was undertaken to determine the impact of uniform sheath blight on yield loss of different cultivars and to determine the benefit of preventative fungicide applications under inoculated field plot conditions.

PROCEDURES

Cultivars included the first year included ‘4484’, ‘Bengal’, ‘Cheniere’, ‘CL 131’, CL 171AR’, CL XL730’, ‘CL XL729’, ‘Cybonnet’, ‘Francis’, ‘Jupiter’, RU0501102, ‘Sierra’, ‘Trenasse’, ‘Wells’, and ‘XL 723’. In 2007, cultivars included 4484, Bengal, ‘CL 161’, ‘CL 171AR’, ‘CL XL730’, ‘CL XL 729’, ‘CL XP 744’, ‘CL XP745’, ‘CL XP 746’, ‘Cocodrie’, Cybonnet, Francis, Jupiter, RU0501099, RU0501145, ‘Sabine’, Sierra, Trenasse, Wells, and XL 723. Cheniere and CL 131 were dropped in 2007 due to the LL 601 issue.

Seed were planted 0.5-in. deep in a conventional Dewitt silt loam seedbed on 12 April 2006 and 23 April 2007 in plots 5-ft wide by 25-ft long. Study sites were on the same farm but in different fields each year. The study cultivars were arranged in paired plots with an untreated versus treated plot, replicated 4 times in a randomized complete block design. Fertilization, weed control, insect control, and irrigation were according to University of Arkansas Cooperative Extension Service guidelines, with the exception that total nitrogen rate was 175 lb N/acre (as urea) in 2006 and 147 lb N/acre (as urea) in 2007. All plots were inoculated with 100 ml floating calcium alginate beads containing hyphal pieces of *Rhizoctonia solani* AG1-1A isolate RS 407 at panicle initiation by hand-sprinkling between the center plot rows on 22 June in both years. Preventative fungicide treatment (Quadris® at 12.3 fl oz/acre) was applied just prior to disease development to the treated plot of each cultivar pair on 29 June 2006 and 27 June 2007, respectively, with a compressed-air, self-propelled plot sprayer calibrated to deliver 10 gpa volume using flat fan tips. Plots were visually evaluated for disease 28 days after fungicide application in both years and harvested with a small plot combine on 9 September 2006 and 12 September 2007, respectively. Harvested grain was weighed and converted to standard weight at 12% grain moisture. Subsamples were processed to obtain head and total milled rice using Grain Inspection, Packers, and Stockyards Administration (GIPSA) procedures. Yield and quality loss were determined by comparing untreated and treated plots within cultivar and year.

RESULTS AND DISCUSSION

Sheath blight was moderate in July and early August of 2006, but persisted through the grain-fill period, eventually reaching the panicles. The preventative fungicide reduced sheath blight severity significantly on all 15 cultivars tested, with untreated cultivars having 14% (Bengal) to 56% (4484) severity while treated cultivar plots ranged from 0.6% (Bengal) to 15.5% (Trenasse) (Table 1). Sheath blight continued to develop through heading and ratings should have been continued later than taken, and severity may have been underestimated in 2006.

Effect of preventative fungicide application on yield varied widely by cultivar (Table 1). Fungicide treatment resulted in higher yield for Cheniere, CL 171AR, CL XL 730, Cybonnet, Francis, RU0501102, Sierra, Trenasse, and Wells cultivars in 2006 (Table 1). Cultivars 4484, Bengal, CL XP 729, Jupiter, and XL 723 did not show a significant yield response from fungicide treatment (Table 1). Significant yield gain over the untreated control varied from 11.7% for Francis to 37.4% for CL 131 (Table 1). Both Wells and CL XL 730 showed higher yield losses than expected based on past disease ratings, approximately 20% loss for each cultivar (Table 1). One confounding factor in this study was the erratic presence of stem rot in some of the plots. An attempt was made to assess stem rot but the erratic distribution in the test area resulted in no consistent observations (data not shown). The effect of fungicide treatment on milling quality also varied with cultivar (Table 1). Cultivars Cheniere, CL 131, CL 171AR, Cybonnet, and Sierra had significantly higher head and total rice milling yields when treated, while RU0501102 and Wells had significantly higher total milled rice yields when treated but head rice was not affected (Table 1).

Sheath blight was aggressive until July 17, 2007 when weather conditions changed to very hot and dry, slowing disease progress. The fungicide treatment reduced disease severity significantly on 18 of 20 cultivars tested (Table 2). Untreated plots varied from 26% to 78.3% severity while treated plots ranged from 15.8% to 42.9% (Table 2). Effect of fungicide treatment on yield varied greatly, depending on cultivar, with gain over untreated ranging from -2.7% to 24.4% (Table 2). Significant yield gains from fungicide treatment were noted for 12 of 20 cultivars tested, with Trenasse having the largest yield response (Table 2). Francis, Trenasse, Bengal, Wells, Cocodrie, CL 171AR, CL 161, Cybonnet, Sierra, CL XP 744, RU0501099, and Sabine all had significant yield responses to the fungicide treatment while 4484, CL XL 730, CL XP 745, Jupiter, CL XP 729, XL 723, RU0501145, and CL XP 746 did not have measurable yield response (Table 2). Results in 2007 showed only 5 of the 20 cultivars tested had higher head rice yields from the fungicide treatment and only 3 of 20 showed a gain in total milled rice for the fungicide-treated plots (Table 2).

Results from these trials support the basic efficacy of azoxystrobin for control of sheath blight and protection of yield and milling quality; however, even without known, strong single-gene resistance to sheath blight, commercial rice cultivars tested varied greatly in their response to sheath blight and to preventative fungicide application. Semidwarf long-grain cultivars were more susceptible and benefitted the most from fungicide application, while medium-grain and hybrid rice cultivars benefitted less, or inconsistently. Reactions varied somewhat between years, e.g., under 2006 conditions, the new hybrid CL XL 730 did benefit from fungicide treatment but did not under 2007 conditions.

Based on these data, disease reactions for sheath blight should be checked against yield loss periodically for different cultivars, and it remains clear that preventative fungicide applications do not always result in a yield or milling quality benefit to rice. Therefore, scouting and wise decision-making when using fungicides remains warranted for Arkansas, making their use more profitable than if simply sprayed over all acreage preventatively.

SIGNIFICANCE OF FINDINGS

Based on these results, Arkansas growers using preventative fungicide applications could save up to $30/acre by not treating cultivars resistant to sheath blight, such as XL 723 or Bengal. On the other hand, growers can protect yield and milling quality by treating highly susceptible cultivars like CL 161 with an appropriate fungicide application, when disease intensity justifies it.

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Table 1. Effect of preventative fungicide application on sheath blight, yield, and milling quality of 15 rice cultivars in Arkansas during 2006.

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

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

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

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

Table 1. Effect of preventative fungicide application on sheath blight, yield, and milling quality of 20 rice cultivars in Arkansas during 2007.

	Sheath blight		Yield		Yield	Head rice		Total milled rice	
Cultivar	Untreated	Quadris®[z]	Untreated	Quadris®[z]	gain	Untreated	Quadris®[z]	Untreated	Quadris®[z]
	(% of plot height affected)		----(bu/acre 12% GM[y]) ----		(% above unt)	---------------- (%) ----------------			
4484	34.3	16.6*x	174.1	181.1	3.9	45.5	50.3*	64.9	65.2
Bengal	40.0	16.7*	218.2	225.6*	3.3*	62.0	63.0	67.3	67.8
CL 161	60.3	33.7*	183.3	212.6*	13.8*	62.7	62.0	64.8	67.0*
CL 171 AR	56.7	35.3*	153.6	203.3*	24.4*	62.0	62.0	69.0	69.5
CL XL 730	27.2	20.3	187.2	211.4	11.4	58.8	58.0	68.5	67.8
CL XP 729	26.0	15.8	238.5	247.9	3.8	57.3	58.8	67.8	68.0
CL XP 744	43.3	21.7*	213.9	223.2*	4.2*	57.3	56.8	69.3	69.0
CL XP 745	48.3	22.9*	183.2	198.6	7.8	57.5	57.0	68.8	68.8
CL XP 746	37.6	24.3*	168.6	179.2	5.9	58.8	59.3	69.3	69.3
Cocodrie	45.7	22.6*	230.7	227.2*	-1.5*	57.0	59.0	64.0	66.0*
Cybonnet	58.6	30.1*	151.6	173.5*	12.6*	60.0	62.8*	68.5	69.0
Francis	50.9	36.1*	145.6	165.2*	11.9*	56.3	58.8*	66.2	67.8
Jupiter	44.0	24.5*	153.1	177.5	13.7	64.3	65.0	68.3	68.8
RU0501099	44.5	19.0*	145.3	157.3*	7.6*	58.5	60.3	67.8	68.8
RU0501145	37.9	17.3*	222.3	228.8	2.8	54.3	54.7	63.8	63.5
Sabine	60.0	37.6*	227.1	241.2*	5.8*	58.0	60.5*	66.8	67.8
Sierra	73.1	42.9*	176.8	196.0*	9.8*	51.8	52.5	68.0	68.8
Trenasse	78.3	37.9*	184.7	193.3*	4.4*	51.7	54.0*	62.0	65.3*
Wells	42.5	27.5*	205.3	199.9*	-2.7*	53.3	52.3	69.3	70.8
XL 723	35.4	20.2*	157.7	172.2	8.4	60.3	61.0	69.0	69.8
XL 723	23.1	4.9*	269.5	279.1	3.6	61.3	62.0	70.8	70.8

[z] Quadris® applied at 12.8 fl oz/acre using a self-propelled plot sprayer calibrated to deliver 10 gpa, 7 days after panicle differentiation for Trenasse (earliest maturing cultivar).
[y] GM = grain moisture, measured using a calibrated GAC 2000 instrument (Dickey-John, Inc.).
[x] * = Values within variable and cultivar (paired) were significantly different at P=0.05.

PEST MANAGEMENT: DISEASES

Evaluation of Rice Cultivars and Breeding Lines in the URRN for Disease Reaction at Two Off-Station Locations During 2007

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ABSTRACT

Rice cultivars and breeding lines are included in the Uniform Regional Rice Nursery (URRN) each year in the South, some as potential future cultivar releases. The 200 entries are evaluated extensively on experiment stations in Arkansas and the other southern rice states, and less extensively in off-station locations that may be more naturally conducive to certain diseases and other problems. We evaluate the nursery at conducive locations in Lonoke County and Poinsett County each year for reaction to inoculated and naturally occurring diseases in the respective areas.

The climate was favorable for disease development until mid-July 2007, when conditions became very hot and dry for the balance of the growing season, severely limiting disease development.

Sheath blight occurred at the Lonoke site and appeared aggressive until the hot, dry period. Stem rot was inoculated at the Poinsett County site and was very uniform and aggressive on this potassium-depleted soil type. Bacterial panicle blight was inoculated at the Lonoke site; however, disease development varied somewhat with the maturity of the cultivar/lines and appeared to be influenced by the hot, dry conditions late in the growing season. Other diseases were very erratic in the nurseries. Sheath blight was evident in the Lonoke URRN where 118 of 200 entries rated 50% or greater severity while bacterial panicle blight at this site rated 50% or greater panicle sterility on 43 of the 200 entries. At the Poinsett site, 187 of the 200 entries rated 3 or greater stem-rot severity using a 1 to 5 rating scale, reflective of the limited resistance in current U.S. southern germplasm to this disease, especially under potassium-limited circumstances. Results were shared with southern U.S. rice breeding programs.

INTRODUCTION

Rice diseases remain a major problem in Arkansas and the South, largely due to the type of cultivars planted, the management systems currently used, and the climate. While management of diseases has improved as a result of sustained grower check-off funded research, disease problems remain a constant battle for producers since cultivars, management, and climate change year to year.

Sheath blight remains the most important disease, favored by intensive nitrogen use, rice-soybean rotations, and the hot, humid conditions in flooded rice fields. We estimate that 75% of fields in rice-soybean rotations have the potential for sheath blight damage, under the right conditions. Sheath blight is also the most dependable disease in the South, causing routine damage each year, while blast, another important disease, is much more erratic and climate-dependent. Blast will likely increase in importance over the next decade as water supplies continue to become less abundant, susceptible cultivars continue to be widely grown, and current fungicides start to break down to variants of the blast pathogen.

Fertilizer prices are continuing to increase to near record levels and growers are looking for ways to skip fertilizer applications on the depleted silt loam soils common in much of the Arkansas rice-growing region. Often, they decide to skip phosphorus (P) and potassium (K) applications while keeping nitrogen applications at recommended or even excessive levels. This practice has resulted in an increase in stem rot incidence and severity over the past 15 to 20 years, and the disease is now rivaling sheath blight in many fields with regard to damage. Bacterial panicle blight continues to be an annual problem on 'Bengal' rice, but the advent of the new cultivar 'Jupiter', a partially resistant line, should help control this difficult disease for the time being. This is a good example of the power of using resistant cultivars in disease management. Other diseases, like the smuts, narrow brown leaf spot, black sheath rot, straighthead, etc., damage a certain percentage of rice acreage every year but vary with conditions. Nevertheless, management of the various diseases of rice requires an integrated and sustained research program, with the basis being at least some level of resistance in our high-yielding cultivars. Without a base level of resistance, many rice cultivars cannot be grown in our environment, regardless of yield potential, as we discovered years ago in the attempt to grow California medium-grain cultivars in Arkansas. This disastrous experiment by some growers illustrated the speed and intensity of rice blast disease when attacking a defenseless cultivar under our conditions, and entire fields were plowed under despite the use of deep flood and fungicides.

Evaluating cultivars and breeding lines under field conditions is a last step prior to their release to growers, and follows earlier evaluations by Dr. Lee in the disease-resistance program at the Rice Research and Extension Center near Stuttgart. The objectives of this project were to evaluate breeding lines and varieties in the URRN for reactions to specific diseases in inoculated nurseries, including bacterial panicle blight and stem rot.

PROCEDURES

Seed of the URRN were planted in 7-row (7-in. spacing) by 8-ft long plots on a cooperator farm in Lonoke County, Ark., on 23 April and at the Lake Hogue on-farm test site on 10 May in Poinsett County. Both sites were managed according to current University of Arkansas Cooperative Extension Service recommendations for fertilization, irrigation, and weed control but fungicides were not used. The Lonoke site received at total of 166 lb N as urea, divided as 92 lb N preflood, 37 lb N on 21 June, and a final 37 lb N on 28 June, while the Poinsett site received a single preflood application of 137 lb N as urea on 15 June.

The Lonoke site was inoculated with the bacterial panicle blight pathogen by spraying a fresh cell-suspension on emerging panicles in each plot as heading began. Because of differences in maturity, different plots were inoculated on different days, with inoculations made to selected plots on 24 July, 27 July, and finally on 31 July. The Lonoke site was evaluated for bacterial panicle blight as each plot reached 100% headed stage, based on a visual estimation of the percent of affected panicles with a visual estimation of the percent of blanking for affected panicles divided by 100. Sheath blight occurred at this site as well, and was evaluated at grain-fill based on a visual estimation of the average percent of plant height affected by the disease. Other diseases were minor at this location and recorded in Table 1 as noted.

The Poinsett site was inoculated with the stem rot pathogen by applying 400 ml of rice hull/rough rice inoculum containing mycelium and sclerotia of the pathogen evenly over the center rows of each plot on 3 July. The disease was visually rated using a 1 to 5 (1 = no symptoms noted; 2 = sheaths infected; 3 = most tillers had the sheaths and outer surface of culm infected but not penetrated; 4 = most tillers had the culm penetrated but lumen not colonized; and 5 = most tillers had lumen colonized and many tillers were prematurely killed) rating scale on 24 August when lines were heading to near grain-fill. Other foliar diseases that developed at Site 2 were erratic and noted in Table 1 as appropriate. Stalk borers were abundant at this location and interfered with disease evaluation for some lines.

RESULTS AND DISCUSSION

Results from evaluation of the URRN at the Lonoke and Poinsett county sites are reported in Table 1. Rice cultivars or breeding lines rated with 50% or more sheath blight severity at the Lonoke site included 118 of the 200 entries, while 43 of 200 entries rated greater than 50% severity for bacterial panicle blight at this location (Table 1). The lines most susceptible to sheath blight included RU0503012, RU0303129, RU0702034, RU0701093, and RU0701124 while the most-resistant lines included RU0702152, RU0603166, and RU0603187 (Table 1). For bacterial panicle blight, the most-susceptible lines included RU0602171, RU0701105, RU0704156, RU0701102, and PI595900 while many lines did not develop severe disease (Table 1). Based on past experience, lines with low bacterial panicle blight may simply have escaped disease pressure due to the environmental conditions and timing of inoculation, rather than through resistance. Thus, these data are more valid for identifying susceptibility than resistance within a given year. Over multiple years and locations, resistance can probably be assumed if the reaction is consistent.

All but 13 of the 200 entries rated at least a 3 on the 1 to 5 severity scale for stem rot at the Poinsett County site, which is a reflection of the limited resistance available for this disease in current southern rice germplasm (Table 1). In addition, 97 lines rated 4 or above at this site (Table 1). This level of susceptibility is risky given the current status of our soils and the prevalence of stem rot in much of the rice-growing region of Arkansas. The most-susceptible and highly damaged lines included RU0503012, RU0101093, RU0604186, RU0504198, and RU0503126 although many other lines were similarly damaged (Table 1). The least-damaged included RU0702152, RU0603187, RU0704193, RU0704198, and RU0301081 although a few others had similar reactions as well (Table 1). It appeared that many of the less-damaged lines were also later in maturity, which may prove misleading as stem rot is a late-developing and progressive stem invader.

Other diseases were minimal in these plots during 2007, largely because of the intense hot, dry period from mid-July through August in the region. This weather pattern largely shut down the smuts, blast, and other foliar diseases and contributed to erratic results for bacterial panicle blight.

SIGNIFICANCE OF FINDINGS

These data represent novel and comparative disease reactions for many breeding lines nearing potential release and thus should help prevent the release of extremely susceptible cultivars to growers and help breeders identify potential sources of resistance to use in the future. Data should be viewed within the context of the number of sites, observations, and years, and may be more helpful in identifying susceptibility rather than resistance.

ACKNOWLEDGMENTS

Funding for this research was provided by rice grower check-off funds through the Arkansas Rice Research and Promotion Board and the Division of Agriculture, University of Arkansas. We gratefully acknowledge Mr. Robert Moery of Lonoke County for his help and the use of his land and the support of the Division of Agriculture, University of Arkansas.

Table 1. Reaction of URRN rice cultivars and breeding lines to diseases at two off-station sites in Arkansas during 2007.

	Lonoke County site			Poinsett County site			
Cultivar/line	Bacterial panicle blight	Sheath blight severity	False smut	Stem rot severity	Stalk borer damage	Bacterial panicle blight	Blast
	(% sterility)[z]	(% of plant height)[z]	(% panicles affected)[z]	(1-5 scale)[z]	(% of tillers)[z]	(% sterility)[z]	(0-9 rating)[z]
RU0301081	6	50		2.0			
RU0602085	15	56		4.0	30		
RU0503092	15	56		4.0	1		
RU0501096	2	38		3.0			
RU0602109	72	65	1	3.5	15		
RU0503006	12	53		4.5	15		
RU0401087	1	70		4.0			
RU0602103	12	63		3.0	30		
RU0503009	20	72		3.5	20		
RU0601010	1	50		2.5	15		
RU0502022	0	63	1	4.0	10		
RU0503012	1	78		4.5	10		
RU0601013	48	62		4.0			
RU0504083	64	63		3.5	10		
RU0604035	9	67		4.0	5		
RU0604122	9	74		3.5	15		
RU0101093	0			4.5			
RU0202008	42	74		3.0	10		
RU9903092	1	38		3.0	1		
RU0001124	12	56		2.5	1		
RU0401084	12	50		4.0			
RU0502094	4	68		3.5	1		
RU0503095	1	42		3.0	15		
RU0401136	72	59		3.5			
RU0402125	5	53		4.0			
RU0103184	72	47		4.0	15		
RU0601027	1	68		2.5			
RU0402028	35	67		4.0			

continued

Table 1. Continued.

Cultivar/line	Lonoke County site: Bacterial panicle blight	Lonoke County site: Sheath blight severity	Lonoke County site: False smut	Poinsett County site: Stem rot severity	Poinsett County site: Stalk borer damage	Poinsett County site: Bacterial panicle blight	Poinsett County site: Blast
	(% sterility)z	(% of plant height)z	(% panicles affected)z	(1-5 scale)z	(% of tillers)z	(% sterility)z	(0-9 rating)z
RU0003178	30	55		3.0			
RU0601030	30	50		3.5			
RU0702031	24	60		3.5	10		
RU0303129	45	78		4.0	20		
RU0404191	9	50		4.0	20		
RU0702034	1	75		4.0	5		
RU0604114	3	50		3.0	10		
RU0604156	32	67		4.5	1		
RU0202183	10	53		3.0			
PI 561735	63	50		3.5			
RU9203126	8	47		3.0	10		
RU0103123	48	65		2.5			
RU0301041	0	67		3.0			
RU0602189	8	56		3.5			
RU0403166	40	59		4.5			
RU0601044	8	53		4.0			
RU0302082	16	63		3.5	5		
RU0703046	35	74		4.0	5		
RU0401145	42	72		3.0	5		
RU0602174	24	68		3.0	25		
RU0703049	1	60		3.5			
RU0301050	1	59		3.5			
RU0602183	42	61		4.0	20		
RU0103104	2	45		4.0	30		
RU0504156	42	53		4.0			
RU0504196	54	53		3.5			
RU0504193	45	55		3.5			
RU9603178	9	42		4.0			

continued

Table 1. Continued.

	Lonoke County site			Poinsett County site			
Cultivar/line	Bacterial panicle blight	Sheath blight severity	False smut	Stem rot severity	Stalk borer damage	Bacterial panicle blight	Blast
	(% sterility)[z]	(% of plant height)[z]	(% panicles affected)[z]	(1-5 scale)[z]	(% of tillers)[z]	(% sterility)[z]	(0-9 rating)[z]
RU9404036	20	53		3.0	40		
RU0002174	14	44		3.5	5		
PI 606331	5	61		4.0	15		
CL 171 AR	6	60		3.5			
RU0601061	0	62		3.5			
RU0602168	27	50		4.0			
RU0703063	28	44		4.0			
RU0401182	56	55	1	3.5			
RU0602171	90	63		4.5			
RU0703066	1	50		4.0			
RU0401067	18	53		4.0			
RU0702068	72	44		4.0		5	
RU0703069	64	63		4.5			
RU0701070	12	57		3.0			
RU0702071	70	47		4.0		5	
RU0703072	1	45		3.5			
RU0604186	72	67		4.5			
RU0504198	32	56		4.5	5		
RU0603075	40	43		4.0			
RU0501102	1	59		2.5			
RU0704077	12	41		4.0			
Francis	48	50		3.0			
RU0001188	4	57		2.5			
WLLS	1	40		4.0			
RU0501081	18	59		3.0			
RU0702082	36	47		3.0			
RU0704083	2	71		3.5			
RU0501084	32	55		4.5			

continued

Table 1. Continued.

Cultivar/line	Lonoke County site: Bacterial panicle blight	Lonoke County site: Sheath blight severity	Lonoke County site: False smut	Poinsett County site: Stem rot severity	Poinsett County site: Stalk borer damage	Poinsett County site: Bacterial panicle blight	Poinsett County site: Blast
	(% sterility)z	(% of plant height)z	(% panicles affected)z	(1-5 scale)z	(% of tillers)z	(% sterility)z	(0-9 rating)z
RU0702085	9	63		3.0			
RU0703086	1	70		4.0	35		
RU0701087	48	40		3.0			
RU0702088	42	44		2.5			
RU0703089	0			4.5			
RU0601090	12	57		3.0			
RU0702091	40	53		3.0			
RU0703092	8	70		4.0	15		
RU0701093	14	75		3.0			
RU0702094	35	47		4.0			
RU0603095	1	65		3.0			5
RU0701096	45	38		3.5			
RU0702097	36	55		3.5			
RU0703098	40	44		4.0			
RU0501099	42	35		2.5			
RU0704100	8	60		4.5	15		
RU0703101	20	70		3.0			
RU0701102	81	44		4.0			
RU0702103	63	44		4.5			
RU0503178	9	44		4.0			
RU0701105	90	48		3.5			
RU0702106	32	44		4.0			
RU0703107	64	63		3.0			
RU0601108	35	57		4.0			
RU0702109	16	63		4.5			
RU0703110	32	47		4.5			
RU0701111	32	53		4.0			
RU0702112	28	60		4.0			

continued

Table 1. Continued.

Cultivar/line	Lonoke County site			Poinsett County site			
	Bacterial panicle blight	Sheath blight severity	False smut	Stem rot severity	Stalk borer damage	Bacterial panicle blight	Blast
	(% sterility)z	(% of plant height)z	(% panicles affected)z	(1-5 scale)z	(% of tillers)z	(% sterility)z	(0-9 rating)z
RU0703113	40	63		3.5			
RU0704114	30	47		4.0			
RU0702115	32	67		4.0			
RU0703116	48	53		3.5			
PI 606331	7	70		4.0			
RU0003009	1	40		3.5	20		trace leaf blast
Sierra	8	44		4.0	40		
PI595900	80	71		3.0			
RU0601121	4	44		3.5			
RU0704122	1	42		3.5			
RU0703123	54	40		3.8			
RU0701124	3	75		4.5			
RU0702125	30	42		4.5			
RU0503126	63	61		4.5			
RU0701127	8	52		3.5			
RU0702125	2	56		4.5			
RU0703129	1	45		4.0			
RU0601130	49	47		4.0			
RU0702131	20	56		4.5	15		
RU0703132	1	45		4.5			
RU0501133	1	48		3.5			
RU0702134	63	68		4.0			
RU0703135	56	40		4.5	10		
RU0501136	56	56		3.5			
RU0702137	63	61	2	4.5			
RU0703138	1	50		3.0			
RU0501139	21	32	1	3.5			
RU0502177	0	67		4.5			

continued

Table 1. Continued.

Cultivar/line	Lonoke County site: Bacterial panicle blight	Lonoke County site: Sheath blight severity	Lonoke County site: False smut	Poinsett County site: Stem rot severity	Poinsett County site: Stalk borer damage	Poinsett County site: Bacterial panicle blight	Poinsett County site: Blast
	(% sterility)[z]	(% of plant height)[z]	(% panicles affected)[z]	(1-5 scale)[z]	(% of tillers)[z]	(% sterility)[z]	(0-9 rating)[z]
RU0703141	42	40		3.5			
RU0701142	9	46		3.0			
RU0702143	5	44		4.0			
RU0703144	5	44		3.5			
RU0501145	1	42		3.5			
RU0602146	0	50		3.5			
RU0703147	35	60		4.5	35		
RU0701148	72	45		3.5			
RU0702149	48	37		3.5			
RU0503150	12	48		4.0			
RU0501151	24	32		3.0			
RU0702152	63	24		2.5			
RU0703153	56	40		4.5			
RU0704154	72	56		4.0			
RU0602155	48	39	1	4.0			
RU0704156	81	50		4.0			
RU0704157	64	44		3.5			
PI 593241	0	52		3.5			
RU0103123	12	47		3.5			
RU9901081	45	55		3.0			
RU0701161	63	42		3.0			
RU0702162	63	32		4.0			
RU0503163	35	68		4.0			
RU0401164	45	33		4.0			
RU0702165	20	45		4.0			
RU0603166	18	24		3.0			
RU0701167	63	50		3.0			
RU0702168	76	58		4.0			

continued

Table 1. Continued.

	Lonoke County site			Poinsett County site			
Cultivar/line	Bacterial panicle blight	Sheath blight severity	False smut	Stem rot severity	Stalk borer damage	Bacterial panicle blight	Blast
	(% sterility)[z]	(% of plant height)[z]	(% panicles affected)[z]	(1-5 scale)[z]	(% of tillers)[z]	(% sterility)[z]	(0-9 rating)[z]
RU0503169	18	50		3.5			
RU0601170	56	55		3.0			
RU0702171	54	56		4.0			
RU0703172	1	46		3.0			
RU0501173	18	50		4.0			
RU0702174	15	56		4.5	10		
RU0703175	3	35		3.5			
RU0701176	42	33	1	3.0			
RU0702177	64	42		4.0			
RU0703178	0			3.5			
RU0701179	30	45		3.5			
RU0702180	48	44		4.0	10		
RU0703181	48	47		4.0			
RU0601182	35	35		3.5			
RU0702183	67	60		4.0			
RU0703184	56	35		4.0			
RU0601185	20	33		3.5			
RU0704186	56	31		4.5			
RU0603187	48	23		2.5			
RU0601188	4	36		3.3			
RU0702189	28	50		4.0			
RU0703190	27	42		4.0			
RU0704191	72	50		4.5			
RU0702192	27	63		4.0			
RU0704193	12	43		2.5			
RU0704194	32	50		3.5			
RU0702195	56	39		3.5			
RU0704196	63	60		4.0			

continued

Table 1. Continued.

	Lonoke County site			Poinsett County site			
Cultivar/line	Bacterial panicle blight	Sheath blight severity	False smut	Stem rot severity	Stalk borer damage	Bacterial panicle blight	Blast
	(% sterility)[z]	(% of plant height)[z]	(% panicles affected)[z]	(1-5 scale)[z]	(% of tillers)[z]	(% sterility)[z]	(0-9 rating)[z]
RU0704197	49	45		4.5			
RU0704198	2	38		2.5			
PI 561734	67	53		3.5			
RICE TEC	0	45		3.0			

[z] Bacterial panicle blight percent sterility = estimated percent of panicles with bacterial panicle blight symptoms x estimated percent sterility on symptomatic panicles/100; sheath blight severity percent of plant height = estimated percent of plant height (based on center four rows) with sheath blight symptoms; false smut percent panicles affected = percent of panicles within the center four rows with at least one false smut gall visible; stem rot severity was rated on a 1 to 5 scale where 1 = no symptoms evident on sheaths; 2 = symptoms in sheaths only; 3 = inspected tillers typically had all sheaths penetrated and the outer surface of the culm showing some infection but no penetration of the lumen; 4 = inspected tillers typically had the sheaths and culm penetrated but the lumen was not yet colonized by the fungus; 5 = inspected tillers were typically penetrated and the lumen colonized, usually prematurely killed; stalk borer damage percent of tillers = estimated percentage of tillers within the plot that showed stalk borer entry; blast 0 to 9 rating = leaf lesions were rated on a 0 to 9 scale where 0 = no symptoms and 9 = large coalescing lesions and death of leaves on most plants, neck rot was rated where 0 = no symptoms and 9 = 90 to 100 percent of panicles killed and intermediate numbers represented 10% increments of panicle death and sterility.

Influence Of Flood Depth On Rice Water Weevil Infestation And Damage

J.L. Bernhardt

ABSTRACT

Dry seeding of rice followed by a delay in the application of a permanent flood is a common practice for Arkansas rice farmers. Once rice is flooded, rice water weevils are attracted to the rice, lay eggs, and larvae feed on plant roots. This study was initiated for additional information on the natural pattern of infestation by rice water weevils and any yield differences when permanent flood is maintained at two depths and at two depths for variable amounts of time. Rice with a season-long, 2-inch flood had the lowest infestation of rice water weevil larvae and plots with a season-long, 4-inch flood had the highest infestation. In the plots with variable depths and length of time at a depth, there was a trend of progressively lower densities of weevils and control of 16, 23, and 33% where the 2-inch flood was maintained for 2, 3, or 4 weeks, respectively. The use of flood depth as a cultural practice to lower the number of rice water weevil larvae can be successfully used by rice farmers. Shallow flood depths for up to 4 weeks after did not appear to be detrimental to the rough rice yield and did not increase incidence of rice blast disease.

INTRODUCTION

An abundant supply of good-quality irrigation water is needed for optimal rice production. Irrigation water can be used to supplement rainfall in the early growth stages of drill-seeded rice, but ample quantities are needed when the permanent flood is applied. A flood depth of 4 inches is generally recommended. Due to many factors, the water depth between levees can vary from shallow (1- to 2-inches) to deep (4- to 8-inches) in any rice field.

Whatever the water depth, the onset of permanent flood attracts rice water weevil adults, *Lissorhoptrus oryzophilus* Kuschel, a pest common to Arkansas rice fields. Characteristic narrow, longitudinal scars that parallel the mid-vein of rice leaves are evidence of feeding by adults. Once plants are submerged, females begin to lay eggs in the submerged portions of leaf sheaths. The larvae feed on rice roots and when the damage is severe, rice yields will be reduced. In order to prevent damaging levels of larvae, insecticides are available that control adults but must be applied within 10 days after permanent flood to control adults before eggs are deposited.

Production costs are on the rise and rice growers look for options to reduce costs. To avoid using an insecticide for rice water weevil control, growers may try cultural practices to reduce the infestation of insect pests below economic thresholds. A cultural practice that could be used, but not thought of as a cultural practice that may reduce the number of rice water weevils, is depth of permanent flood. The density of rice water weevil larvae can vary greatly across any rice field, but significant differences have been noticed at different water depths. For example, in 2004 a large field in Lawrence Co. was sampled for weevil larvae 3 weeks after onset of flood. Between the high- and low-side of several paddies there was a 2- to 3-inch difference in water depth, and there was an average 88% difference in larval densities (Bernhardt, unpublished data). This suggests that water depth may have an impact on rice water weevil infestation, ovipositional behavior, or larval survival. The study was initiated for additional information on the natural pattern of infestation by rice water weevils and any yield differences when a permanent flood is maintained at two depths and at two depths for variable amounts of time.

PROCEDURES

Rice plots were arranged in a randomized block design with four replications. Plots had 9 rows with a 7-inch spacing, were 25-ft long, and had a seeding rate of 90 lb/acre. Each plot of rice was surrounded by levees. Flood depth treatments were: 4-inch depth maintained all season (deep water check); 2-inch depth maintained all season (shallow water check); initial flood of 2-inch depth maintained for 1, 2, 3, or 4 weeks, then a 4-inch depth maintained for the remainder of the season. Plots were not treated for any insect and were infested by a natural population of rice water weevils. Three soil/plant core samples, 4-inch diameter by 4-inch depth, were taken from each plot at 3 and 4 weeks after permanent flood and evaluated for rice water weevil larvae. In the laboratory, each soil core was washed with pressurized water to loosen soil and remove larvae from the roots into a 40-mesh sieve. The sieve was immersed in a saturated salt solution to float the larvae. Larvae were removed, sized, and counted. A central portion of each plot measuring 4 rows by 20 ft was cut with a small plot binder and threshed in a Vogel thresher. Grain moisture was corrected to 12% prior to analyses with PROC ANOVA (Statistical Analysis System). Herbicides were applied according to weed species present. Fertilizer was applied in recommended amounts for 'Wells' rice in a 2-way split.

RESULTS AND DISCUSSION

The natural population of rice water weevils in the plots was low and possibly had been a result of over 80% of the plots having an initial shallow flood. Equally interesting was that larval densities were higher in the 4-week samples than in the 3-week-after-flood samples. This is the opposite of the normal infestation pattern and may have been a result of more adults arriving after the plots were changed from a 2-inch to a 4-inch flood (Table 1). Overall weevil infestation was low and no significant differences were found between treatments. However, plots with a season-long, 2-inch flood had the lowest infestation of rice water weevil larvae and plots with a season-long, 4-inch flood had the highest infestation. In the plots with variable depths and length of time at a depth, there was a trend of progressively lower densities where the 2-inch flood was maintained for more weeks. The shallow flood depth and the duration of shallow flood depth tended to have an impact on rice water weevils and resulted in lower numbers of larvae. Equally important, no significant differences were found between grain yields for any treatment.

Any conclusions would be considered as preliminary with only one year of data. However, from a related study in the greenhouse, Stout et al. (2002) reported that when given choices female rice water weevils chose to place decidedly more eggs in plants flooded to a 4-inch depth than in plants in a 0.5-inch flood. They also proposed that weevils could be manipulated by changing water-management practices. The data from this study also support water management as a cultural means of rice water weevil management.

The influence of rice blast disease is of major importance when contemplating shallow floodwater. Rice blast is among the most serious constraints to rice grain yields worldwide (Lai et al., 1999). Also known for some time is that plants grown in dry soil are more susceptible than those plants grown in flooded soil (Kahn and Libby, 1958). Field tolerance of rice varieties to rice blast was studied by Lee and McMinn (1996) with inoculated plants grown on an incline to give flood depths from 4 inches to somewhat upland conditions. Blast symptoms were more severe under upland conditions and declined as continuous flood depth increased. This current study tried to recognize the importance of avoiding rice blast disease by having treatments with a 2-inch flood only during the first 4 weeks of the permanent flood, which coincides with the known infestation period of adult rice water weevils. During the study, minimal leaf blast was observed in all plots regardless of flood depth and no neck or panicle blast was observed in any treatment.

SIGNIFICANCE OF FINDINGS

This preliminary study demonstrated that flood depth as a cultural practice to lower the number of rice water weevil larvae was successful. A shallow flood for up to 4 weeks after the onset of permanent flood did not appear to be detrimental to the rough rice yield and did not increase incidence of rice blast disease.

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Table 1. Densities of rice water weevils (RWW) in plots of rice with combinations of depth and length of time at a depth, and average plot yields for tests at Stuttgart, Ark., 2007.

Flood depth and length	Avg. RWW per core		% Control		
of time for depth	3 WAF[z]	4 WAF	3 WAF	4 WAF	Yield[y]
					(bu/acre)
2-inch full season	10.7	11.5	33	42	202.4
2-inch 4 weeks then 4-inch	10.8	11.3	33	43	212.9
2-inch 3 weeks then 4-inch	12.3	13.8	23	30	208.3
2-inch 2 weeks then 4-inch	13.5	12.8	16	35	202.1
2-inch 1 week then 4-inch	15.9	16.6	0.5	16	203.4
4-inch full season	16.0	19.8	-	-	203.1
	NS[x]	NS			NS

[z] WAF = weeks after permanent flood.
[y] Grain yield in bushels per acre corrected to 12% moisture.
[x] NS = not significant.

Environmental Implications Of Pesticides In Rice Production

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

ABSTRACT

For the past eight years we have collected and analyzed water in Arkansas from four sites each on the L'Anguille and St. Francis rivers from near Jonesboro in the north to near Marianna in the south. In 2002 we included four sites on La Grue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt. In 2003 we included four sites on the Cache River from near the level of Jonesboro in the north to just below I-40 in the south. Since 2002, 55 to 96% of the detections over 2 ppb have been for quinclorac (Facet), and clomazone (Command). Each year, most (60 to 86%) of the detections that were over 2 ppb were less than 5 ppb, and 85 to 99% of the detections over 2 ppb were under 10 ppb. The highest concentration in 2007 was 27.8 ppb for quinclorac. The Cache and the L'Anguille rivers consistently have the most detections over 2 ppb. There is no trend for the overall frequency of detections over 2 ppb (9.2 % in 2000, 12.0% in 2001, 5.2% in 2002, 6.2% in 2003, 5.4% in 2004, 3.7% in 2005, 3.3% in 2006, and 6.3% in 2007).

INTRODUCTION

The goal of this project is to determine if any environmental problems are developing in Arkansas surface waters as a result of pesticides used in rice production. Monitoring for pesticides in water may allow us to detect a potential problem and address it before it becomes a major problem.

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, we sampled the L'Anguille and St. Francis rivers by collecting water from four different sites on each river from near Jonesboro in the north to near Marianna in the south (Fig. 1). In 2002, we added four sites on La Grue Bayou from just below Peckerwood Lake north of Stuttgart to near the mouth southeast of DeWitt, and in 2003 we added four sites on the Cache River from the level of Jonesboro in the north to below Interstate 40 in the south.

PROCEDURES

Sampling Sites

Surface water samples were collected at eight locations during 2000 and 2001, twelve locations in 2002, and sixteen locations in 2003 through 2007. Water samples were taken from four sites on the L'Anguille River where it crosses Highways US 79 near Marianna, US 64 near Wynne, State 14 near Harrisburg, and near Claypool reservoir north of Harrisburg (Fig. 1). Water samples were taken from four sites on the St. Francis River where it crosses US 79 near Marianna, US 64 near Parkin, State 75 near Marked Tree, and State 18 east of Jonesboro. In 2002, an additional four sites were sampled on La Grue Bayou at a county road approximately 0.5 km below Peckerwood Lake, the second bridge on Highway 146 west of the Highway 33 junction, near the town of La Grue at Highway 33 before the junction with Highway 153, and where the La Grue crosses Highway 1 outside of DeWitt. In 2003 we added four sites on the Cache River where it crosses State Highway 91 west of Jonesboro, a dirt road off County 37 at Algoa, State Highway 260 near Patterson, and US 70 south of I-40.

Sampling Procedure

Water samples were collected and extracted onto C18 Speedisks using a mobile field extractor, which allows us to extract the samples immediately after collecting them while we are driving to the next site. A 500 mL aliquot of each sample was extracted onto C18 disks in the field with the mobile extractor using conventional C18 disk technology. The disks were stored on ice packs and eluted on return to the lab. Samples were then analyzed by gas chromatography mass spectrometry (GCMS) and high performance liquid chromatography (HPLC).

For quality control, at one site on each river four replicate subsamples were collected. Two subsamples were fortified with known amounts of the compounds and two were left unfortified. Analysis of these samples allowed us to verify recovery and reproducibility. Sampling was performed at two-week intervals during the rice production season from May through August 2003. In 2004 we began collection in mid-April and stopped in mid-August.

The compounds chosen for analysis changed as their use in the field changed. Molinate used to be the most frequently detected pesticide and at the highest concentrations, but since it was dropped from use and was no longer being detected, it was dropped from the list. Each year analysis is for approximately 10 compounds that we could reasonably expect to find. In 2007 analysis was for 10 pesticides and three pesticide degradation products. The compounds were Bolero (thiobencarb), Command (clomazone), 2,4-D, Facet (quinclorac), Garlon (triclopyr), Pursuit (imazethapyr), Quadris (azoxystrobin), Raptor (imazamox), Stam (propanil), Tilt (propiconazole) plus triclopyridinol (degradation product of triclopyr), and cyhalofop-acid and diacid (both degradation products of cyhalofop-butyl, trade name Clincher).

RESULTS AND DISCUSSION

It is not surprising to find low levels of pesticides in runoff water adjacent to fields when and where the compounds are used, especially with the sensitive analytical equipment that is now available. Trying to find meaningful trends 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 water samples from small rivers surrounded by rice fields, we have chosen a concentration of 2 ppb as the cutoff level for making comparisons.

Three different pesticides were detected in samples collected from each of the rivers on the first sampling trip on 24 and 25 April (Table 1). Only one of the four samples from La Grue Bayou contained a compound on this trip, and it contained only one compound, azoxystrobin.

Clomazone and quinclorac were the two most frequently detected compounds in 2007 (Table 1). A total of 73 samples provided 102 detections of compounds at concentrations greater than 2 ppb. Quinclorac was detected in 42% of these 73 samples, and clomazone was detected in 36%. Both compounds were also detected most frequently when they were being used. Most of the detections of clomazone (81%) occurred on three sampling trips covering one month from 8 May to 7 June. There were only two detections of clomazone over 2 ppb after 7 June. Most of the detections of quinclorac (90%) occurred during a six-week period covering four sampling trips from 6 June to 18 July.

The 102 detections over 2 ppb in 2007 are the largest number of detections over the past 6 years (Table 2). Part of this increase is because analysis was being conducted for 13 compounds in 2007. In 2003, analysis was for 10 compounds, so although the 79 detections in 2003 were lower than in 2007, the percent of detections was almost the same (6.2% in 2003 verses 6.3% in 2007) where 100% is equivalent to finding every compound in every sample. In 2000, the percent of detections was 12% (Mattice et al., 2000) and in 2001 it was 9.2% (Mattice et al., 2001). The percent of detections between 5.1 to 6.3% in the years 2002, 2003, 2004, and 2007 may reflect the norm with the percent of detections in 2005 and 2006 being unusually low and the percent of detections in 2000 and 2001 being unusually high.

The distribution of concentrations has been similar in 5 of the last 6 years (Table 3). The percent of detections between 2 to 5 ppb in those 5 years varied from 75 to

86%. In 2005 it was 60%. In 2005 there was a corresponding increase in the percent of detections in the 5 to 10 ppb range and also the 10 to 40 ppb range. In the 10 to 40 ppb range, 8 of the 10 values were between 10 to 20 ppb (Mattice et al., 2005). The year 2005 appears to be aberrant both in terms of distribution of concentrations as shown in Table 3 and also the frequency of detections as shown in Table 2.

The L'Anguille and the Cache rivers routinely produce the largest number of detections (Table 4). The L'Anguille produces an average of 25.5 detections per year and the Cache produces 29.2 detections per year. Combined for the 6 year period they have accounted for 74% of the detections, although they have 50% of the sampling sites.

The upper portions of the L'Anguille and Cache are completely surrounded by rice fields, so virtually all the water is coming from areas under rice agriculture. Farther downstream there could be a dilution effect if larger percentages of water flowing into these two rivers come from areas not under rice production. From 2003 to 2007 there were 114 detections from the upper most sampling sites on the L'Anguille (site A) and the Cache (site Q) compared to only 44 at the lowest sites D and T consistent with a dilution effect (Table 4).

The reverse trend is observed for the St. Francis River and La Grue Bayou. The St. Francis River begins in southeast Missouri where rice production is not as prevalent as farther downstream in Arkansas, so the upstream sampling site E might have few detections and the downstream sampling site H, where there is more rice production, would have more detections (Table 4; Fig. 1). The first sampling site K on La Grue Bayou is approximately 0.5 km downstream from Peckerwood Lake. If the lake is a reservoir where pesticide degradation can occur, then the upstream site, which is essentially lake water, would be expected to provide a low detection frequency of pesticides. Farther downstream where there is more inflow from rice-producing areas we would expect to have increasing detections. The uppermost sites on the St. Francis (E) and La Grue (K) produced 12 detections over six years, and the two most downstream sites H (St. Francis) and N (La Grue) produced 32 detections, indicating this is the case.

Each river has 25% of the sampling sites, but from 2003 to 2005 most of the detections came from the Cache River (46% in 2003, 43% in 2004, and 40% in 2005; Table 4). In 2006, the L'Anguille and Cache rivers produced almost the same frequency of detections with 43% from the L'Anguille and 41% from the Cache, a difference of 1 detection. In 2007 the L'Anguille had 38 detections (37%) and the Cache had 34 detections (33%).

Over the past 6 years 63 to 86% of the samples that contained a compound at a concentration over 2 ppb contained only one compound (Table 5). In 2007, 37% of the samples containing a compound contained two or more. This is similar to 2002 when 32% contained two or more compounds and 2005 when 30% contained two or more. In 2007, most of the increase, 34%, was for samples that contained only two compounds. Twelve of the samples that had two compounds had one compound with a concentration between 2.0 and 2.5 ppb (Table 1). A decrease in concentration of 0.5 ppb would have caused those samples to be listed in the one-compound-per-sample category. In that case, 79% of the samples containing a compound at a concentration over 2 ppb would have had only one compound, and 18% would have had two compounds. This would be similar to years 2003 to 2006. This illustrates that care needs to be taken in attaching significance to what appear to be large changes in percentages, because small changes in concentrations can have a large affect on how samples are distributed in categories. For the past 4 years there have been no samples with more than three compounds with concentrations over 2 ppb.

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. Not surprisingly, clomazone and quinclorac, which were detected most often, were also the compounds that were detected most frequently on consecutive sampling dates (Table 6). Also, this occurred on the L'Anguille and the Cache rivers, which had the highest numbers of detections (Table 4). There is a period from late May through early June when we can expect to find both clomazone and quinclorac at concentrations over 2 ppb on the L'Anguille and the Cache rivers, especially at the most upstream sites A and Q (Table 1; Fig. 1).

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

Comparing our results to EPA ecotoxicity data in the Pesticide Action Network database (PAN, 2007) indicates that on two occasions in the past 6 years concentrations of propanil (9.5 ppb in 2004) or 2,4-D (25.5 ppb in 2007) may have been high enough to cause an effect on some form of development of green algae or diatoms. These two compounds are rarely found, and when they are found they are at lower concentrations. They have been found infrequently in water because of their short environmental half-lives. The half-life of propanil is only 17 to 154 hr in environmental water (Anonymous, 2007a), and the half life of 2,4-D in water ranges widely from 10 to >50 days depending on environmental conditions. The half life of 2,4-D in sediment and mud is less than 1 day (Anonymous, 2007b).

The two compounds that are most frequently found, clomazone and quinclorac, require much higher concentrations to have a detrimental affect on a variety of test species listed in the PAN database, so unless there is a strong synergistic effect between these two compounds, they are not likely to be causing an environmental problem. We were not able to find any study in the literature investigating a possible synergism between these two compounds.

SIGNIFICANCE OF FINDINGS

Most of the detections have been low-level and sporadic. Exceptions for being sporadic would be for clomazone (Command) in the first part of the sampling season and for quinclorac (Facet) in the middle part of the season (Tables 1 and 6). These compounds were detected frequently but usually at low concentrations. Comparing our results to ecotoxicity data indicates no developing environmental problem unless there is a strong synergism between clomazone and quinclorac, the two most commonly found compounds. Individually they have low toxicity, and there are no data available regarding a synergistic effect.

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Table 1. Results for the year 2007 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]	azo	clom	con	cy	24D	ima	pro	qui	tri
			(ppb corrected for recovery)								
4/24	LA	A		14.0							
4/24	LA	B	5.3	3.2							
4/24	LA	C		2.3							
4/24	SF	F	5.0								
4/24	SF	G			2.4						
4/24	SF	H			4.3						
4/24	LG	N	7.7								
4/25	CA	Q		4.6							
4/25	CA	R			2.4						
4/25	CA	S			2.6						
4/24	CA	T			3.6						
5/08	LA	A	11.5	7.4							
5/08	LA	B	4.1	7.4							
5/08	LA	C		6.5							
5/08	SF	F	2.1								
5/08	SF	G		2.7	2.7						
5/09	CA	Q		10.7						2.0	
5/09	CA	R		5.9							
5/09	CA	S		3.9							
5/22	LA	A		3.6						5.3	
5/22	LA	B	2.8	3.3							
5/22	LA	C		3.2							
5/22	LA	D		2.1	19.4						
5/22	SF	E	7.4								
5/22	SF	H			5.6						
5/22	LG	K						2.7			
5/22	LG	L						2.6			
5/22	LG	N	8.3								
5/23	CA	Q		2.0					3.5		
5/23	CA	R		4.2							
5/23	CA	S	2.4	4.5							
5/22	CA	T	4.3	6.2				3.4			
6/06	LA	A		2.7						4.1	
6/06	SF	H								2.9	
6/06	LG	M		2.1						27.8	
6/07	CA	Q		6.9						5.1	
6/07	CA	R		2.9							
6/07	CA	S		2.0							
6/19	LA	A		5.0				7.3		4.8	
6/19	LA	B								2.2	
6/19	LA	C								4.7	2.0
6/19	SF	G								2.3	
6/19	SF	H			2.5					2.8	
6/19	LG	L								3.0	
6/19	LG	M								11.2	
6/19	LG	N						2.6		3.4	
6/20	CA	Q								8.0	

continued

Table 1. Continued.

Date	River	Site[z]	azo	clom	con	cy	24D	ima	pro	qui	tri
			Compounds and amounts detected[y]								
			--------------------------- (ppb corrected for recovery)---------------------------								
6/20	CA	R					25.5			8.1	
6/20	CA	S								6.4	
6/19	CA	T						2.9			
7/03	LAA								4.3		
7/03	LAB			3.6					2.1		
7/03	LAC								2.7		
7/03	LAD					8.4			2.4		
7/03	SF	F			3.8						
7/03	SF	G			2.5					2.0	
7/03	SF	H	2.3								
7/03	LG	L				4.9				4.0	
7/04	CA	Q									2.0
7/04	CA	S								2.9	
7/03	CA	T		2.0						3.1	
7/17	LAA								2.4		
7/17	LAC								2.5		
7/17	LG	K						2.1			
7/18	CA	Q	3.3							3.3	
7/18	CA	R								3.9	
7/18	CA	S								3.5	
8/01	LAA	8.9		2.5							
8/01	LAB	2.5									
8/01	LAC	2.4							2.0		
8/01	LAD					3.0					
8/01	LG	L						3.1			
8/01	CA	T						2.5			
TOTAL			16	26	13	1	3	9	1	31	2
% in 73 samples			22	36	18	1	4	12	1	42	3
% of 102 detections			16	25	13	1	3	9	1	30	2

[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] azo = azoxystrobin; clom = clomazone; con = propiconazole; cy = cyhalofop-butyl; 24D = 24-D; ima = imazethapyr; pro = propanil; qui = quinclorac; tri = triclopyr.

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

Year	2002	2003	2004	2005	2006	2007
Number of rivers	3	4	4	4	4	4
Possible detections	958	1280	1440	1792	1792	1616
Detections	49	79	77	67	59	102
Percent	5.1	6.2	5.4	3.7	3.3	6.3

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

Concentration	Number of detections[z]					
range	2002	2003	2004	2005	2006	2007
(ppb)						
2-5	37 (76%)	68 (86%)	63 (82%)	40 (60%)	48 (81%)	76 (75%)
5-10	9 (18%)	10 (13%)	13 (17%)	17 (25%)	7 (12%)	19 (19%)
10-40	3 (6%)	1 (1%)	1 (1%)	10 (15%)	4 (7%)	7 (7%)

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

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

	Detection frequency					
River/site	2002	2003	2004	2005	2006	2007
L'Anguille						
A[z]	14	8	9	4	10	14
B	9	6	5	2	4	10
C	7	3	9	4	10	9
D	2	4	2	2	1	5
Total	32	21	25	12	25	38
St. Francis						
E	0	0	0	0	2	1
F	0	2	3	0	1	3
G	2	3	3	2	0	6
H	5	4	3	1	2	6
Total	7	9	9	3	5	16
LaGrue						
K	0	5	2	0	0	2
L	3	2	3	1	1	5
M	3	4	1	2	2	3
N	4	2	4	0	2	4
Total	10	13	10	3	5	14
Cache						
Q	not	16	11	9	8	11
R	sampled	8	7	4	6	7
S		6	7	3	7	8
T		6	8	3	3	8
Total		36	33	19	24	34

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

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

No. of compounds	Number of samples[z]					
per sample	2002	2003	2004	2005	2006	2007
1	23 (68%)	49 (80%)	63 (82%)	34 (69%)	44 (86%)	46 (63%)
2	9 (26%)	9 (15%)	14 (18%)	12 (24%)	6 (12%)	25 (34%)
3	1 (3%)	1 (2%)	0	3 (6%)	1 (2%)	2(3%)
4	0	1 (2%)	0	0	0	0
5	1 (3%)	1 (2%)	0	0	0	0

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

Table 6. Consecutive detections of selected pesticides by site in 2007.

Date	clomazone						quinclorac									Z[z]	P
4/24	A[y]	B	C	Q												B	G
5/08	A	B	C	Q	R	S										B	G
5/22	A	B	C	Q	R	S	A									B	G
6/06	A			Q	R	S	A				H		M	Q		B	
6/19				Q			A	B	C	G	H	L	M	Q	S		
7/03							A	B	C	G		L			S		
7/17							A		C						S		
8/01									C								

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

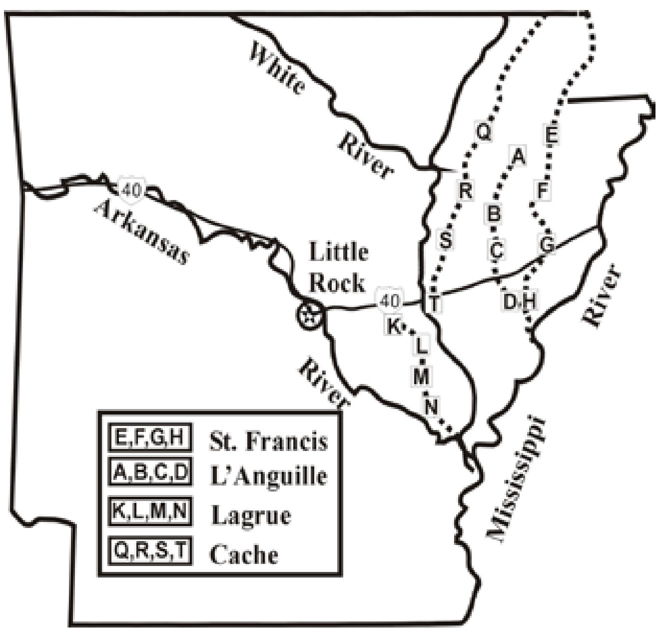

Fig. 1. Sampling sites for the 2007 water monitoring program.

PEST MANAGEMENT: WEEDS

Confirmation And Management Of Clomazone-Resistant Barnyardgrass

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

ABSTRACT

A barnyardgrass biotype from Independence County near Cord, Ark., was confirmed resistant to clomazone (Command) in 2007. The resistant biotype had a 1.8- to 2.4-fold higher tolerance to clomazone compared with a susceptible standard, and the resistant biotype was not effectively controlled with a labeled use-rate of clomazone. The resistant biotype was effectively controlled (≥85%) with labeled rates of quinclorac (Facet) and imazethapyr (Newpath) applied preemergence and thiobencarb (Bolero) applied as a delayed preemergence treatment. This is the third rice herbicide to which barnyardgrass populations in Arkansas have developed resistance.

INTRODUCTION

Barnyardgrass is the most common and troublesome weed of rice in Arkansas (Norsworthy et al., 2007). In addition to its widespread occurrence, there are biotypes of barnyardgrass that are resistant to both propanil (Stam) and quinclorac in the rice-growing region of Arkansas (Lovelace, 2003). Hence, producers readily adopted the use of clomazone for barnyardgrass in rice following its registration in rice in the late 1990s, with clomazone still being the most frequently used herbicide in rice today (Norsworthy et al., 2007). Repeated use of any herbicide increases the likelihood for evolution of resistance. Based on the occurrence of herbicide-resistant barnyardgrass biotypes, not only in Arkansas but throughout the world, it is evident that barnyardgrass has a higher propensity to develop resistance than most other weeds, likely because of extensive genetic diversity within the species.

Barnyardgrass samples harvested from production fields where herbicide failure occurs are sent to the University of Arkansas each year for evaluation of herbicide resistance. In the winter of 2006, a sample was received from Cord, Ark., for evaluation of resistance to clomazone as well as several other herbicides. Propanil, quinclorac, fenoxaprop (Ricestar HT), cyhalofop (Clincher), imazethapyr, and glyphosate (Roundup WeatherMax) controlled this biotype similar to a susceptible standard that was used for comparison. However, clomazone applied preemergence at a labeled rate (0.8 pt/acre Command on a silt loam soil) failed to adequately control the barnyardgrass sample from Cord, unlike the susceptible standard, which was adequately controlled through 21 days after treatment. Screening of both the sample from Cord and the susceptible standard was repeated and results were similar. Thus, an experiment was conducted to determine the difference in response of the Cord population and a susceptible standard of barnyardgrass to clomazone. Additionally, a greenhouse experiment was conducted to determine the effectiveness of rice herbicides applied preemergence or delayed-preemergence for controlling the resistant biotype.

PROCEDURES

Approximately 30 seeds of the resistant and susceptible biotypes were seeded in 4-inch-diameter pots containing a Taloka silt loam soil. The experimental design was completely randomized with four replications of five clomazone rates ranging from 0.075 to 1.2 lb ai/acre. The highest rate was four times the normal use rate of clomazone for a silt loam soil. A nontreated control was included for comparison, and the experiment was repeated. The spray applications were made inside a stationary chamber with a boom containing two flat fan 800067 nozzles calibrated to deliver 20 gal/acre. After spraying, pots were placed in the greenhouse with 76/68° F day/night temperatures and 16-h photoperiod and were overhead-watered once daily. Barnyardgrass control was rated on a scale of 0 to 100%, with 0 equal to no control and 100 equal to complete control at 14 and 28 days after treatment.

The effectiveness of preemergence and delayed-preemergence herbicide for controlling the clomazone-resistant biotype was also evaluated in the greenhouse. Experimental procedures were similar to those for the previous dose-response experiment. The herbicides evaluated included: imazethapyr applied preemergence at 0.031 and 0.063 lb ai/acre, quinclorac applied preemergence at 0.25 and 0.5 lb ai/acre, thiobencarb applied preemergence at 4 lb ai/acre, and pendimethalin applied delayed-preemergence at 0.76 and 1.0 lb ai/acre. The delayed-preemergence applications were made 2 days after planting. A nontreated control was included. The experiment had four replications and was conducted once. Barnyardgrass control was visually rated at 21 days after the preemergence treatments.

RESULTS AND DISCUSSION

The resistant biotype was 2.37 times more tolerant than the susceptible biotype to clomazone at 14 days after treatment, and clomazone failed to provide effective control when applied at the labeled rate of 0.3 lb/acre (Fig. 1). At 28 days after treatment, the labeled rate of clomazone provided less than 50% control of the resistant biotype, and the resistant biotype was 1.81 times more tolerant than the susceptible biotype to clomazone.

Quinclorac and imazethapyr applied preemergence provided effective control (85 to 100%) of the resistant biotype. Likewise, thiobencarb applied delayed-preemergence controlled the resistant biotype 89% through 21 days after treatment. However, pendimethalin applied preemergence was less effective, providing no more than 76% control at the highest evaluated rate.

SIGNIFICANCE OF FINDINGS

This is the first documented clomazone-resistant barnyardgrass biotype in the world. The ramifications of this biotype are tremendous considering that most of the rice acreage in Arkansas is treated with clomazone. The labeled rate of clomazone on a silt loam soil currently costs producers $9.85/acre. If resistance to clomazone becomes widespread, other more expensive herbicides such as quinclorac at $24.63/acre for 0.5 lb of product will be needed for early-season barnyardgrass control.

ACKNOWLEDGMENTS

The continued support of weed management research in rice by the Arkansas Rice Research and Promotion Board and the Division of Agriculture, University of Arkansas is gratefully appreciated.

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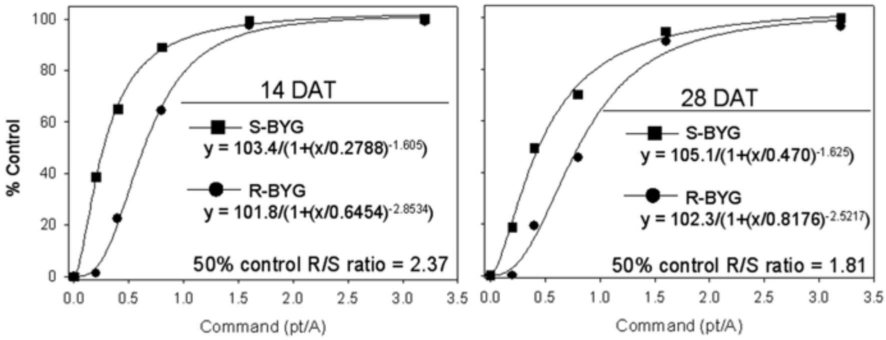

Fig. 1. Control of clomazone-susceptible (S-BYG) and -resistant barnyardgrass (R-BYG) at 14 and 28 days after treatment with a preemergence application of clomazone (Command 3 ME). These are the average results from two dose-response experiments. The soil type was a Taloka silt loam.

Newpath Use With And Without Command For Weed Control In Furrow-Irrigated Clearfield Rice

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

ABSTRACT

Research on weed management in furrow-irrigated rice is needed as water availability becomes more limited in rice-production regions of Arkansas. Research was conducted at Keiser and Pine Tree, Ark., in 2007 with the objectives being to determine (a) if the addition of Command to Newpath would improve preemergence (PRE) weed control in furrow-irrigated, Clearfield rice, and (b) if increasing the Newpath rates would improve weed control without injuring rice. Newpath was applied at 4, 5, and 6 oz product/acre PRE with and without Command at 0.8 or 1.6 pt product/acre, depending on soil type, followed by Newpath postemergence (POST) at the same rate as used PRE. No rice injury was observed during the growing season at either site. Command plus Newpath applied PRE did not improve early-season control of Palmer amaranth, pitted morningglory, or barnyardgrasss over Newpath alone. Increasing the PRE Newpath rate to 6 oz/acre did not improve pitted morningglory control. Newpath applied PRE on a clay soil generally provided lower weed control than on the silt loam soil. Increasing the Newpath rate did not improve rice yields.

INTRODUCTION

One constraint to rice production is water use for irrigation purposes (Scott et al., 1998). Groundwater resources in regions of Arkansas are being depleted partly due to the extensive water demands for rice production. One alternative is the production of rice on raised beds in a manner similar to that commonly used for soybean, cotton, and corn, with rice being furrow-irrigated as needed throughout the growing season. In addition to the benefit of reduced water usage (Borell et al., 1997; Vories et al., 2002), furrow-irrigated rice production requires less time, labor, money, and energy (Tracy et al., 1991). Disadvantages associated with furrow-irrigated rice are slight yield reductions, maturity delays, and more costly weed control (Tracy et al., 1991).

Weed-management programs in furrow-irrigated rice production will most likely require residual herbicides due to the frequent wetting of the soil and absence of a sustained flood. Although it is likely that the weed spectrum associated with furrow-irrigated rice will be similar to that of furrow-irrigated row crops rather than flooded rice culture, weed-management research in furrow-irrigated rice is lacking.

Command and Newpath are two residual herbicides labeled for use in rice. Newpath can be used only on Clearfield rice, which became available to growers in 2002 (Anonymous, 2006). Command is the most commonly used PRE herbicide in Arkansas rice production (Norsworthy et al., 2007), with use rate contingent upon soil type. The maximum use rate of Newpath per application on Clearfield rice is 4 oz/acre; however, up to 6 oz/acre can be applied on enhanced Clearfield rice (Anonymous, 2006). Whether weed control is further improved at the higher use rates is not known, especially in furrow-irrigated rice.

The objectives of this research were to determine (a) if the addition of Command to Newpath would improve PRE weed control in furrow-irrigated, Clearfield rice and (b) if increasing the Newpath rates would improve weed control without injuring rice.

PROCEDURES

Field experiments were conducted at the Northeast Research and Extension Center, Keiser, Ark., during 2007 on a Sharkey clay with 1.4% organic matter and a pH of 6.1, and at Pine Tree, Ark., in 2007 on a Calloway silt loam with 1.0% organic matter and a pH of 6.6. Experiments at both test sites followed a soybean crop. Based on soil test recommendations, potassium (K) was broadcast-applied at Keiser at 42 lb K/acre, and phosphorus (P) and potassium were broadcast-applied at Pine Tree at 60 lb P/acre and 100 lb K/acre in March. The test sites were then immediately tilled, and raised beds were formed similar to those commonly used for row-crop production to facilitate furrow irrigation. There was a 30-inch spacing between beds at Pine Tree and a 38-inch spacing at Keiser.

Water management at both sites was similar to standard drill-seeded, flooded rice production from planting through the 5- to 6-leaf rice stage in that plots were irrigated (flushed) only during prolonged periods without rainfall (usually 12 to 14 days). When rice reached the 5- to 6-leaf stage, the test sites were furrow-irrigated every 5 days until panicle initiation. Beds were allowed to become saturated before irrigation was ceased. Rice was then irrigated every 2 days through 3 weeks after 50% heading at Keiser and 4 weeks after 50% heading at Pine Tree unless ≥1 inch of rainfall occurred during an irrigation sequence. When rainfall occurred between irrigation events, the irrigation schedule was reset to the day of the rainfall event.

The Clearfield hybrid 'CL 730' was drill-seeded at 8 seeds/ft row in 7.5-in-wide rows on 23 April at Pine Tree and 24 April at Keiser. Roundup WeatherMax (glyphosate) was applied at 22 oz/acre with a tractor-mounted sprayer immediately prior to planting to control all existing vegetation.

Urea was applied at 46 lb nitrogen (N)/acre to rice at the 6-leaf stage in early June, mid-June, and late June for a total of 138 lb N/acre at Pine Tree. At Keiser, urea was applied at 60 lb N/acre in early June followed by 46 lb N/acre in mid-June followed by 60 lb N/acre in early July for a total of 166 lb N/acre. The higher N rate at Keiser was needed because of the Sharkey clay soil (Slaton, 2001).

Herbicide treatments included Newpath at 4, 5, and 6 oz/acre applied PRE with and without Command at 0.8 pt/acre at Pine Tree and 1.6 pt/acre at Keiser, then followed by the same rate of Newpath applied POST to 5- to 6-leaf rice. Command was applied at the recommended use rate for the soil type at each test site. Additionally, a nontreated control was included. Plots were 30-ft long with three beds at Pine Tree and 40-ft long with three beds at Keiser. Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat fan nozzles calibrated to deliver 10 gal/acre.

Weed control and crop injury were rated on a scale of 0 to 100%, with 0 equal to no control or injury and 100 equal to complete control or crop death. Weed control and crop injury were rated immediately prior to the POST application and at 2 and 9 weeks after POST applications (WAT) at both sites. Rice was harvested when it reached physiological maturity, and weights were standardized to 12% moisture.

RESULTS AND DISCUSSION

The addition of Command to Newpath PRE did not improve early-season Palmer amaranth control over Newpath alone (data not shown). Averaged over Command use, Newpath applied at 4 oz/acre PRE at Pine Tree controlled Palmer amaranth 48% compared with 79% control when applied at 6 oz/acre (Table 1). At Keiser, Palmer amaranth control improved from 21% following Newpath at 4 oz/acre PRE to 29% when applied at 6 oz/acre PRE. The greater control at Pine Tree was attributed to the silt loam soil, whereas Keiser was a clay soil.

The ineffectiveness of Newpath to provide a high level of residual control at both Keiser and Pine Tree resulted in many Palmer amaranth plants being greater than 12-inches tall when the POST Newpath application was made. As a result, Palmer amaranth control was less than 60% throughout the remainder of the growing season, regardless of Newpath rate.

Command applied PRE provided no additional pitted morningglory control over Newpath alone (data not shown). Averaged over Command use, pitted morningglory control following Newpath applied PRE ranged from 85 to 95% at Pine Tree and only 28 to 30% at Keiser at 8 WAT (Table 2). Newpath applied POST at the same rates used PRE completely controlled pitted morningglory at Pine Tree through 9 WAT. At Keiser, pitted morningglory control ranged from 79 to 88% at 2 WAT and 52 to 70% at 9 WAT. Sequential applications of Newpath at 6 oz/acre at Keiser improved pitted morningglory control over applications at 4 and 5 oz/acre. However, the highest level of control (70%) at 9 WAT at Keiser would be deemed less than acceptable in a standard production system. Moreover, the slight increase in control will probably not be offset by the cost of increasing the Newpath rate to 6 oz/acre PRE followed by 6 oz/acre POST.

Command applied with Newpath PRE did not improve barnyardgrass control over Newpath alone. Barnyardgrass control at Pine Tree was 79% following Newpath PRE at 4 oz/acre compared with 94% at 6 oz/acre (Table 3). At Keiser, increasing the PRE Newpath rate did not improve barnyardgrass control, which averaged 82% prior to Newpath POST. Averaged over locations, Command use, and Newpath rates, barnyardgrass control was 94% at 2 WAT and 93% at 9 WAT.

Rice yields at Keiser were less than those at Pine Tree partially because irrigation at Keiser was terminated too early, resulting in blanking of the lower three to four grains in each panicle. Rice yields were similar among Newpath rates at each location (Table 4), evidence that increasing the Newpath rate did not negatively affect yield, which was expected since no visual injury was noted throughout the growing season (data not shown). In the nontreated plots at Pine Tree, rice failed to produce grain, evidence of the competitiveness of the weed population at that site.

SIGNIFICANCE OF FINDINGS

Managing weeds in furrow-irrigated rice is quite challenging relative to flooded rice culture. Regrowth of noncontrolled weeds and mid-season weed emergence prior to rice canopy formation occurred in furrow-irrigated rice. In furrow-irrigated Clearfield rice, increasing the PRE Newpath rate appears to slightly improve early-season weed control on a few weed species on a silt loam soil but not a clay soil. However, subsequent POST treatment often results in a similar level of weed control among Newpath rates. There appeared to be little or no benefit to increasing the PRE plus POST Newpath rate from 4 oz/acre in furrow-irrigated rice, regardless of soil type. Although Command generally did not provide added weed control, its use with Newpath PRE does ensure that multiple herbicide modes of action are being used to control barnyardgrass, which reduces the likelihood of developing resistance to Newpath.

ACKNOWLEDGMENTS

The continued support of weed management research in rice by the Arkansas Rice Research and Promotion Board and the Division of Agriculture, University of Arkansas is gratefully appreciated.

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Table 1. Percentage visual Palmer amaranth control with Newpath applied preemergence followed by (fb) postemergence at three rates at Pine Tree and Keiser, in 2007. Ratings were taken at 0, 2, and 9 weeks after postemergence treatment (WAT), averaged over the use and nonuse of Command applied preemergence.

	Palmer amaranth control			
	0 WAT			
Newpath rate	Pine Tree	Keiser	2 WAT[z]	9 WAT[z]
(oz/acre)	(%)			
4 fb 4	48	21	55	42
5 fb 5	70	25	51	39
6 fb 6	79	29	57	43
LSD (0.05)	19	5	NS[y]	NS

[z] Averaged over Pine Tree and Keiser.
[y] NS = not significant.

Table 2. Percentage visual pitted morningglory control with Newpath applied preemergence followed by postemergence at three rates at Pine Tree and Keiser, in 2007. Ratings were taken at 0, 2, and 9 weeks after postemergence treatment (WAT), averaged over the use and nonuse of Command applied preemergence.

	Pitted morningglory control					
Newpath	0 WAT		2 WAT		9 WAT	
rate	Pine Tree	Keiser	Pine Tree	Keiser	Pine Tree	Keiser
(oz/acre)	(%)					
4 fb 4	85	30	100	79	100	53
5 fb 5	94	28	100	83	100	52
6 fb 6	95	30	100	88	100	70
LSD (0.05)	8	NS[z]	NS	5	NS	11

[z] NS = not significant.

Table 3. Percentage visual barnyardgrass control with Newpath applied premergence followed by (fb) postemergence at three rates at Pine Tree and Keiser, in 2007. Ratings were taken at 0, 2, and 9 weeks after postemergence treatment (WAT), averaged over the use and nonuse of Command applied preemergence.

	Barnyardgrass control			
	0 WAT			
Newpath rate	Pine Tree	Keiser	2 WAT[z]	9 WAT[z]
(oz/acre)	(%)			
4 fb 4	79	81	92	89
5 fb 5	86	83	95	94
6 fb 6	94	81	94	95
LSD (0.05)	10	NS[y]	NS	NS

[z] Averaged over Pine Tree and Keiser.
[y] NS = not significant.

Table 4. Rice yield following Newpath applied preemergence followed by (fb) postemergence at three rates at Pine Tree and Keiser in 2007. Yields were averaged over the use and nonuse of Command applied preemergence.

	Rice yield	
Newpath rate	Pine Tree	Keiser
(oz/acre)	(bu/acre)	
Nontreated	0	35
4 fb 4	164	98
5 fb 5	181	80
6 fb 6	167	84
LSD (0.05)	37	36

Rice Cutgrass: An Emerging Weed in Arkansas Rice

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

ABSTRACT

Rice cutgrass (*Leersia oryzoides*) is encroaching into rice fields from ditch banks and canals, especially monocultured rice fields where tillage is limited. Experiments were conducted to evaluate the effectiveness of various herbicides alone and in herbicide programs on rice cutgrass. Roundup WeatherMax, Ignite, and Select were the most effective herbicides when applied alone, but none of these are labeled for over-the-top application in rice. Of those herbicides that can be applied over-the-top of rice, Newpath and Regiment were the most effective albeit Newpath can be used only in Clearfield rice. Multiple applications of Newpath provided complete rice cutgrass control in the field, and a herbicide program containing Regiment controlled rice cutgrass 83%. Use of all other rice herbicides alone or as a program approach to managing rice cutgrass were ineffective.

INTRODUCTION

Consultant and producer calls concerning control of rice cutgrass in rice, particularly reduced-tillage fields where rice is grown without rotation to other crops, have been increasing in recent years. It is believed that rice cutgrass, a perennial found in ditch banks and canals throughout the rice-growing region of Arkansas, is moving into rice fields as more and more tillage is reduced each year. Little is known about the effectiveness of herbicides in controlling rice cutgrass. Based on the experience of consultants and producers, it appears that most rice herbicides fail to provide effective control (Norsworthy et al., 2007).

The objective of this research was to evaluate the effectiveness of various herbicides and herbicide programs for control of rice cutgrass.

PROCEDURES

Rice cutgrass was transplanted into 3-inch-diameter pots containing silt loam soil and treated with Stam at 4 qt/acre, Facet at 0.67 lb/acre, Regiment at 0.63 oz/acre, Command at 1.6 pt/acre, Newpath at 4 oz/acre, Permit at 1.33 oz/acre, Bolero at 2 qt/acre, Clincher at 15 oz/acre, Ricestar HT at 17 oz/acre, Grasp at 2 oz/acre, Roundup WeatherMax at 22 oz/acre, Ignite at 27 oz/acre, and Select at 1 pt/acre at the 2- to 3-leaf stage. Crop oil concentrate was added at 1% (v/v) to Clincher, Newpath, Select, Facet, Regiment, Permit, and Grasp. All applications were made in a spray chamber with a two-nozzle boom calibrated to deliver 20 gal/acre. Pots were placed in a greenhouse immediately after treatment, and rice cutgrass control was visually evaluated at 14 and 28 days after treatment on a 0 to 100% scale, where 0 equals no control and 100 equals complete control. The experiment was replicated four times and was repeated.

Additionally, a field trial was conducted at the Rice Research and Extension Center in Stuttgart, Ark., in 2007 evaluating six herbicide programs in drill-seeded rice. The Clearfield cultivar ‘CL 171’ was seeded in 7.5-inch-wide rows at 24 seed/ft of row on 18 April. Rice cutgrass was grown in the greenhouse in 3-inch-diameter pots containing silt loam soil prior to initiating the experiment and later transplanted at the 2-leaf stage into field plots. Field plots were flushed (irrigated) prior to transplanting rice cutgrass for ease of transplanting and to minimize physiological stress caused by transplanting. Urea was applied at 100 lb N/acre to rice at the 6-leaf stage prior to flooding and at 55 lb N/acre 1 month after flooding. Herbicides were applied to 3-leaf rice cutgrass and 3-leaf rice followed by a preflood application 2 weeks after the initial treatment. Herbicide programs included: Newpath at 4 oz/acre followed by (fb) Newpath at 4 oz/acre; Newpath at 6 oz/acre fb Newpath at 6 oz/acre; Command at 1.6 pt/acre plus Bolero at 2 qt/acre fb Stam at 4 qt/acre plus Ricestar HT at 17 oz/acre; Command at 1.6 pt/acre plus Facet at 0.67 lb/acre fb Stam at 4 qt/acre plus V-10142 at 0.009 lb ai/acre; Command at 1.6 pt/acre plus V-10142 at 0.009 lb/acre fb Stam at 4 qt/acre plus Regiment at 0.63 oz/acre; and Command at 1.6 pt/acre plus Grasp at 2 oz/acre fb Stam at 4 qt/acre plus Clincher at 15 oz/acre. Rice cutgrass control and crop injury were rated preflood prior to applying the second tank-mixture and at 2, 4, and 8 weeks after the final treatments. Appropriate adjuvant was added to each herbicide program. The experiment was replicated four times.

All data were subjected to analysis of variance, and means were separated using Fisher’s protected Least Significance Difference test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Single applications of Roundup WeatherMax, Ignite, and Select were the only herbicides to provide at least 90% control of rice cutgrass (Table 1). However, none of these herbicides can be applied over-the-top of rice. A single application of Newpath and Regiment provided 52 to 62% control, but Newpath can be applied only in Clearfield rice. Common rice herbicides such as Stam, Facet, Regiment, Ricestar HT, and Command provided <25% rice cutgrass control, which partially explains the proliferation of rice cutgrass in continuous rice culture. The effectiveness of Roundup WeatherMax, which is widely used in RoundupReady soybean, probably reduces the occurrence of rice cutgrass in fields that are frequently rotated to soybean.

In drill-seeded rice, multiple applications of Newpath, regardless of rate, provided complete control of rice cutgrass (Table 2). However, the first application of Newpath at 3-leaf rice provided no more than 60% control, similar to the results in the greenhouse trial. Stam plus Regiment applied preflood was the most effective conventional (non-Clearfield) rice herbicide program probably because of the effectiveness of Regiment on rice cutgrass (based on the greenhouse trial). Regiment stunted rice cutgrass, which eventually led to shading of these plants by rice. It is possible that multiple applications of Regiment would have resulted in rice cutgrass control comparable to that obtained with two applications of Newpath. It should be noted, however, that the risk of resistance evolution of weeds to Newpath or Regiment, two ALS-inhibiting herbicides, is high when these products are used in fields where rice is continuously grown.

Rice showed adequate tolerance to each of the three most effective herbicide programs, with no more than 8% injury observed (Table 2).

SIGNIFICANCE OF FINDINGS

This research shows that most rice herbicides are not effective for controlling rice cutgrass, but multiple applications of Newpath provided complete control, and Regiment appears to be the most effective herbicide for use in non-Clearfield rice. These findings point to the need for additional rice cutgrass research to evaluate the effectiveness of multiple applications of Regiment; the impact of fall management practices, particularly tillage; the efficacy of Roundup applications on rice cutgrass vegetative persistence; and the impact of rice cutgrass density on rice grain yield.

ACKNOWLEDGMENTS

The continued support of weed management research in rice by the Arkansas Rice Research and Promotion Board and the Division of Agriculture, University of Arkansas is gratefully appreciated.

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Table 1. Visual control of 2- to 3-leaf rice cutgrass at 28 days after treatment in the greenhouse, averaged over two trials.

Herbicide	Rate/acre	Rice cutgrass control
		(%)
Bolero	2 qt	15 de[z]
Clincher	15 oz	12 de
Roundup WeatherMax	22 oz	100 a
Ignite	27 oz	94 a
Ricestar HT	17 oz	8 e
Newpath	4 oz	62 b
Select	1 pt	90 a
Stam	4 qt	8 e
Facet	0.67 lb	9 e
Command	1.6 pt	24 d
Regiment	0.63 oz	52 bc
Permit	1.33 oz	43 c
Grasp	2 oz	34 cd

[z] Means within a column followed by the same letter are statistically similar.

Table 2. Percentage visual rice cutgrass control and injury with herbicide programs applied at the 3-leaf stage of rice followed by preflood applications at Stuttgart, Ark., in 2007. Preflood ratings reflect control and injury from those herbicides applied at the 3-leaf stage of rice.[z]

			Rice cutgrass control		Rice injury	
Herbicide	Timing	Rate/acre	Preflood	8 wk postflood	Preflood	4 wk postflood
			(%)			
Newpath fb	3-lf	4 oz	50 b	100 a	0 c	3 b
Newpath	preflood	4 oz				
Newpath fb	3-lf	6 oz	60 a	100 a	0 c	0 b
Newpath	preflood	6 oz				
Command +	3-lf	1.6 pt +	23 c	35 d	11 a	15 a
Bolero fb	3-lf	2 qt fb				
Stam +	preflood	4 qt +				
Ricestar HT	preflood	17 oz				
Command +	3-lf	1.6 pt +	67 a	57 c	3 b	1 b
Facet fb	3-lf	0.67 lb fb				
Stam +	preflood	4 qt +				
V-10142	preflood	0.009 lb ai				
Command +	3-lf	1.6 pt +	25 c	83 b	8 b	4 b
V-10142 fb	3-lf	0.67 lb fb				
Stam +	preflood	4 qt +				
Regiment	preflood	0.63 oz				
Command +	3-lf	1.6 pt +	20 c	7 e	8 b	4 b
Grasp fb	3-lf	2 oz fb				
Stam +	preflood	4 qt +				
Clincher	preflood	15 oz				

[z] Means within a column followed by the same letter are statistically similar.

PEST MANAGEMENT: WEEDS

Effect Of High Rates Of Imazethapyr And Imazamox On Hybrid And Conventional Clearfield Rice

R.C. Scott, K.L. Smith, B.A. Goldschmidt, T.W. Dillon, and N.D. Pearrow

ABSTRACT

The objective of this research was to evaluate new Clearfield (CL) hybrid rice varieties for their tolerance to both Newpath and late "salvage" applications of Beyond herbicides. Treatment factors were rice variety, herbicide rate, and application timing. Each study was duplicated using two planting dates for each study. First planting was 23 May followed by a second planting on 14 June 2007. 'CL 171' and 'CL 161' were planted at 90 lb/acre and hybrids 'CL XL 730', 'CL XL 729', and 'CL XP 745' were planted at 30 lb/acre. In Study 1, Newpath at 0, 4, 8, 12, or 24 oz/acre was applied sequentially on 2- and 4-leaf rice. All Newpath treatments also contained non-ionic surfactant (NIS) at 0.25% v/v. In Study 2, treatments were Beyond at 0, 5, or 10 oz/acre applied at panicle initiation (PI); PI + 14 days; or boot. All plots in Study 2 also received sequential applications of Newpath at 4 oz/acre on 2- and 4-leaf rice.

In study 1, CL 171 and CL 161 generally were not injured, nor was yield decreased with Newpath rates up to 24 oz/acre. Hybrid varieties were generally only injured with rates higher than 8 oz/acre and only the earlier planted CL XL 729 showed yield decreases when 24 oz/acre Newpath were applied. In study 2, CL 171 and CL 161 were not affected by any Beyond rate or timing. Hybrid CL varieties generally were injured when 10 oz/acre of Beyond were applied at PI + 14 days or boot. Hybrid CL yield decreases were measured for all application timings of 10 oz/acre of Beyond and when 5 oz/acre were applied at PI + 14 days or boot. As a result of this research, we have requested that the current Arkansas 24C label for Beyond applications to CL rice be adjusted. The proposed "cut-off" date for Beyond applications will be at PI in hybrid CL rice and will remain at PI + 14 days for the conventional CL varieties.

INTRODUCTION

With an average of over 20% of Arkansas rice being planted in Clearfield (CL) varieties, Clearfield rice has become very important to Arkansas rice production (Wilson and Runsick, 2007). Clearfield hybrid rice was first released in 2003 and has gained in market share through 2006 (Wilson and Runsick, 2007). Hybrid rice varieties offer superior yields and good disease resistance when compared to most conventional varieties, and, in the case of CL hybrid rice, superior weed-control options. On CL hybrids, 8 oz/acre of Newpath (imazethapyr) may be applied per growing season in sequential applications (Anonymous, 2003).

Because CL rice and red rice are the same genus and species, out-crossing of the CL trait to red rice is a very real possibility. Studies have shown that hybrid CL varieties are more likely to outcross with red rice than conventional lines (Shivrain et al., 2007). In addition to crop rotation, proper use of Newpath, not saving seed, and late applications of Beyond (imazamox) herbicide under a 24C state label round out a complete resistance-management program for CL rice (Anonymous, 2005). By the summer of 2004, out-crossing of Clearfield rice to red rice had been documented in a commercial field in Arkansas (Scott and Burgos, 2004). Late applications of Beyond can decrease the chance of simultaneous flowering of CL rice and red rice, thereby decreasing the chances of out-crossing (Meins et al., 2004).

The objective of this research was to evaluate new CL hybrid rice varieties for their tolerance to both Newpath and late "salvage" applications of Beyond herbicides.

PROCEDURES

Two studies were established in 2007 to determine the effect of high rates of Newpath and Beyond on hybrid Clearfield rice. These studies were conducted on a silt loam soil with a pH of 4.8 at the University of Arkansas at Pine Bluff farm near Lonoke, Ark.

Treatment factors were rice variety, herbicide rate, and application timing. Each study was duplicated using two planting dates. The first planting was 23 May, followed by a second planting on 14 June. CL 171 and CL 161 were planted at 90 lb/acre and hybrids CL XL 730, CL XL 729, and CL XP 745 were planted at 30 lb/acre.

In Study 1, Newpath at 0, 4, 8, 12, or 24 oz/acre was applied sequentially on 2- and 4-leaf rice. All Newpath treatments also contained NIS at 0.25% v/v. In Study 2, treatments were Beyond at 0, 5, or 10 oz/acre applied at panicle initiation (PI); PI + 14 days; or boot. All plots in Study 2 also received sequential applications of Newpath at 4 oz/acre on 2- and 4-leaf rice. Treatments in both studies were replicated three times.

All plots were maintained chemically weed-free to minimize weed impact on injury and yields. However, all studies had a late infestation of Amazon sprangletop that was not controlled adequately in the check plots. This weed interference lowered yields of the "treated, weed-free checks"; this, along with a later-than-normal planting date for both studies, resulted in some variability in the yield data. Visual ratings were collected on rice injury, and plots were harvested using a small-plot combine. All data were analyzed in ARM using a least significant difference (LSD) test (P = 0.05).

RESULTS AND DISCUSSION

Study 1

Rice injury was evaluated 4 weeks after treatment (WAT) for the first planting date (23 May) and 2 WAT for the second planting date (14 June). Similar results for rice injury were seen with both planting dates. In the first planting, CL 171 and CL 161 showed no significant injury from Newpath rates as high as 12 oz/acre (Table 1), with 5% injury. When 24 oz/acre were applied, injury was 8%. Hybrid rice varieties showed significant injury as Newpath rates increased. CL XL 730 and CL XL 729 did not show significant injury with 4 or 8 oz/acre; however, they did have 20 and 18% injury, respectively, with sequential applications of 24 oz/acre. CL XP 745 was significantly injured with rates over 4 oz/acre. Applications of 8 or 12 oz/acre resulted in 7% injury and 24 oz/acre resulted in 17% injury of CL XP 745.

Injury results in the second planting were similar (Table 2). CL 171 and CL 161 were not significantly injured with Newpath applications as high as 24 oz/acre; injury ranged from 5 to 7%. CL XL 730 had no significant injury when 4 or 8 oz/acre of Newpath were applied; Newpath at 12 or 24 oz/acre resulted in 22 and 13% injury, respectively. CL XL 729 and CL XP 745 did not show significant injury when 4 oz/acre was used; injury from 10 to 25% was seen with higher Newpath rates.

At the earlier planting date, CL XL 729 yields were decreased (Table 3). Yield ranged from 251 to 281 bu/acre when 4 to 12 oz/acre of imazethapyr were applied and decreased to167 bu/acre when 24 oz/acre were applied. However, no yield decrease was measured for CL XL 729 in the second planting date (Table 4). No significant differences in yield were measured for CL 171, CL 161, CL XL 730, or CL XP 745 at either planting date. It is important to note that several of the yields for treated checks in some varieties were significantly lower than the Newpath treatments, which illustrates the role Newpath may play in increasing yield through improved weed control.

Study 2

The percentage of rice heading was evaluated 1 week after boot. With the early planting date, heading was reduced on CL XP 745 when Beyond was applied at 10 oz/acre (Table 5). No significant decreases in heading were seen for any other varieties. With the later planting date, no heading decrease was observed for CL 171 and CL 161 (Table 6). When 10 oz/acre of Beyond were applied at PI+14 days or boot, CL XL 730 and CL XL 729 heading decreased 9 to 15%.

Significant differences in yield were measured for the earlier-planted hybrid rice varieties (Table 7). CL XL 730 yields were reduced by 78 to 102 bu/acre when 10 oz/acre of Beyond were applied at PI; PI + 14 days; or boot. CL XL 729 yields were reduced by 95 to 110 bu/acre when 5 oz/acre of Beyond were applied at PI + 14 days or boot and reduced by 75 to 130 bu/acre when 10 oz/acre of Beyond were applied at PI; PI + 14 days; or boot. CL XP 745 yields were reduced by 69 to 91 bu/acre when 5 oz/acre of Beyond were applied at PI or PI + 14 days and reduced 70 to 78 bu/acre when 10 oz/acre of Beyond were applied at PI; PI+14 days; or boot. Due to significant variability in yield from this very late planting date, no yield differences were noted for any variety in the later-planted test (Table 8).

SIGNIFICANCE OF FINDINGS

As a result of this research, the current Arkansas 24C label for Beyond applications to CL rice is being adjusted. The "cut-off" date for Beyond applications will be at PI in hybrid CL rice and will remain at PI + 14 days for the conventional CL varieties.

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We would like to thank the Arkansas Rice Research and Promotion Board for their support and funding of this research and the Arkansas rice growers for their check-off dollars that make the Promotion Board possible. The authors also thank the Division of Agriculture, University of Arkansas, BASF Corporation, Horizon Ag, and RiceTec LLC for their support of this work.

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Table 1. Rice injury by variety from Newpath - planted on 23 May 2007.

Newpath rate[z]	Rice injury 4 weeks after treatment				
	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)	(%)				
0	0	0	0	0	0
4	5	5	5	5	5
8	5	5	8	8	7
12	5	5	10	12	7
24	8	8	20	18	17
LSD (0.05)	5	5	10	12	6

[z] Newpath was applied sequentially to 2- and 4-leaf rice. Rate shown was applied twice to each plot.

Table 2. Rice injury by variety from Newpath - planted on 14 June 2007.

Newpath rate[z]	Rice injury 4 weeks after treatment				
	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)	(%)				
0	0	0	0	0	0
4	5	5	7	3	7
8	5	5	7	10	10
12	7	7	22	23	25
24	5	5	13	15	20
LSD (0.05)	NS[y]	NS	7	9	7

[z] Newpath was applied sequentially to 2- and 4-leaf rice. Rate shown was applied twice to each plot.
[y] NS = not significant.

Table 3. Rice yield by variety following application of Newpath - planted on 23 May 2008.

Planting date	Newpath rate[z]	Rice yield				
		CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
	(oz/acre)	(bu/acre)				
5/23/07	0[y]	138	142	239	191	180
	4	168	172	293	251	195
	8	186	191	304	272	224
	12	177	160	369	281	234
	24	194	182	296	167	201
LSD (0.05)		53	NS[x]	47	60	NS

[z] Newpath was applied sequentially to 2- and 4-leaf rice. Rate shown was applied twice to each plot.
[y] A late infestation of Amazon sprangletop was not properly controlled in the treated check and negatively impacted yield of these plots.
[x] NS = not significant.

Table 4. Rice yield by variety following application of Newpath - planted on 14 June 2008.

Planting	Newpath	Rice yield				
date	rate[z]	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
	(oz/acre)	----------(bu/acre)----------				
6/14/08	0[y]	117	118	217	181	191
	4	135	114	207	183	205
	8	131	124	229	200	193
	12	122	130	195	178	172
	24	138	116	204	179	168
LSD (0.05)		NS[x]	NS	NS	NS	NS

[z] Newpath was applied sequentially to 2- and 4-leaf rice. Rate shown was applied twice to each plot.
[y] A late infestation of Amazon sprangletop was not properly controlled in the treated check and negatively impacted yield of these plots.
[x] NS = not significant.

Table 5. Rice heading by variety with Beyond applied at panicle initiation (PI), PI + 14 days, or boot - planted on 23 May 2007.

Beyond		Rice heading – 1 week after boot				
rate[z]	Timing	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)		----------(%)----------				
0	--	40	13	15	28	90
5	PI[y]	43	17	23	43	88
5	PI + 14 days	40	25	40	37	92
5	Boot	25	5	13	13	90
10	PI	60	20	33	42	90
10	PI + 14 days	47	15	15	20	83
10	Boot	33	18	5	5	55
LSD (0.05)		NS[x]	NS	29	33	20

[z] All plots received applications of 4 oz/acre Newpath on 2- and 4-leaf rice.
[y] PI = panicle initiation.
[x] NS = not significant.

Table 6. Rice heading by variety with Beyond applied at panicle initiation (PI), PI + 14 days, or boot - planted on 14 June 2008.

Beyond		Rice heading – 1 week after boot				
rate[z]	Timing	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)		----------(%)----------				
0	--	40	8	62	58	85
5	PI[y]	45	13	62	55	82
5	PI + 14 days	43	15	62	57	82
5	Boot	50	20	60	57	82
10	PI	42	15	57	50	80
10	PI + 14 days	47	17	50	48	80
10	Boot	50	20	53	43	77
LSD (0.05)		NS[x]	NS	8	9	3

[z] All plots received applications of 4 oz/acre Newpath on 2- and 4-leaf rice.
[y] PI = panicle initiation.
[x] NS = not significant.

Table 7. Rice yield by variety with Beyond applied at panicle initiation (PI), PI + 14 days, or boot - planted on 23 May 2008.

Beyond		Rice heading – 1 week after boot				
rate[z]	Timing	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)		(%)				
0	--	190	203	299	285	253
5	PI[y]	173	160	268	238	184
5	PI + 14 days	146	154	217	175	162
5	Boot	172	156	231	190	224
10	PI	154	136	220	210	173
10	PI + 14 days	164	157	221	203	178
10	Boot	170	181	197	155	183
LSD (0.05)		42	56	74	40	59

[z] All plots received applications of 4 oz/acre Newpath on 2- and 4-leaf rice.
[y] PI = panicle initiation.

Table 8. Rice yield by variety with Beyond applied at panicle initiation (PI), PI + 14 days, or boot - planted on 14 June 2008.

Beyond		Rice heading – 1 week after boot				
rate[z]	Timing	CL 171	CL 161	CL XL 730	CL XL 729	CL XP 745
(oz/acre)		(%)				
0	--	143	137	240	186	193
5	PI[y]	133	121	223	192	206
5	PI + 14 days	150	128	279	173	190
5	Boot	165	123	214	202	218
10	PI	132	120	194	162	204
10	PI + 14 days	132	129	195	153	183
10	Boot	165	131	201	171	216
LSD (0.05)		NS[x]	NS	NS	NS	NS

[z] All plots received applications of 4 oz/acre Newpath on 2- and 4-leaf rice.
[y] PI = panicle initiation.
[x] NS = not significant.

Soil Aggregate Content and Carbon Sequestration in Rice Rotations

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ABSTRACT

No-till (NT) rice production is not a common practice in Arkansas. Nationally there is a developing carbon © market that could be of interest to farmers and would necessitate using a NT approach to rice production. While there exist significant data on the impact of NT production on non-flooded row crops, little information is available on the effect of NT rice production on soil aggregate dynamics and subsequent C sequestration via increased soil aggregates. Samples were taken from a long-term cropping study that compared conventional-till and NT rice rotations. Percent soil water stable aggregates were significantly affected by rotation, tillage, depth of soil, and aggregate size class. Interactions between all main and sub-plot components were present. Changes in the percent aggregates were most prevalent in the top 0- to 5-cm soil layer in NT plots. Mixing of soil layers in conventional-till (CT) plots resulted in no differences in water stable aggregates between the top 0- to 5-cm and lower 5- to 10-cm soil layers. Smaller aggregates (0.25 to 0.50 mm) dominated all treatment combinations with the percentage of aggregates in any size class decreasing as aggregate size increased. There was a trend of increasing aggregates with increasing frequencies of rice in any rotation. Carbon content differed significantly between tillage treatments in the larger aggregate class sizes but did not differ significantly in the two small class sizes. Carbon contributions to the soil via aggregate abundance were most evident in the larger aggregate size classes and in rotations where rice appeared most frequently. Farmers who NT rice can expect increases in soil C levels with the rates of C sequestration dependent on the frequency rice is grown in the rotation and what crops rice is rotated with.

INTRODUCTION

There is a great deal of discussion at this time on the potential for using row-crop production to sequester C and thus assist in mitigating global warning. Carbon markets are developing and their interface with production agriculture is essential if a strategy of involving rice farmers in the sequestration of C is to be successful. On 26 April 2007 there was a meeting held in Little Rock that outlined a program put forward by the Chicago Climate Exchange that would allow rice farmers to participate in a C-offset program. This program would provide farmers with payments for capturing carbon. To do this farmers would need to embrace a NT approach to rice production. Currently there are few rice producers in Arkansas who are committed to NT rice production and it will likely take more than C payments to persuade them to adopt NT rice production.

The process of sequestering C through NT production is closely tied to a number of soil processes. One of those is the increasing percentage of water stable aggregates in NT production when compared to CT systems. Research has shown that NT production will enhance soil structure and quality (Amezketa, 1999; Hussain et al., 1999). One measurement used to determine soil 'quality' is the abundance of water stable aggregates in the soil profile. These aggregates provide structure and allow for better water infiltration into the soil. They also prevent the soil from 'sealing' or forming a crust that can significantly reduce crop emergence. Additional benefits of increasing water stable aggregates are reduced runoff, better air infiltration, and reduced resistance to root penetration. The formation of water stable aggregates and their subsequent C content is closely tied to the volume of crop residue and quality of crop residue, air and soil temperatures, and whether decomposition is anaerobic or aerobic. Rotations used in Arkansas rice production can range from continuous rice to three-phase rotations where rice is rotated with soybeans, corn, and wheat. Crop species diversity and altering aerobic and anaerobic environments in these rotations are expected to result in different rates and amounts of C being added to the soil. One objective of this study was to determine the amount of C added to the soil via increased water stable aggregates in different rotations that were CT- or NT-managed.

PROCEDURES

A site at the University of Arkansas Rice Research and Extension Center near Stuttgart, Ark., was selected for this study and cut to a 0.15% slope in February of 1999. Soil at the site is characterized as a Stuttgart silt loam and classified as a fine, smectitic, thermic Albaqultic Hapludolf. Initial soil samples showed a pH range of 5.6 to 6.2 with C content averaging 0.84% and nitrogen (N) 0.08%. Plots measuring 250-ft by 40-ft were laid out in a north-south direction. These plots were then divided in half east-west with each side randomized as CT or NT treatments. Each tillage treatment was then split into standard- and high-fertility treatments. For rice, 'standard' fertility consisted of a single pre-flood N application of 100 lb urea/acre plus 40 lb P_2O_5/acre, and 60 lb K_2O/acre applied prior to planting. Rates increased to 150 lb N/acre, 60 lb P_2O_5/acre, and 90 lb K_2O/acre for the 'enhanced' treatment with application times remaining the same. Two varieties of each crop species were planted in a continuous strip across the CT and NT treatments. The following rotations that started in 1999 were: 1) continuous rice, 2) rice-soybean, 3) soybean-rice, 4) rice-corn, 5) corn-rice, 6) rice (wheat) rice (wheat), 7) rice (wheat)-soybeans (wheat), 8) soybeans (wheat)-rice (wheat), 9) rice-corn-soybeans, and 10) rice-soybeans-corn.

In February 2005, soil samples were taken using a 7.6-cm diameter core from all plots that were planted to rice in 2004. This sample time was selected because it contained a rice component from single-, double-, and triple-phase rotations. Rotation treatments sampled were: 1) continuous rice, 2) rice-soybean, 3) rice-corn, 4) rice (wheat)-rice (wheat), 5) rice (wheat)-soybeans (wheat), 6) rice-corn-soybeans, and 7) rice-soybeans-corn. The 'Wells' rice variety had been planted into each plot the previous season and received the 'standard' fertility treatment. Four samples were taken from each plot to a depth of 4 inches. Each core was divided into a 0- to 2-inch and 2- to 4-inch section. Samples were passed through an 8-mm sieve and air-dried. Sub-samples of 150 g soil were divided into 0.25-mm to 0.5-mm, 0.50-mm to 1.00-mm, 1.00-mm to 2.00-mm, 2.00- to 4.00-mm, and >4.00-mm size classes using the 'wet'-sieve method described by Yoder (1936). Samples were dried and weighed to determine the percent of total soil weight in each size class.

Carbon and N analysis for individual aggregate-size classes was determined with a LECO TruSpec CN analyzer (LECO Corporation, St. Joseph, Mich.). Total C was calculated via the dry-combustion method (Nelson and Sommers, 1996). Total N was calculated by the Dumas method (Bremner, 1996).

RESULTS AND DISCUSSION

To determine the amount of C added to the soil via water stable aggregates, we analyzed data on the effects of rotation, tillage, soil depth, and aggregate-size class on percent aggregates (Table 1). All main effects and most two-and three-way interactions were very highly significantly different. This result illustrates the complexity of processes contributing to aggregate enrichment and their potential C content.

The distribution of aggregate-size classes varied across tillage and soil depth (Fig. 1). For both NT and CT treatments there was a significantly higher percentage of aggregates in the 0.25- to 0.50-mm size classes when compared to all larger size classes. As aggregate size increased, there was a corresponding decrease in the abundance of each larger aggregate size class. Percentage of aggregates in aggregate size classes larger than the 0.25- to 0.50-mm size was significantly higher in the NT sample from the 0- to 2-inch soil depth when compared to values from both CT sample depths and the 2- to 4-inch sample in the NT treatment (Fig. 1). There was not a significant difference between soil depths in the CT treatment. This result is attributed to the mixing of soil that takes place during normal tillage operations. Differences in aggregate-size classes and overall water-stable aggregate content were most evident between the upper (0- to 2-inch) soil depth and the 2- to 4-inch soil depth in the NT treatment. These results show that NT plays a significant role in increasing soil water-stable aggregates and that a majority of this increase is in the upper soil layer.

As indicated in the ANOVA table (Table 1), percent water-stable aggregates were significantly affected by rotation, soil depth, and aggregate-size class (Fig. 2). Regardless of rotation and soil depth, there was a significantly higher percentage of water-stable aggregates in the 0.25- to 0.50-mm size class when compared to all larger size classes. Differences between total water-stable aggregates in the 0- to 2-inch soil layer and the lower 2- to 4-inch soil layer were greatest in the rice (wheat)-rice (wheat) rotation. This rotation is the most intensive of all rotations tested because of its continuous cropping and a composition of crops that are high residue producers. Of all the rotations tested, three-phase rotations that contained rice every third year had the lowest percentages of all aggregate size classes and total percent water-stable aggregates in the 0- to 2-inch soil layer. These results, and those comparing tillage treatments, show that water-stable aggregates accumulate in NT treatments in the 0- to 2-inch soil layer and that the amount and size composition of aggregates are dependent on crop species and their frequency in a rotation.

Soil-aggregate contribution to soil C is dependent on the amount of each aggregate-size class in the soil and their C content. Carbon content varied between aggregate-size classes with the highest values found in the 1.00- to 2.00-mm size class regardless of tillage treatment (Fig. 3). Water-stable aggregates in the three largest size classes contained significantly more C in the NT treatments than those same size classes in the CT treatments. There were no tillage differences in aggregate C content for the two smallest size classes. A majority of water-stable aggregates for all treatment combinations were found in the smallest aggregate-size class (Fig. 2). Increases in soil C that might occur in NT treatments that are related to the two smallest aggregate-size classes would need to come from an increase in water-stable aggregate abundance and not aggregate enrichment. Increasing the amount of aggregates in the three largest size classes would result in increased soil C.

Soil C content as influenced by aggregate accumulation will occur in the 0- to 2-inch soil layer of NT treatments (Fig. 1) and be dependent on crop species' frequencies in a rotation (Fig. 2). Aggregate enrichment will occur primarily with the addition of larger aggregates (Fig. 3). Total carbon enrichment for the 0- to 2-inch soil layer in NT treatments was most influenced by the larger volume of the smallest (0.25- to 0.05-mm) aggregate size class (Fig. 4). However, the contribution of rotation components was significant with a clear trend of increased C from larger enriched aggregates as the frequency of rice included in a rotation increases. Lowest C contributions came from the larger aggregate sizes in the three-phase rotations that contained rice every third year. There was a significant increase in C in the rice-corn rotation when compared to the rice-soybean rotation. This difference is attributed to the larger volume of residue produced by the corn crop when compared to soybean.

In all cases soil C increased with NT compared to CT with rotation-species mix significantly influencing aggregate size and volume and thus C sequestration. Markets that target C credits need to be aware that these differences exist so that they can adjust their payments to farmers who are interested in becoming part of a C-trading system.

SIGNIFICANCE OF FINDINGS

This study shows how NT farming in rice can increase soil quality through increasing soil aggregates. Above the benefits of increasing aggregates, there is an associated increase in soil C that has the potential to become a tradable commodity in the future. This study shows what rotations are best-suited to increase C sequestration in rice production systems.

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Table 1. Analysis of variance summary for the main effects of rotation, tillage, soil depth, and aggregate size class and their interactions for the percentage of water stable aggregates in the 0- to 2-inch and 2- to 4-inch soil depths from plots that were CT or NT and planted into seven rotations at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

Variation source	P value
Rotation	<0.001
Tillage	<0.001
Soil depth	<0.001
Aggregate size class	<0.001
Rotation x tillage	0.471
Tillage x soil depth	<0.001
Rotation x soil depth	<0.001
Soil depth x aggregate size class	<0.001
Tillage x aggregate size class	<0.001
Rotation x aggregate size class	<0.001
Rotation x tillage x soil depth	<0.001
Tillage x soil depth x aggregate size class	<0.001
Rotation x soil depth x aggregate size class	<0.001
Rotation x tillage x aggregate size class	<0.050
Rotation x tillage x soil depth x aggregate size class	0.170

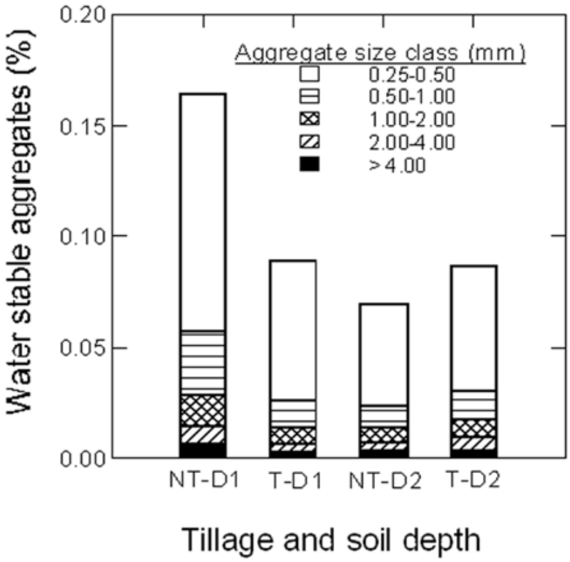

Fig. 1. Percent water stable aggregates for five size classes (0.25 -0.50 , 0.50 - 1.00, 1.00 - 2.00, 2.00 - 4.00, >4.00 mm) collected at a depth of 0- to 2-inches (D1) or 2- to 4-inches (D2) in plots that were conventional-till (CT) or no-till (NT) managed in a long-term rotation study at the University of Arkansas Rice Research and Extension Center. (SE between totals = 0.00052, SE between aggregate class sizes = 0.00116)

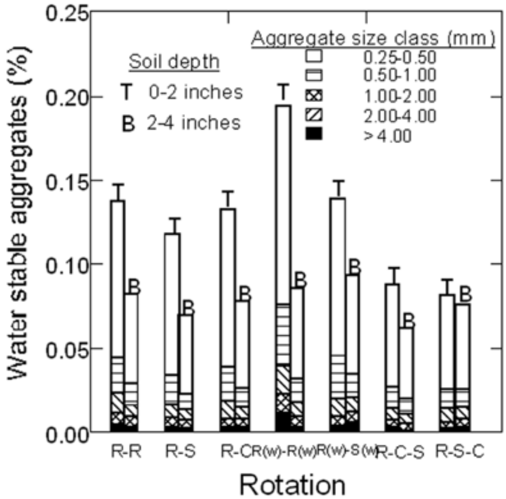

Fig. 2. Percent water stable aggregates for five size classes (0.25-0.50, 0.50-1.00, 1.00-2.00, 2.00-4.00, >4.00 mm) collected at a depth of 0- to 2-inches or 2- to 4-inches in plots representing seven rotations; continuous rice (R-R), rice-soybeans (R-S), rice-corn (R-C), rice (wheat)-rice (wheat) (R(w)-R(w)), rice (wheat)-soybeans (wheat) (R (w)-S (w)), rice-corn-soybeans (R-C-S), and rice-soybeans-corn (R-S-C) at the University of Arkansas Rice Research and Extension Center. (SE for totals = 0.00098, SE for aggregate size classes = 0.00218)

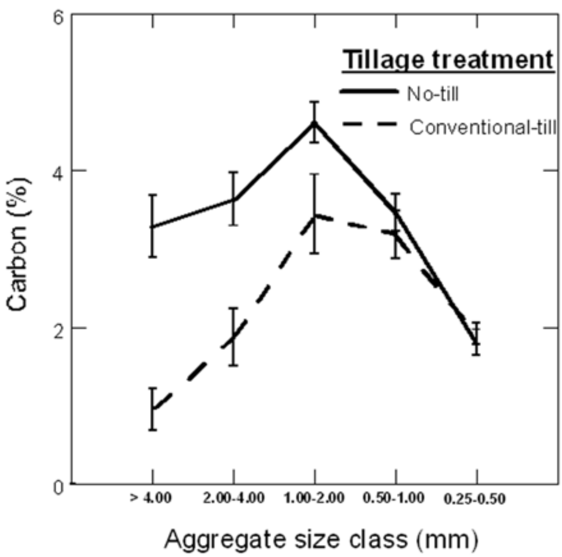

Fig. 3. Carbon content of five aggregate size classes from plots that were CT or NT at the University of Arkansas Rice Research and Extension Center. (SE = 0.1638)

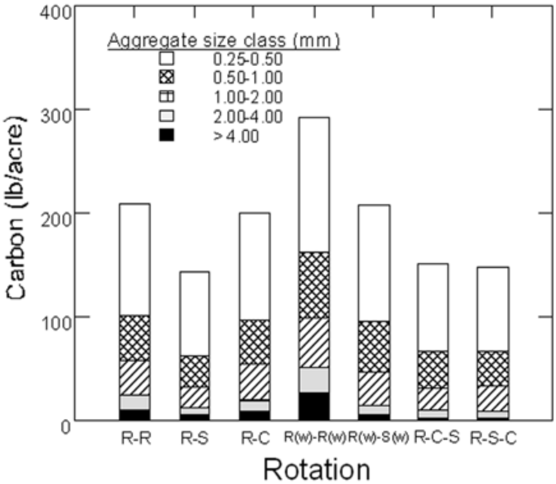

Fig. 4. Carbon contribution (lb/acre) of five aggregate size classes in the 0- to 2-inch soil layer from fields that were NT managed and planted into seven rotations; continuous rice (R-R), rice-soybeans (R-S), rice-corn (R-C), rice (wheat)-rice (wheat) (R(w)-R(w)), rice (wheat)-soybeans (wheat) (R (w)-S (w)), rice-corn-soybeans (R-C-S), and rice-soybeans-corn (R-S-C) at the University of Arkansas Rice Research and Extension Center. (SE for size class = 7.97)

Utilization Of On-Farm Testing To Evaluate Rice Cultivars

J.D. Branson, D.L. Frizzell, C.E. Wilson, Jr., J.A. Yingling, C.E. Parsons, R.D. Cartwright, J.W. Gibbons, and R.J. Norman

ABSTRACT

Rice diseases reduce yield, milling quality, and profit in Arkansas rice production each year. Resistant cultivars are the first line of defense against disease, and the correct cultivar choice for a particular field will result in less production costs and higher profits to the grower, by minimizing disease problems. Diseases are greatly influenced by the environment as well, and rice is grown in a variety of different environmental and cultural management situations around the state. Therefore, performance evaluations across many environmental and management situations are important to overall cultivar selection. The Disease Monitoring Program (DMP) was initiated in 1995 with three main objectives. These objectives include: 1) to monitor the disease pressure in the different regions of Arkansas, 2) to determine disease reactions of rice cultivars to diseases not commonly observed on Experiment Stations, and 3) to compare the yield potential of commercially available cultivars and advanced experimental lines. Field studies consisting of 20 to 25 cultivars are implemented in 15 to 20 grower fields annually. Rice cultivars are seeded in 8-row (17.8-cm spacing) x 7.62-m-long plots and replicated three times in a randomized complete block design. Beginning in 2007, an additional five locations were dedicated to only Clearfield cultivars.

INTRODUCTION

Rice diseases are an important constraint to profitable rice production in Arkansas. Based on IPM disease management methods, we encourage the use of host resistance, optimal cultural practices, and fungicides when necessary to reduce disease potential.

These options provide growers the maximal 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 Arkansas. With some knowledge of field history, growers can pick the cultivar that offers the highest yield potential with the minimal risk for their situation; however, the knowledge to make these selections accurately each year requires ongoing field research. Cultivars are developed under controlled experiment station conditions. 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 may not be observed in nurseries conducted on experiment stations. The Disease Monitoring Program was designed to better address the many risks faced by newly released cultivars. Replicated plots are planted in grower fields across Arkansas and monitored for the development of problems and for their performance under grower management.

Rice cultivars 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 cultivars became widespread and false smut became a consistent problem where it had never been noticed before. Blast risk has been increasing as high-yielding, but susceptible, cultivars continue to be planted on larger and larger acreage.

Monitoring these types of changes allows extension specialists and county agents to provide early warning to researchers and growers. It also assists in development of management information to deal with increased risks until solid research data are available to solve new problems. Monitoring of diseases, cultivar reaction, and cultivar performance must be conducted over time and across different environments to be of value. Replicated variety plots on different farms provide research data to make these evaluations, but also are the basis for hands-on education of county agents, consultants, and producers.

The distribution of the different research sites requires considerable travel across the rice-producing areas 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.

The Rice Disease Monitoring Program has evolved into a major part of the rice cultivar development process. The goal of the Rice Extension Program is to have a complete production package when cultivars are released. This includes yield potential, disease reactions, N fertilizer recommendations, and DD50 thresholds. The on-farm evaluation of new cultivars allows a complete disease-management package to be developed as well as better information on yield potential and yield response under various environmental and cultural management conditions. Yield potential varies among locations, even within a single year. Examples of data obtained from 2007 demonstrate the variability and suitability of cultivars depending on the conditions on a given farm.

The current study was initiated due to the need for more information about cultivars available to producers. The objectives, therefore, include: 1) to monitor the disease pressure in the different regions of Arkansas, 2) to determine disease reactions of rice cultivars to diseases not commonly observed on experiment stations, and 3) compare the yield potential of commercially available cultivars and advanced experimental lines.

PROCEDURES

Field studies were conducted in 15 counties during 2007. Counties included Chicot, Clay, Craighead, Crawford, Crittenden, Independence, Jackson, Lawrence, Lincoln, Lonoke, Phillips, Poinsett, Prairie, Randolph, and Woodruff. Beginning in 2007, an additional five locations were dedicated to only Clearfield cultivars. The varieties in the conventional test included 'Bengal', 'Cocodrie', 'Cybonnet', 'CL 161', 'CL 171 AR', 'Francis', 'Jupiter', 'Pirogue', 'Presidio', 'Spring', 'Trenasse', 'Wells', 'Sabine', 'Sierra', '4484', and Rice Tec hybrids 'XL 723', 'XL 744', 'CL XL 729', 'CL XL 730', and 'CL XL 745'. Varieties in the Clearfield test included CL 161, CL 171 AR, Rice Tec hybrids CL XL 729, CL XL 730, and CL XL 745 and fifteen University of Arkansas experimental lines (i.e., 'STG05IMI-05-049', 'STG05IMI-05-121', 'STG05IMI-05-123', 'STG05IMI-05-079', 'STG05IMI-01-083', 'STG05IMI-01-113', 'STG05IMI-02-021', 'STG05IMI-02-043', 'STG05IMI-02-055', 'STG05IMI-03-101', 'STG05IMI-04-019', 'STG05IMI-04-077', 'STG05IMI-04-091', 'STG05IMI-05-031', 'STG05IMI-05-082', and 'STG05IMI-06-129'). The tests in Craighead County and Independence County were abandoned due to poor emergence.

Cultivars were sowed in 8-row (7-inch spacing) x 25-ft-long plots and replicated three times in a randomized complete block design. Conventional rice cultivars were seeded at 90 lb/acre while all hybrids were seeded at 30 lb/acre. Under normal conditions, tests do not receive applications of imazethapyr (Newpath®) herbicide labeled for Clearfield rice. However, these five locations that consisted of only Clearfield cultivars were planted in Clearfield rice fields. These tests received two applications of Newpath and one application of imazamox (Beyond®) per Clearfield rice stewardship. Application of this herbicide allows evaluation of cultivar tolerance and hopefully provides advanced knowledge of cultivars that may not have complete resistance.

Plots were managed by the grower with the rest of the field with respect to fertilization, irrigation, weed, and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically and rated for disease, 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 following harvest on selected locations.

RESULTS AND DISCUSSION

Conventional Disease-Monitoring Program

Rice Tec hybrids were the highest-yielding entries in the conventional studies at each location (Table 1). Across all seven harvested locations, the top three entries were XL 723 (208 bu/acre), CL XL 729 (208 bu/acre), and CL XL 730 (200 bu/acre). Jupiter (181 bu/acre), Francis (178 bu/acre), Pirogue (177 bu/acre), and Wells (175 bu/acre) were the highest-yielding conventional varieties. Rice Tec XL 723 was the highest-yielding entry at three of the seven harvested locations. Rice Tec XL 729 was the highest-yielding entry at three of the seven harvested locations. Rice Tec XL 744 was the highest-yielding entry at one of the seven harvested locations.

Monitoring the severity of disease and the reaction of the various cultivars to the presence of disease is a significant part of this program. The information observed in these plots is often the basis for disease ratings developed for use by growers (Table 2). This is particularly true for minor diseases that may not be encountered frequently, such as narrow brown leaf spot, false smut, and kernel smut. A description of the diseases encountered during 2007 follows.

Sheath blight was very aggressive but not widespread in the plots at Chicot County. Sheath blight was rated 9 (dead plants) in small areas of cultivars CL 161, CL 171 AR, Trenasse, and Cybonnet; 8 (panicle damage) for Wells; and 7 (70% of plant height) for CL XP 745 and CL XP 744. There was little impact on yield, however, since the affected areas were so limited within plots. We have isolated the sheath blight pathogen from this location to test virulence compared to other isolates. CL XP 745 and CL XP 744 were severely affected at this location and their yields reflect this. Many tillers in plots of these two hybrids were discolored on the sheaths and died prematurely. At first we thought this was narrow brown leaf spot but samples tested negative for the pathogen. Then we inspected for crown and stem-boring insects but could not find any. At this point, we do not know what caused premature death in these hybrids at this location, but concern is warranted. Other cultivars and hybrids did not exhibit the same symptoms as far as we could determine.

Black sheath rot was rather uniform at the Lawrence County DMP with CL 171 AR rated 7 (on a 0 to 9 rating scale where 0 = no disease evident and 9 = symptoms at the top of the plant) and all other cultivars rated 6 or below. The hybrids were rated 4 to 6 but no differences were apparent. The disease appeared to develop slowly and did not seem to affect yields much, if at all. Straw strength differences were also noticed at this site, with CL XL 730, CL XP 745, and CL XP 744 all having weaker-appearing straw (tendency to lean or begin to lodge) than conventional cultivars or CL XL 729 or XL 723.

Diseases in general were not substantial in the 2007 DMP trials and the hot, dry weather after mid-July diminished foliar disease development in the state. Cultivar disease reactions were adjusted based on 2007 observations and presented in Table 2. In general, hybrids remained the most disease-resistant cultivars under Arkansas conditions.

Across all locations, CL 161 attained the best milling yield with an average of 61% head rice (Table 3). Jupiter, Pirogue, Bengal, and CL 171 AR were very similar, which is not unsusal for the medium- and short-grain varieties. Spring, Rice Tec XP 744, and 4484 had the lowest head rice percentage of all varieties examined.

Clearfield Disease-Monitoring Program

Rice Tec Clearfield hybrids were the highest-yielding entries in the Clearfield studies (Table 4). Rice Tec CL XL 729 was highest over all locations, followed by CL XL 730 and CL XP 745. Several experimental lines from the University of Arkansas breeding program were included in the study, some of which performed better than CL 161 or CL 171 AR. These experimental lines that performed well will be further evaluated in 2008. They may represent the future Clearfield varieties if they continue to perform well. This program and other testing programs become essential for determining the fate of these new lines.

Sheath blight was widespread and aggressive at the Prairie County Clearfield DMP as well, with semi-dwarf long-grain cultivars CL 161 and CL 171 AR rated up to 8 (0 to 9 scale) in certain plots, but hybrids rated only 4 to 5 under the same conditions. Some stunting, delays in maturity, and erratic growth were noted at the Prairie and Lincoln Clearfield DMP locations. At first, the symptoms were suspected to be the result of sensitivity to Newpath herbicide, but this could not be substantiated so the cause may have been other unknown factors. Yield was not always correlated with the symptoms noted.

SIGNIFICANCE OF FINDINGS

The 2007 on-farm rice evaluation and disease-monitoring program 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 in 2008. Plots served as the centerpiece for nine different local rice field days and 29 winter grower meetings.

ACKNOWLEDGMENTS

The authors appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the rice check-off funds administered by the Arkansas Rice Research and Promotion Board. The authors appreciate the cooperation and seed provided by Kirk Johnson, Dr. K.A.K. Moldenhhauer, and Dr. Jim Stroike. The authors especially thank the following county agents who made this work possible: Craig Allen, Mike Andrews, Ron Baker, Stan Carter, Randy Chapecka, Herb Ginn, Robert Goodson, Mike Hamilton, Carl Hayden, Chad Norton, Shawn Payne, Tony Richards, Susan Scott, Eugene Terhune, Brandon Thiesse, and Rick Thompson. The authors also thank the Division of Agriculture, University of Arkansas.

Table 1. Yield performance of selected varieties in replicated rice disease monitoring tests located in grower fields in Arkansas during 2007.

	Grain yield								
	Chicot	Jackson	Lawrence	Lonoke	Poinsett	Randolph	Woodruff	Mean[z]	C.V.[y]
	(bu/acre)								(%)
4484	172	138	159	176	159	155	188	164	10.0
Bengal	140	149	227	165	130	143	156	158	20.3
CL 161	124	141	145	149	125	156	153	142	9.0
CL 171 AR	123	160	175	146	126	140	152	146	12.6
Cocodrie	110	179	189	159	144	152	161	156	16.2
Cybonnet	113	130	179	158	140	154	154	147	14.6
Francis	140	173	216	198	172	169	178	178	13.5
Jupiter	162	192	192	206	166	146	203	181	12.7
Pirogue	149	174	235	196	156	153	178	177	17.2
Presidio	115	172	179	162	151	139	149	152	14.1
RT CL XL 729	179	191	236	219	189	214	231	208	10.6
RT CL XL 730	172	183	239	213	183	193	216	200	11.9
RT CL XP 745	154	195	173	224	181	149	207	183	14.9
RT XL 723	178	206	214	210	206	212	231	208	7.6
RT XP 744	138	190	193	232	175	161	203	185	16.4
Sabine	119	184	188	146	164	147	146	156	15.5
Sierra	105	158	192	146	115	179	121	145	22.7
Spring	119	151	153	162	26	154	162	132	37.0
Tranasse	127	173	191	154	160	164	181	164	12.6
Wells	134	173	212	184	173	175	178	175	13.0
Mean	139	171	194	180	152	163	177		
$LSD_{(0.05)}$	20.1	43.9	52.6	14.5	24.6	18.9	15.6		
C.V. (%)	8.7	15.6	16	4.9	9.5	6.8	5.3		

[z] Mean = average across seven locations.

[y] C.V.= coefficient of variation, provides an indication of yield variability across environments. Lower numbers are better.

Table 2. Rice variety reactions[z] to diseases (2007).

Variety/hybrid	Sheath blight	Blast[y]	Stem rot	Kernel smut	False smut	Brown spot	Straight-head	Lodging	Black sheath rot	Bacterial panicle blight	Narrow brown leaf spot
Bengal	MS	S	VS	MS	MS	VS	VS	MR	MR	VS	S
Jupiter	MS	MS	S	MS	MS	R	MS	MR	MR	MR	MS
Clearfield 161	VS	S	S	S	S	R	MS	MS	S	S	MS
CL 171AR	VS	MS	S	S	S	R	MS	MS	MS	S	MS
Cocodrie	S	MS	S	VS	S	R	VS	MR	MS	VS	MS
Cybonnet	VS	R	S	S	S	R	MS	MR	S	MS	S
Francis	MS	VS	S	VS	S	R	MS	MS	MS	VS	S
Pirogue	MR	MR	S	MS	S	R		MS	MR	MS	MS
Sabine	S		S	S	S	R		MR	MS	S	MS
Sierra	MS	VS	S	S	S	R	MS	MR	MS	MS	MS
Spring	S	MS	VS	MS	MS	R	VS	S	MS	S	MS
Trenasse	VS	S	S	S	S	R	VS	MS	MS	S	MS
Wells	S	S	VS	MS	S	R	MS	MS	MS	S	S
RiceTec XL 723	MS	R	S	MS	S	R	MR	MS	MS	R	MR
RiceTec CL XL 729	MS	MR	S	MS	S	MR	MR	MS	MS	MR	MR
RiceTec CL XL 730	S	MR	S	MS	S	R	MR	S	MS	MR	MR
RiceTec XP 744	S	R	S	MS	S	R		S	MS	R	MR
RiceTec CL XP 745	S	R	S	MS	S	R		S	MS	R	MR

[z] Reaction: R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible. Reactions were established from both historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

[y] Based on reaction to common races of the rice blast fungus in Arkansas for the most part; however, Banks and other Pi-ta resistant gene-based varieties are susceptible to Race IE-1k, a previously rare race that has increased in importance in the state since 2004. All rice varieties should be monitored periodically for blast since the blast fungus is capable of developing new races that can overcome known resistance genes.

Table prepared by R.D. Cartwright, Professor/Extension Plant Pathologist and F.N. Lee, Professor of Plant Pathology.

Table 3. Yield performance of selected varieties in replicated rice disease monitoring tests located in grower fields in Arkansas during 2007.

	Milling yield					
Cultivar	Chicot	Lawrence	Poinsett	Randolph	Woodruff	Mean
	----------------------	(% head rice - % total milled rice)				------------------------
Bengal	60-69	55-69	63-69	56-69	53-72	57-70
Cybonnet	53-73	55-69	59-68	56-65	49-71	54-69
Cocodrie	56-61	54-68	61-68	53-65	56-73	56-67
CL 161	60-69	58-69	62-68	59-68	64-71	61-69
CL 171 AR	50-70	57-69	59-69	61-68	57-73	57-70
Francis	54-69	49-69	60-69	55-68	54-71	54-69
Jupiter	59-69	57-69	61-67	55-67	57-71	58-69
Pirouge	54-70	52-69	56-69	50-67	49-72	52-69
Presidio	48-68	57-69	60-68	62-68	64-70	58-69
RT CL XL 729	42-68	53-69	56-67	61-68	58-73	54-69
RT CL XL 730	44-69	52-69	58-68	62-69	54-72	54-69
RT CL XP 745	35-70	51-70	54-69	59-69	61-72	52-70
RT XL 723	43-69	55-67	58-69	57-67	66-73	56-69
RT XP 744	36-70	57-69	54-69	57-68	42-73	49-70
Sabine	58-68	52-69	63-68	54-67	57-71	57-69
Sierra	40-69	60-69	50-69	58-68	55-73	53-70
Spring	25-67	52-68	45-65	54-68	61-72	47-68
Trenasse	45-68	55-70	54-67	58-68	42-69	51-68
Wells	43-70	55-67	53-70	58-69	57-73	53-70
4484	40-66	52-68	52-67	56-69	49-70	50-68

Table 4. Yield performance of selected Clearfield varieties in replicated rice disease monitoring tests located in grower fields in Arkansas during 2007.

Cultivar	Grain yield					
	Jackson	Lincoln	Phillips	Prairie	Mean	C.V.
	(bu/acre)					(%)
CL 161	91	148	132	123	123	19.7
CL 171 AR	100	153	131	115	125	18.5
RT CL XL 729	151	192	204	191	185	12.6
RT CL XL 730	153	180	144	175	163	10.8
RT CL XP 745	150	150	172	170	161	7.6
STG05IMI-01-083	96		123	134	117	16.7
STG05IMI-01-113	100	170	141	137	137	20.9
STG05IMI-02-021	94	151	134	125	126	18.7
STG05IMI-02-043	85	152	130	141	127	23.1
STG05IMI-02-055	90	149	124	150	128	22.0
STG05IMI-03-101	102	164	127	128	130	19.6
STG05IMI-04-019	85	147	127	136	124	21.8
STG05IMI-04-077	91	136	105	128	115	17.9
STG05IMI-04-091	93	148	158	137	134	21.5
STG05IMI-05-031	73	129	115	109	107	22.1
STG05IMI-05-049	79	123	128	99	107	21.1
STG05IMI-05-079	103	142	111	138	124	15.7
STG05IMI-05-082	95	142	97	128	115	20.0
STG05IMI-05-121	92	151	130	106	120	21.9
STG05IMI-05-123	92	151	117	133	123	20.3
STG05IMI-06-129	97	151	140	117	126	19.0
Mean	96	147	119	125	122	
LSD	16	15	20	16		
C.V.	9.8	6.3	9.2	7.2		

A Model To Predict Safe Stages Of Development For Draining Rice Fields

P.A. Counce, K.B. Watkins, and T.J. Siebenmorgen

ABSTRACT

A computer program has been developed to predict the stage of development for draining rice at which the risk of reduced grain yield or milling quality from insufficient water is considered to be near zero. Experiments to test program predictions were conducted in 2007: one experiment each at Dewitt and Stuttgart, Ark. The model predicted the safe stages for draining as R7 (one kernel on the main-stem panicle is yellow) for both locations. Yields were not reduced by draining at the R7 stage of development compared to draining at 28 days after 50% heading (DAH). Draining at R7 allows a minimum water savings of one irrigation. Budget analysis indicates water savings from one less 3-inch irrigation to be between $4.46 to $24.79 per acre depending on water-table depth of the well. Consequently, our tests in 2007 showed that the program predictions allowed earlier draining, water savings, and no losses of grain yield or milling quality. The 2007 results are consistent with results from two previous years of experiments on draining rice by the rice growth-staging program.

INTRODUCTION

A rice growth-staging system has been developed to allow clear communication among farmers, researchers, extension personnel, and others as to the physiological stage of a rice crop (Counce et al., 2000). Research on growth-staging has allowed us to time the intervals between different reproductive growth stages after heading (Watson et al., 2005; Clements et al., 2003). This is partially because of the objective features of the staging system, which allow clear determination of each growth stage.

Generally, rice yield is sensitive to water stress through the R9 (all kernels that reached R6 have a brown hull) growth stage. As is true for corn and grain sorghum, the crop is sensitive to drought stress until the kernels are filled. Thus, it is generally accepted that any water deficit prior to crop maturity is likely to lead to reductions in both rough rice yield and milling quality. With this caveat in mind, it is worthwhile to know when to drain rice without reducing rough rice yield or milling quality and yet maximize water usage by avoiding unnecessary irrigations.

Consequently, we are faced with the prospect that rice can in some cases be drained at 2 weeks after 50% heading without reducing yield or quality and the other fact that the plant is sensitive to drought stress until the kernels have filled. It is apparent that the soil profile contains significant water after draining and this water can prevent drought stress. Within the root zone of a DeWitt silt loam soil with 4 to 8 inches to the impervious layer, there are 2.6 to 4.0 inches of water available to the rice crop after draining (0.44 inches of water per inch of soil (Davis, 2002)). The crop uses between 0.25 inch/day at the R3 growth stage (heading or emergence of the main stem panicle) and 0.79 inch/day at the R8 growth stage (one or more brown kernels on the head) (Lage et al., 2003). Therefore, water use by the rice crop is great as heads emerge, progressively lessens as the grain develops, and reaches very low levels toward harvest.

With these three elements–intervals between growth stages in DD50 units, water use at different growth stages, and soil water content at draining–an Excel computer program has been developed to predict the safe growth stage for draining rice. Data needed for input are soil type, rooting-zone depth, and the projected (or actual) date of 50% heading. The program incorporates datasets relating reproductive stages to DD50 units for different cultivars (Watson et al., 2005; Clements et al., 2003). The outputs from the program are a predicted growth stage and date of that stage for safely draining a rice field without reducing grain yield or milling quality. Results of field experiments to test the model are reported herein.

PROCEDURES

The first experiment was conducted on a Stuttgart silt loam soil within a 50-acre rice field approximately 3 miles southwest of DeWitt, Ark. (DeWitt location). The plots were 4-ft by 8-ft areas bordered by 14-gauge sheet metal 8-inches above the soil surface and driven into the soil 8-inches deep (the depth of the impervious layer). The experiment at Stuttgart, Ark., was conducted on a DeWitt silt loam soil with field plots 34-ft wide by 120-ft long. Each plot at Stuttgart was bounded by its own normal earth levees. At both Stuttgart and DeWitt, the control treatment was drained 28 days after heading (DAH). There were four replications in each experiment. The cultivar in each experiment was Wells.

The computer program has three components: (1) Prediction of reproductive growth-stage intervals with DD50 units; (2) prediction of maximum water use for each growth-stage interval; and (3) prediction of plant-available water for a given soil at draining. The timing between reproductive stages of development was noted in the field for selected plants of twelve rice cultivars. Subsequently, calculations of DD50 intervals were made (Watson et al., 2005; Clements et al., 2002). Maximum water-use values per day were derived from Lage et al. (2003) and were multiplied by the number of days for a given site and growth stage. The length of specific developmental periods at a given location was determined from the number of DD50 units required for a given stage of development and historical maximum and minimum temperatures at the site for that calendar period. Soil water available after draining was determined by multiplying the depth of the effective root zone by the inches of water available per inch of soil. Soil water-supplying properties can be estimated (among other sources) from Davis (2002). Beyrouty et al. (1996) determined that, although some roots extend to 16 inches, greater than 90% of the roots are in the upper 8 inches. Beginning at R9 and working backward, the amount of water to reach each previous stage of development was summed. First, the water use from R9 to R8 was calculated, then the amount of water used from R9 to R7, then R9 to R6, etc. At a given reproductive growth stage, if the amount of water in the cumulative water-use column was less than or equal to the amount of soil water available at draining, it was deemed to be a safe stage of development to drain the rice field.

Plots were harvested by hand with a sickle and threshed with a stationary thresher. Rough rice harvest moisture content and rough rice yield were determined shortly after harvest for each plot. Subsequently, grain was partially dried in shallow metal pans at room temperature for 1 to 12 hours and stored in two plastic bags within each other at approximately 45°F until transporting to Fayetteville for controlled drying and for determination of brown, milled, and head rice yield determination. Data were subjected to analysis of variance.

The goal of the program is to allow growers to save money by draining rice without reducing rice grain yield or milling quality. Consequently, the predictions are to be conservative to insure there is ample water available so that yield and quality are not reduced. To minimize risk, three assumptions are made: (1) no rainfall will occur after draining the rice field; (2) the maximum water use by the crop is assumed at each growth stage; and (3) no water will be extracted below 8 inches even if the impervious soil layer extends beyond 8 inches. Some rice roots, even with an impervious soil layer, do penetrate below this depth (Sharma et al., 1994; Beyrouty et al., 1996). We know that some of these three assumptions are overly conservative and, consequently, they add a measure of safety to the model's predictions.

RESULTS AND DISCUSSION

Water use predictions cumulative to R9 backward indicated that the safe stage of growth for draining rice would be R7 for both locations (Tables 1 and 2). Grain yields did not differ between controls and plots drained by growth-stage predictions (Table 3). There was no difference in head rice yields at either location due to treatment (Table 4).

Given the results of this study, it is reasonable to expect a minimum savings of one irrigation. Given this irrigation savings, cost savings of $4.46 to $24.79 per acre could be realized by employing the program (Table 5). These results are consistent with the results of studies conducted to test the model's projections in the past 2 years.

SIGNIFICANCE OF FINDINGS

Water pumping costs are a significant part of the costs of producing rice. The goal is to provide all the water needed to produce the maximal rough rice yields and head rice yields. The earlier draining permitted by using the output from the computer draining program resulted in no reductions in either rice grain yield or milling quality. In addition, budget analysis revealed water savings from $4.46 to $24.79 per acre depending upon water depth. These results are consistent with the previous 2 years of research (2005 and 2006) with the growth-staging program and thus provide confidence to the program's predictions.

ACKNOWLEDGMENTS

We thank Arkansas rice producers for support of this project through check-off funds. We especially thank Danny Bulloch for his cooperation. We also appreciate the support of the Division of Agriculture, University of Arkansas.

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Table 1. Dates of draining treatments for two experiments on draining rice conducted on the Arkansas Grand Prairie in 2007.

Draining treatments	DeWitt	Stuttgart
Drain at R7[z]	August 6 (17 DAH)	August 3 (18 DAH)
28 DAH[y]	August 17	August 13

[z] Date (growth stage) at which one grain on main stem panicle is yellow.
[y] DAH, days after heading.

Table 2. Projections for crop water use by Wells rice grown in randomized complete block design experiments conducted at DeWitt and Stuttgart, Ark., in 2007.

Rice growth stage[z] (RGS) interval	Maximum water use/day	Cumulative water use DeWitt	Cumulative water use Stuttgart
	(inches)		
R3-R4	0.256	4.71	4.71
R4-R5	0.236	3.94	3.94
R5-R6	0.209	3.04	3.04
R6-R7	0.189	2.45	2.45
R7-R8	0.118	1.51	1.51
R8-R9	0.079	0.92	0.92
Available soil moisture	--	1.54	1.72
Predicted safe RGS	--	R7	R7

[z] Rice growth stage (RGS) morphological markers:
R3 - Panicle exertion from boot, tip of panicle is above collar of flag leaf on main stem
R4 - One or more floret on main stem panicle has reached anthesis
R5 - At least one caryopsis on the main stem panicle is elongating to the end of the hull
R6 - At least one caryopsis on the main stem panicle has elongated to the end of the hull
R7 - At least one grain on the main stem panicle has a yellow hull
R8 - At least one grain on the main stem panicle has a brown hull
R9 - All grains which reached R6 have brown hulls

Table 3. Grain yield from draining experiments from three Arkansas locations with Wells rice in 2007.

Treatment	Grain yield	
	DeWitt	Stuttgart
	(bu/acre)	
Drained by program predictions at rice growth stage R7[z]	177.7	203.4
Control[y]	167.9	211.1
CV (%)	9.57	11.17
Significance	NS[x]	NS

[z] Rice growth stage R7 is when one grain on the main stem panicle has turned yellow.
[y] Controls were drained at 28 days after 50% heading.
[x] NS = not significant.

Table 4. Head rice yields from draining experiments from three Arkansas locations with Wells rice in 2007.

Treatment	Head rice yield	
	DeWitt	Stuttgart
	(%)	
Drained by program predictions at rice growth stage R7[z]	66.0	59.2
Control[y]	66.4	59.9
CV	1.53	1.86
Significance	NS[x]	NS

[z] RGS R7 is when one caryopsis on the main stem panicle has turned yellow.
[y] Controls were drained at 28 days after heading.
[x] NS = not significant.

Table 5. Variable cost savings associated with a 3 acre-inch reduction in applied water for varying pump lifts.

Variable cost item	Pump lift					
	50	100	150	200	250	300
	(ft)					
Diesel consumption (gallons per acre-inch[z])	0.49	0.99	1.48	1.98	2.47	2.97
Fuel & lubrication cost ($/acre)[y]	3.75	7.58	11.34	15.16	18.92	22.75
Repairs & maintenance cost ($/acre)[x]	0.35	0.35	0.50	0.50	1.69	1.69
Labor cost ($/acre)[w]	0.35	0.35	0.35	0.35	0.35	0.35
Total cost savings ($/acre)	4.46	8.29	12.19	16.02	20.96	24.79

[z] Diesel consumption was varied by pump lift using an engineering formula supplied by Dr. Phil Tacker (University of Arkansas Extension Agricultural engineer).
[y] Fuel consumption for 3 acre-inches multiplied by $2.20/gal for on-farm diesel (2007 Arkansas rice budgets) plus $0.33/gal for engine oil.
[x] Derived from 2007 Arkansas rice budgets. Values for deeper pump lifts were adjusted upward to reflect greater repair expenditures for larger wells.
[w] Derived from 2007 Arkansas rice budgets. Assumes a labor wage of $8.12/hour.

Nitrogen Content In Floodwater Of Drill-Seeded, Delayed-Flood Rice Following Urea Fertilization

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ABSTRACT

Nitrogen (N) fertilizer has the potential to enter surface waters via runoff from rice fields. This study attempts to determine the days after fertilizing that floodwater should be held to minimize N loss via runoff. Microplots were established to quantify the N remaining in the floodwater following preflood- and midseason-N fertilization. Preflood-N fertilizer remained in the floodwater for more than a week after flooding, while midseason-N fertilizer remained for only 5 days. The length of time that rice field floodwater should be held after fertilization appears to depend on N rate, N application (preflood or midseason), and perhaps floodwater temperature. Recommendations regarding the length of time floodwater should be held after fertilization with urea may need to account for these factors.

INTRODUCTION

In the drill-seeded, delayed-flood rice production system, preflood and midseason are the two common times for nitrogen (N) fertilizer application (Norman et al., 2003). The preflood N fertilizer rate is double to triple the midseason-N rate. The preflood-N fertilizer rate is applied aerially as urea onto dry soil at the 4- to 5-leaf stage to provide sufficient N for rapid plant growth during maximum tillering. Fields are quickly flooded to incorporate urea into the soil. Soil-incorporated urea is less likely to be lost via ammonia volatilization or nitrification/denitrification as long as the flood is maintained. Rice uptake of N fertilizer applied preflood reaches a maximum by 21 days after application (Wilson et al., 1989). Therefore, proper water management is needed for at least 3 weeks after fertilization to achieve maximum N fertilizer uptake.

The smaller midseason-N fertilizer rate is applied between panicle initiation and 0.5-inch internode elongation. If applied at the proper time, midseason-N fertilizer reaches maximum uptake 3 days after application (Wilson et al., 1989). By this point in the season, the rice plant has an extensive root system that can take up the midseason-N quickly and the rice canopy has grown to shade the floodwater and create a microclimate that may reduce ammonia escape.

Based on previous studies (Moore et al., 1992; Turner et al., 1980), the current recommendation is to hold the floodwater for one week after the preflood- and midseason-N fertilizer applications to achieve maximum plant uptake and minimize any N loss via runoff. This recommendation seems suitable for midseason-N fertilizer applications, which are rapidly taken up by rice. However, the preflood-N fertilizer does not reach maximum uptake until 21 days after fertilization suggesting that floodwater-N content could be elevated for more than one week following fertilization. Prior to uptake, N can be stored in the soil and/or floodwater until it is utilized by the growing rice plants. The objective of this preliminary report is to look at trends to determine when floodwater can be released after preflood- and midseason-N applications to minimize N loss via runoff; more detailed analyses of statistics will be conducted at a later date.

PROCEDURES

Microplot studies were conducted in 2007 at the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs). 'Wells' rice was chosen for this study because it is one of the principal cultivars grown in Arkansas. Rice was seeded at 100 lb/acre and grown upland until the 4- to 5-leaf stage at which time the microplots were established, treatments were initiated, and the permanent flood was established. Metal squares (30- x 30-inch microplots) were placed into the soil to a sufficient depth (~5 inches) that would prevent water movement into or out of the squares.

Samples were collected by submerging 125 mL plastic bottles into the floodwater of each microplot. The water volume for each microplot was measured every sampling day to allow calculation of total N content of rice field floodwater (data not shown). Dataloggers were used to measure floodwater temperature hourly throughout the summer. The floodwater samples were analyzed for pH and then frozen for later analysis. Samples of floodwater were analyzed for nitrate-N using the Gries-Ilosvay procedure and for ammonium-N using the salicylate-hypochlorite procedure (Mulvaney, 1996), both by automated colorimetric analysis on a Sans-plus segmented-flow autoanalyzer (Skalar Inc., Norcross, Ga.). The diacetyl-monoxime microscale colorimetric procedure was used to analyze for urea-N but in this report only total N concentrations are discussed (Greenan et al., 1995).

Preflood-N Fertilizer Study

The preflood-N study was a 2 (planting date) x 4 (preflood-N rate) split plot arrangement with two planting times (emergence dates 28 April and 30 May) and preflood-N fertilizer treatments that consisted of four N rates (0, 60, 120, and 180 lb N/acre) arranged in a randomized block design and replicated four times. The early planting date was fertilized on 4 June and flooded (4-inch flood depth) the next day and the late planting date was fertilized and flooded on 27 June. Water samples were collected at 0, 1, 3, 4, and 6 or 8 days (depending on planting date) and then weekly for the duration of the growing season.

Midseason-N Fertilizer Study

The midseason-N study was a 2 (preflood-N rate) x 5 (midseason-N treatments) split plot arrangement with two preflood-N rates (60 and 120 lb N/acre) and midseason treatments that consisted of two single application rates (60 and 120 lb N/acre), a control (0 lb N/acre), a split application (30 + 30 lb N/acre), and a plot with no rice receiving a single 60 lb N/acre application arranged in a randomized complete block design and replicated four times. The midseason-N was applied by hand directly into the floodwater on 27 June and for the split method the second application was made on 18 July. Samples were collected 0, 1, 2, 3, 4, 5, 6, and 7 days after fertilization and once a week for the rest of the growing season.

RESULTS AND DISCUSSION

Preflood-N Fertilizer Study

The early planting date (emergence 28 April) had higher average floodwater total N concentrations for the first week and required a longer time to reach that of the no-N control compared to the late (emergence 30 May) planting date (Fig. 1). By 14 days after flooding (DAF), all N rates were equal and therefore only the first 2 weeks were reported. Water temperatures between the seeding dates were different and may have contributed to the different floodwater N contents. The early planting date had a lower mean daily temperature for all but 1 day during the first week after flooding even though the maximum daily temperature for the late planting date was only warmer the first 3 DAF (Fig. 2). In contrast, the minimum daily temperature for the late planting date was 2 to 7°F warmer for the first 9 DAF. The warmer nighttime temperatures may have increased plant growth, N uptake rate, and depletion of ammonium from the water via ammonia volatilization.

Floodwater total-N concentrations for each planting date were examined separately since the planting dates showed slightly different trends. For the early planting date, the total-N concentration of the floodwater 1 day after application was elevated for the three N fertilizer rates compared to the control with the 120 and 180 lb N/acre rates being similar and significantly higher than the 60 lb N/acre rate (Fig. 3). Total-N concentrations in the floodwater declined after day 1 for all N fertilizer rates. The 120 and 180 lb N/acre rates had higher floodwater total-N concentrations compared to the 60 lb N/acre preflood-N fertilizer rate and the control through the first 8 DAF. Floodwater of the 60 lb N/acre rate had a higher total-N concentration through the 4 day sampling compared to the control, but had declined to that of the control by day 8. By 14 DAF, preflood-N rate had no significant influence on floodwater total-N concentration.

Floodwater total-N concentration in the late planted trial followed a similar trend as the early planted trial, but with lower total-N concentrations (Fig. 4). By 6 days after flooding, all treatments were within 1 mg N/L of the control concentration. The late planting date had less N in the floodwater and also decreased to near the control-N concentration quicker than the early planting date, presumably due to higher nighttime temperatures, which may increase plant growth, N uptake rate, and ammonia volatilization.

Midseason-N Fertilizer Study

Total-N concentrations of the floodwater following midseason-N fertilization were slightly higher for the 60 compared to the 120 lb N/acre preflood-N rate for the first few days, but were the same by 4 days after midseason-N application (Fig. 5). The rice plants that received 120 lb N/acre preflood-N were visually larger than the rice plants that received 60 lb N/acre preflood-N, but the difference caused by the two preflood-N rates on floodwater-N concentrations was small and therefore the preflood-N rate was ignored in this preliminary report. The midseason-N fertilizer treatments were as follows: 1) 0 lb N/acre, 2) 30 lb N/acre, 3) 60 lb N/acre, 4) 30 + 30 lb N/acre split, and 5) 60 lb N/acre with no rice. The total-N concentration in all treatments with rice growing decreased to background levels 5 days after application (Fig. 6). When no rice was present (Treatment 5), floodwater-N concentration was still elevated above the control 6 days after fertilization. However, by 14 days after fertilization, floodwater-N concentration in the no rice plot was similar to that of the no-N control with rice.

SIGNIFICANCE OF FINDINGS

The length of time that rice field floodwater should be held after fertilization appears to depend on N rate, N application (preflood or midseason), and perhaps temperature as affected by seeding date (or date of flooding). Recommendations regarding how long floodwater should be held after fertilization with urea may need to account for these factors. The floodwater total-N concentration after preflood-N fertilizer application may be dependent on the nighttime temperatures due to the influence of temperature on plant growth and NH_3 volatilization. Data from 2007 suggest that rice field floodwater should be retained at least 14 days after preflood-N application and flooding, regardless of seeding (or flood) date, to allow floodwater total-N concentrations to return to background levels. Floodwater-N concentrations increased as N rate increased and declined rapidly for all preflood-N rates during the first 6 or 8 days after flooding. However, floodwater-n concentrations between 6 (late planted) or 8 (early planted) and 14 days after preflood-N application were not measured. In contrast, following midseason-N fertilizer applications, floodwater-N concentrations return to background levels by 5 days after N application. The study will be repeated in 2008 with slight changes in sample times to more accurately describe floodwater-N content during the second week after N is applied.

ACKNOWLEDGMENTS

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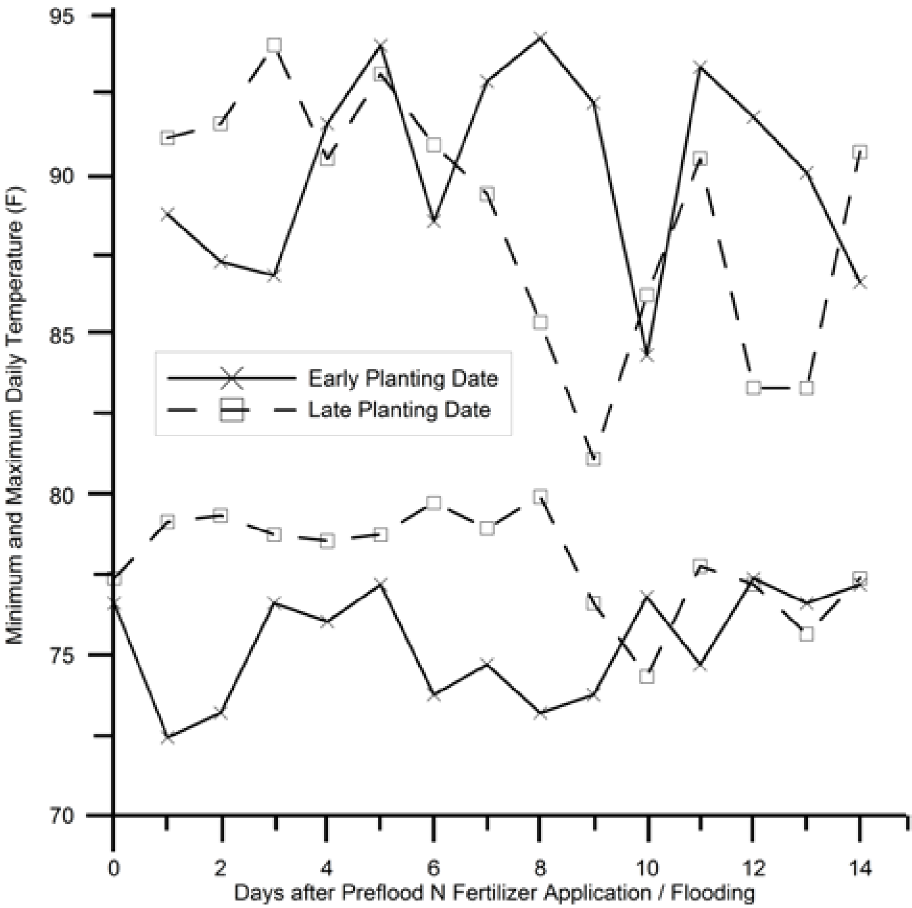

Fig. 1. Influence of planting date on floodwater mean total N concentrations with standard error bars at α=0.05.

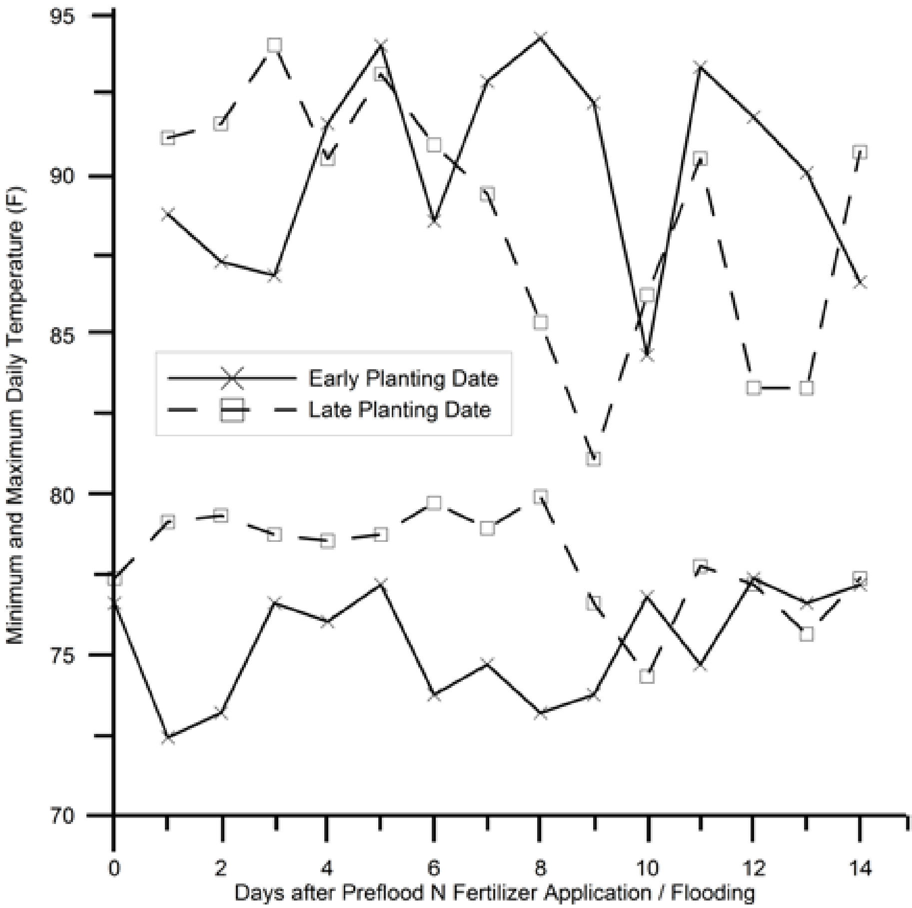

Fig. 2. Minimum and maximum daily floodwater temperatures after flooding for each planting date.

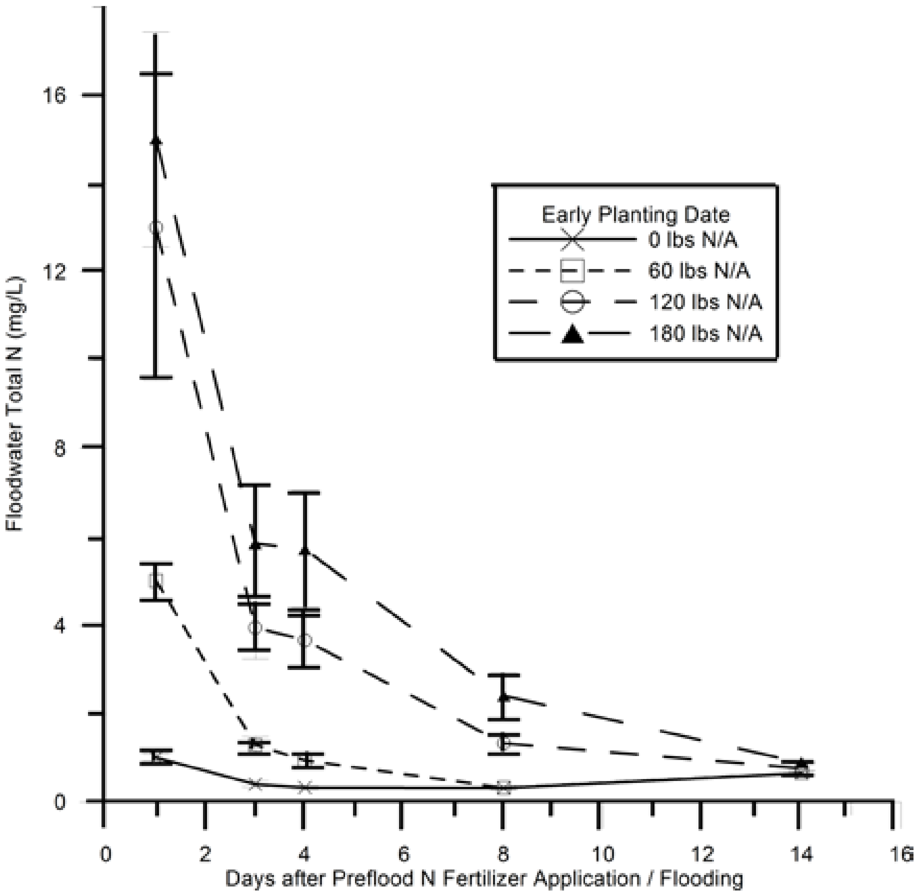

Fig. 3. Floodwater total N concentrations for each treatment of the early planting date with standard error bars at α=0.05.

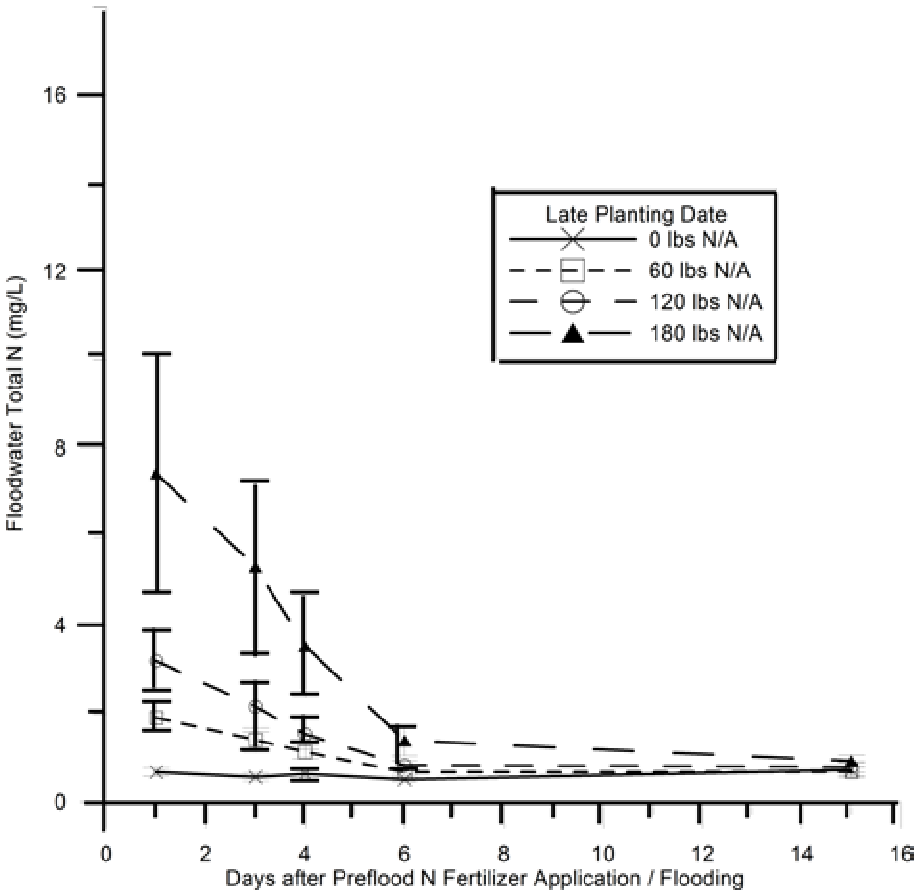

Fig. 4. Floodwater total N concentrations for each treatment of the early planting date with standard error bars at α=0.05.

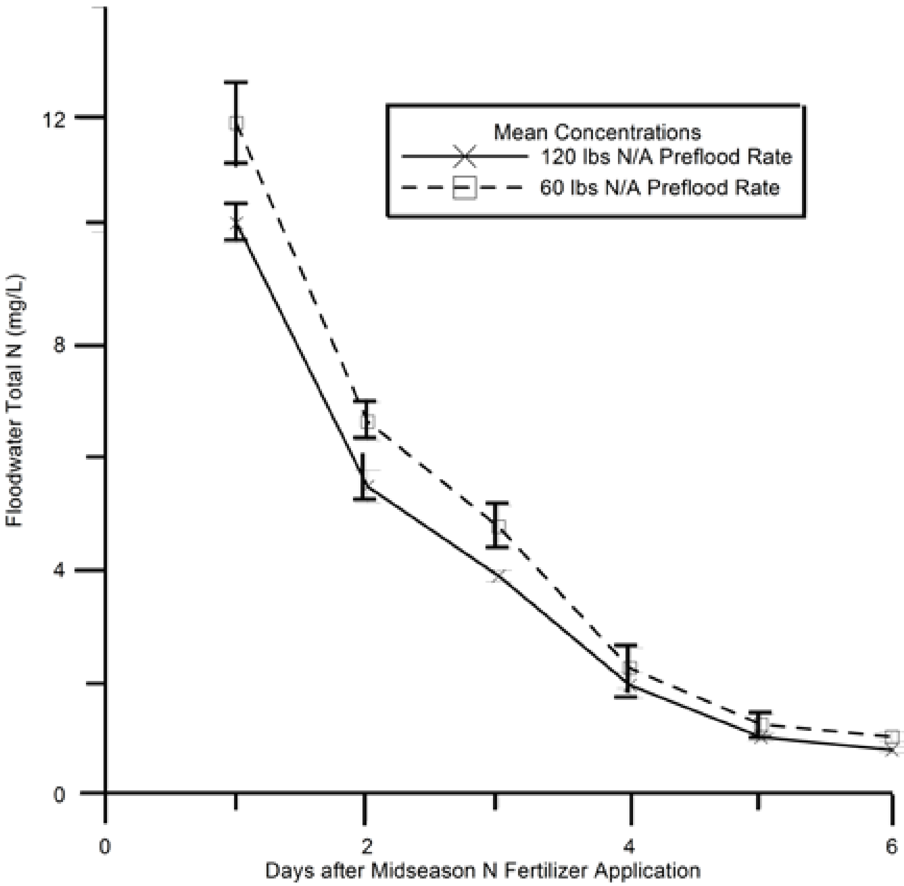

Fig. 5. Influence of preflood N fertilizer rate on mean midseeason floodwater total N concentrations with standard error bars at α=0.05.

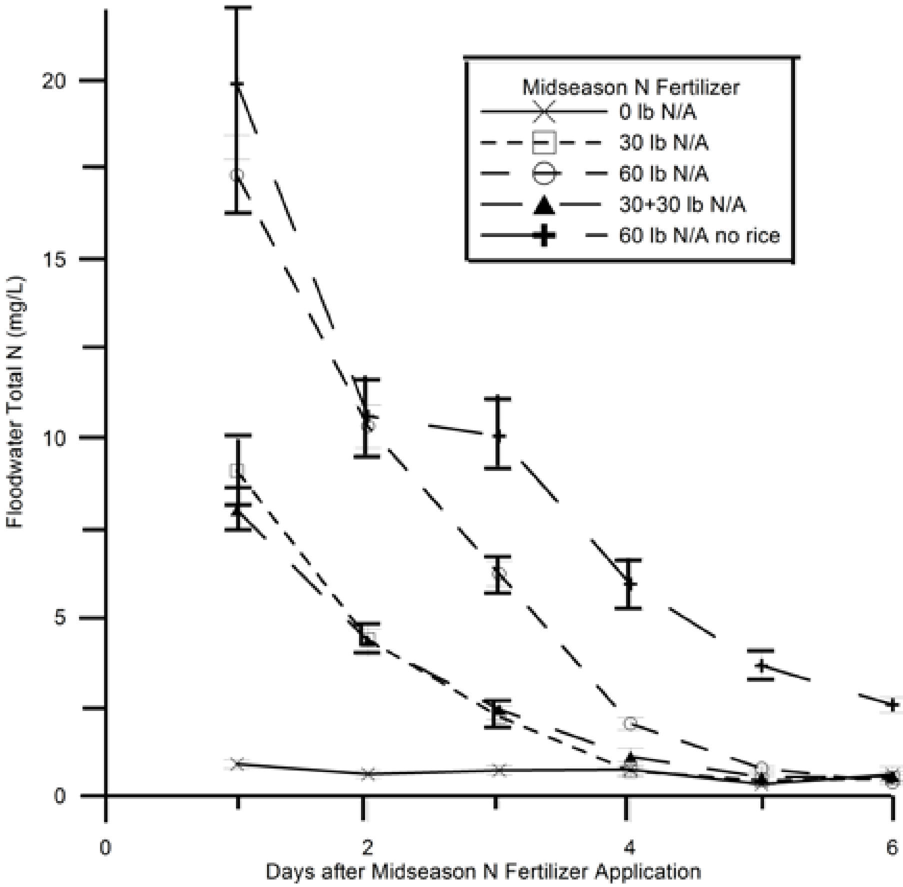

Fig. 6. Floodwater total N concentrations for each treatment of the midseason N fertilizer application with standard error bars at α=0.05.

RICE CULTURE

Development Of Degree-Day 50 Thermal Unit Thresholds For New Rice Cultivars

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ABSTRACT

The DD50 computer program has been one of the most successful programs developed by the University of Arkansas Division of Agriculture. The Degree-Day 50 (DD50) computer program must be continually updated as new, conventional, and hybrid rice cultivars are released. To accomplish this objective, DD50 thermal unit thresholds must be established in a controlled research environment. The DD50 thermal unit accumulations and grain yield performance of each new rice cultivar were evaluated over four seeding dates in the dry-seeded, delayed-flood management system most commonly used in the southern United States. Conventional rice cultivars evaluated in 2007 were as follows: '4484-1693', 'Bowman', 'CL 161', 'CL 171 AR', 'Cybonnet', Francis', 'Jupiter', 'Pirogue', 'Presidio', 'RU0401182', 'Spring', 'Trenasse', and 'Wells'; RiceTec hybrid cultivars included 'XL 723', 'CL XL729', 'CL XL 730', and the two experimental lines, XP744 and CL XP745.

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 Arkansas rice farmers utilize this program as a production management tool and other rice-producing states have developed similar programs based on this model. The program utilizes cultivar-specific data to predict plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. These data are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Each new cultivar remains in the study for a minimum of three years. When a new cultivar is released, the data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study are to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition to these objectives, the influence of seeding date on a cultivar's grain and milling yield performance was considered to determine optimal seeding date for new cultivars.

PROCEDURES

The study was conducted during 2007 at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Thirteen conventional rice cultivars (4484-1693, Bowman, CL 161, CL 171 AR, Cybonnet, Francis, Jupiter, Pirogue, Presidio, RU0401182, Spring, Trenasse, and Wells) and five Rice Tec hybrid cultivars (XL 723, CL XL 729, and CL XL 730, CL XP 745, and XP 744) were drill-seeded at a rate of 40 seeds/ft^2 in nine-row (7-inch spacing) wide plots, 15 ft in length, except the Rice Tec hybrids, which were sown at 16 seeds/ft^2 according to RiceTec hybrid seeding recommendations. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates were 5 April, 23 April, 21 May, and 13 June 2007. The normal cultural practices for dry-seeded delayed-flood rice were followed. All plots received 120 lb N/acre as a single preflood application of urea at the 4- to 5-leaf growth stage. The permanent flood was applied and maintained until the rice reached maturity. Data collected included: maximum and minimum daily temperatures, seedling emergence, and the number of days and DD50 thermal units required to reach 0.5-inch internode elongation and 50% heading. 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 a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels per acre basis. The dried rice was milled to obtain percent total white rice and percent head rice. Each seeding date was arranged as a randomized complete block with three replications. Statistical analyses were conducted with SAS and mean separations were conducted based upon Fisher's protected LSD ($\alpha = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 7 to 21 days (Table 1). Emergence for the 5 April seeding date occurred 21 days after seeding. Time between seeding and emergence of subsequent seeding dates decreased as seeding date was delayed. Also, as the seeding date was delayed, the time between seeding and flooding was generally shorter, ranging from 47 days for the 5 April seeding date and decreasing with each subsequent seeding date down to 30 days for the 13 June seeding date. The number of days between emergence and flooding was generally stable with the exception of the 23 April seeding date. The time from emergence to flooding was 26 days for the 5 April seeding date, increased to 33 days for the 23 April seeding date, and then decreased to 27 and 23 days for the 21 May and 13 June seeding dates, respectively. The longer time between emergence and flooding seen with the 23 April seeding date was caused by a delay in preflood nitrogen application due to wet soil conditions.

The time required from emergence to 0.5-inch internode elongation (IE) averaged 49 days across all cultivars and seeding dates (Table 2). Average time for all cultivars ranged from 53 days when seeded in early April to 42 days when seeded in June, with a maximum time span of 54 days seen in the May seeding date. During 2007, average time of vegetative growth ranged from 44 days for RiceTec CL XL730 to 58 days for Pirogue. The DD50 accumulation during vegetative growth ranged from a low of 1179 for RiceTec CL XL730 to a high of 1589 for Pirogue when averaged across seeding dates. The DD50 accumulation values were relatively similar across all cultivars and seeding dates, but were highest for each cultivar in the May seeding date.

The time required for development between emergence and 50% heading averaged 78 days across all cultivars and seeding dates (Table 3). While many of the commonly produced cultivars were within 2 to 3 days of the average, Spring and Trenasse were much earlier. The time required to reach 50% heading for these cultivars ranged from 6 to 15 days earlier than Wells, depending on seeding date. In contrast, 4484-1693 ranged from 2 to 8 days later than Wells, depending on seeding date. The average DD50 unit accumulations ranged from a low of 1900 for Spring to a high of 2408 for 4484-1693. The average DD50 unit accumulation required to reach 50% heading was 2211 heat units.

When averaged across seeding dates, the cultivars with the highest yields during 2007 included the RiceTec hybrids CL XL 729, CL XL 730, XL 723, and XP 744 (Table 4). The highest-yielding conventional cultivars were 4484-1693, Jupiter, and Wells. During this study year, most cultivars obtained maximum grain yield when seeding either 23 April or 21 May. However, several cultivars achieved maximum grain yield when seeded earlier on 5 April; these included four of the RiceTec hybrids and the experimental line RU0401182. The conventional cultivar, 4484-1693, performed relatively well when seeded late, as did the RiceTec hybrids, CL XL 729, CL XP 745, and XP 744.

Cultivars demonstrating greatest consistent milling yield potential when averaged across seeding dates included Cybonnet, Jupiter, CL 161, and CL 171 AR (Table 5). The 2007 study year indicated a trend toward decreasing milling yield potential as seeding date was delayed. These fluctuations in milling yield may be a response to periods of grain wetting and drying prior to harvest.

SIGNIFICANCE OF FINDINGS

The data from 2007 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 rice cultivar selection, particularly for early- and late-seeding situations.

ACKNOWLEDGMENTS

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Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2007 at the Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date			
Parameter	April 5	April 23	May 21	June 13
Emergence date	April 26	May 3	May 30	June 20
Flood date	May 22	June 5	June 27	July 13
Days from seeding to emergence	21	10	9	7
Days from seeding to flooding	47	43	36	30
Days from emergence to flooding	26	33	27	23

Table 2. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-inch internode elongation of selected rice varieties in studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2007.

	0.5-inch internode elongation									
	05-Apr-07		23-Apr-07		21-May-07		13-Jun-07		Average	
Cultivar[z]	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
4484-1693	54	1338	52	1362	46	1348	41	1188	48	1309
Bowman	56	1387	58	1536	51	1482	45	1316	52	1430
CL 161	51	1244	52	1352	43	1270	40	1145	46	1253
CL 171 AR	53	1296	54	1413	46	1330	42	1209	48	1312
Cybonnet	.	.	.	.	.	.	.	.	.	.
Francis	.	.	.	.	.	.	.	.	.	.
Jupiter	56	1397	58	1536	52	1499	47	1369	53	1450
Pirogue	62	1588	62	1669	54	1558	52	1540	58	1589
Presidio	54	1338	56	1474	49	1425	42	1209	50	1361
RT CL XL 729	51	1244	53	1402	44	1287	40	1156	47	1272
RT CL XL 730	48	1154	49	1272	42	1221	37	1071	44	1179
RT CL XP 745	51	1244	54	1413	43	1270	39	1135	47	1265
RT XL 723	52	1265	52	1352	43	1250	39	1124	46	1248
RT XP 744	52	1286	52	1372	43	1250	40	1166	47	1268
RU0401182	54	1338	56	1474	47	1367	43	1262	50	1360
Spring	.	.	.	.	.	.	.	.	.	.
Trenasse	51	1254	50	1301	44	1290	41	1198	47	1261
Wells	55	1357	56	1474	48	1386	42	1230	50	1362
Mean	53	1315	54	1427	46	1349	42	1221	49	1328
LSD	9	80								
C.V.	3.1	2.3								

[z] The cultivars Cybonnet, Francis, and Spring were not included in these determinations.

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 Rice Research and Extension Center near Stuttgart, Ark., during 2007.

	50% Heading									
	05-Apr-07		23-Apr-07		21-May-07		13-Jun-07		Average	
Cultivar[z]	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
4484-1693	91	2396	91	2504	81	2409	76	2301	85	2402
Bowman	82	2151	88	2387	80	2377	78	2311	82	2306
CL 161	84	2209	88	2397	81	2409	74	2222	82	2309
CL 171 AR	84	2230	88	2408	82	2420	75	2262	82	2330
Cybonnet	83	2189	88	2397	77	2271	74	2240	81	2274
Francis	82	2159	88	2387	77	2271	74	2230	80	2261
Jupiter	82	2161	84	2272	77	2271	73	2192	79	2224
Pirogue	83	2199	86	2344	75	2196	74	2220	80	2240
Presidio	78	2041	85	2292	75	2196	69	2081	77	2152
RT CL XL 729	80	2096	84	2261	78	2292	70	2102	78	2188
RT CL XL 730	80	2104	85	2294	78	2292	70	2123	78	2203
RT CL XP 745	77	2031	80	2158	73	2143	68	2050	75	2096
RT XL 723	79	2077	83	2252	76	2228	69	2092	77	2162
RT XP 744	77	2022	79	2139	73	2143	68	2060	74	2091
RU0401182	84	2319	88	2397	82	2431	76	2281	83	2332
Spring	70	1822	75	2034	67	1951	60	1796	68	1900
Trenasse	74	1938	79	2139	72	2121	65	1966	73	2041
Wells	83	2199	88	2408	78	2303	74	2230	81	2285
Mean	81	2125	85	2304	77	2262	72	2153	78	2211
LSD	20									
C.V.	2.4	1.5								

Table 4. Influence of seeding date on grain yield of selected rice varieties studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2007.

	Grain yields				
Cultivar	5-Apr	23-Apr	21-May	13-Jun	Average
4484-1693	177	184	185	156	176
Bowman	154	161	128	85	132
CL 161	151	170	136	75	133
CL 171 AR	163	150	131	91	134
Cybonnet	171	164	180	69	146
Francis	174	196	161	110	160
Jupiter	175	189	192	116	168
Pirogue	130	133	167	127	139
Presidio	139	126	149	79	123
RT CL XL 729	230	207	200	133	193
RT CL XL 730	210	204	199	124	184
RT CL XP 745	153	233	194	137	179
RT XL 723	231	206	205	117	190
RT XP 744	186	211	204	142	186
RU0401182	177	155	153	121	152
Spring	140	155	86	50	108
Trenasse	169	185	144	102	150
Wells	174	184	188	117	166
Mean	172	179	166	105	157
LSD	31	27	30	28	
C.V.	10.3	8.9	10.8	15.8	

Table 5. Influence of seeding date on milling yield of selected rice varieties studies conducted at the Rice Research and Extension Center near Stuttgart, Ark., during 2007.

	Milling yields				
Cultivar	5-Apr	23-Apr	21-May	13-Jun	Average
4484-1693	43-69	48-70	62-70	44-69	49-69
Bowman	64-72	63-71	60-70	42-66	57-70
CL 161	67-72	62-71	65-72	62-72	64-72
CL 171 AR	68-74	66-72	64-74	60-71	64-73
Cybonnet	68-73	66-71	64-72	62-71	65-72
Francis	65-72	61-71	60-71	54-70	60-71
Jupiter	67-72	69-72	69-73	68-73	68-73
Pirogue	56-73	48-73	60-72	61-73	59-73
Presidio	67-72	59-71	62-70	56-70	61-71
RT CL XL 729	63-73	60-71	59-71	55-70	59-71
RT CL XL 730	63-72	61-72	62-72	52-70	60-72
RT CL XP 745	61-72	60-72	59-73	4871	57-72
RT XL 723	63-72	63-72	59-71	56-70	60-71
RT XP 745	63-72	62-73	59-72	56-72	60-72
RU0401182	64-72	60-70	64-72	54-70	61-71
Spring	62-72	56-70	48-70	56-69	55-70
Trenasse	60-70	58-69	56-69	44-67	54-69
Wells	61-73	58-74	62-73	52-71	58-73
Mean	64-72	61-72	61-72	55-70	60-71
LSD					
C.V.					

Effect Of Nutrisphere On Ammonia-Volatilization Loss Of Urea And The Grain Yield Of Drill-Seeded, Delayed-Flood Rice

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ABSTRACT

Field studies were conducted in Arkansas and Mississippi to determine if Nutrisphere-treated urea could be applied up to 10 days prior to flooding with minimal loss of rice grain yield. Grain yield was measured in three field studies with delayed-flood rice where urea was treated with and without Nutrisphere applied up to 10 days prior to flooding. A laboratory incubation study measured the ammonia volatilization of urea, Nutrisphere-treated urea, Agrotain®-treated urea, and ammonium sulfate applied to soil over a 15-day period. Although there was a significant influence of nitrogen (N) rate and application timing on rice grain yield, there was no significant influence from Nutrisphere. Rice grain yield significantly decreased as the time between N fertilizer application and flooding was increased from 1 to 10 days whether the urea was treated or not treated with Nutrisphere. This finding brought into question Nutrisphere's urease-inhibition claims and the initiation of a laboratory incubation study. In the incubation study, ammonium sulfate had the least amount of ammonia volatilized followed by Agrotain®-treated urea. Urea and Nutrisphere-treated urea had the most ammonia volatilized. Nutrisphere did not significantly inhibit ammonia volatilization of urea and is thus not an effective urease inhibitor.

INTRODUCTION

In the direct-seeded, delayed-flood rice culture system, nitrogen (N) in the form of urea is applied onto dry soil immediately prior to flooding at around the 4- to 5-leaf growth stage or beginning tillering. Once the preflood urea-N has been applied, flooding should be completed as quickly as possible to minimize ammonia volatilization losses (Norman et al., 2004). The floodwater incorporates the N fertilizer into the soil where it is protected against losses via ammonia volatilization and/or nitrification/denitrification as long as a flood is maintained (Savin et al., 2007). Norman et al. (2004) measured ammonia volatilization losses of 15 to 20% of the applied urea-N by 5 days after urea application. Agrotain®-treated urea and ammonia sulfate both lost less than 5% of the applied N by 5 days after application. Consequently, when a field cannot be flooded within 2 to 3 days after urea application, it is recommended Agrotain®-treated urea or ammonium sulfate be used as the preflood-N source. Agrotain® contains the documented urease inhibitor NBPT that slows the conversion of urea to ammonia and minimizes ammonia-volatilization loss in this fashion. Ammonium sulfate is simply a slightly acidic ammonium fertilizer and is not prone to ammonia-volatilization loss compared to urea. Nutrisphere has recently come on the market and is being sold by Specialty Fertilizer Products as a urease inhibitor for application to urea like Agrotain®. Consequently, a study was initiated to determine if Nutrisphere effectively inhibited ammonia volatilization loss of urea and if Nutrisphere enabled urea to be applied up to 10 days prior to flooding with minimal loss of rice grain yield. The objective of the laboratory study was to measure the ammonia volatilization inhibition of Nutrisphere on urea and the objective of the field study was to compare urea and Nutrisphere applied at different rates and times prior to flooding on the grain yield of drill-seeded, delayed-flood rice.

PROCEDURES

Field studies were conducted in 2006 at the Mississippi State University Delta Research and Extension Center (DREC) in Stoneville, Miss., on a Sharkey clay (Vertic Haplaquepts) and in 2007 at two University of Arkansas experiment stations, the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs), and at the Lake Hogue Research Farm (LHRF) near Weiner, Ark., on a Hillemann silt loam (Glossic Natraqualfs). The cultivar chosen for the 2006 Mississippi study was ‘Cheniere’ and the cultivar chosen for the 2007 Arkansas studies was ‘Wells’. Both cultivars are long-grains with excellent yield potential and two of the principal cultivars grown in the southern U.S. Ricebelt. Rice was seeded at ~100 lb/acre in nine-row plots (7-inch spacing) 15 feet in length. The rice was grown upland until the 4- to 5-leaf growth stage at which time a permanent flood (2- to 4-inch depth) was established and maintained until maturity. The Mississippi study was a factorial arrangement of treatments that consisted of two N rates (90 and 150 lb N/acre), two application times (1 and 10 days prior to flooding), and three N sources [urea , Nutrisphere (0.5%)-treated urea, and Nutrisphere (1.0%)-treated urea] arranged in a randomized complete block design and replicated four times. The Arkansas studies were a factorial arrangement of treatments that consisted of two N rates (60 and 120 lb N/acre) plus a control (0 lb N/acre), three application times (~ 1, 5, and 10 days prior to flooding), and two N sources [urea and Nutrisphere (1.0%)-treated urea] arranged in a randomized complete block design and replicated four times. Dates when selected management practices were conducted for all three studies are shown in Table 1. 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 bushel (bu)/acre at 12% moisture. A bushel of rice weighs 45 pounds. Statistical analyses were conducted on grain yield data with SAS and mean separations were based upon protected LSD where appropriate.

An ammonia volatilization study was conducted in the laboratory on four N fertilizer sources: i) urea, ii) ammonium sulfate, iii) Agrotain (0.4%)-treated urea, and iv) Nutrisphere-(1.0%) treated urea. The N fertilizers were applied to a DeWitt silt loam soil (20% volumetric water content) at an N fertilizer rate of 180 lb N/acre. The study was arranged in a randomized complete block design with four replications. Statistical analyses were conducted on the ammonia volatilization data with SAS and mean separations were based upon protected LSD where appropriate. Ammonia volatilization was measured over a 15-day period, after N fertilizer application, utilizing diffusion chambers kept at 25°C. This particular laboratory method with the large-N rate applied works well for measuring the ammonia volatilization potential of an N source, because it accentuates the N loss mechanism and makes it easy to distinguish the difference in ammonia volatilization potential of different N sources. To put things in perspective, the amount of ammonia volatilized from urea and Agrotain in this lab study are about double what we have measured in the field.

RESULTS AND DISCUSSION

Currently, urea applied immediately (i.e., < 2 days) prior to flooding (termed 'preflood') results in the most efficient use of N fertilizer in delayed-flood rice and results in the highest grain yield per amount of N applied. Consequently, this N fertilizer and application method has become the standard by which all proposed N fertilizers and application strategies are compared. Previous studies in Arkansas on silt loam soils have established that if N fertilization rates are not excessive, urea applied 1 day before flooding usually results in better rice yields than when applied 5 days before flooding, and virtually always better than when applied 10 days before flooding (Norman et al., 2004). The studies also found that ammonium sulfate and Agrotain applied 5 and 10 days prior to flooding typically produce rice yields similar to urea or ammonium sulfate and Agrotain applied 1 day before flooding.

There were no interactions between N source, N rate, and/or application timing in any of the three field studies conducted, but there were some significant main treatment effects. In Mississippi at the DREC in 2006, the weather cooperated with no rain during the 10 days prior to flooding after the N sources were applied. Urea treated with Nutrisphere at 0.5% or at 1.0% had no significant effect on rice grain yield at the DREC (Table 2). However, there was a significant grain yield decrease at the DREC when the N sources were applied 10 days prior to flooding compared to 1 day (Table 3). The significant yield decrease when the flood was delayed for 10 days indicates that there was ammonia-volatilization loss prior to flooding and that Nutrisphere did not influence the ammonia-volatilization loss enough to maintain yield like Agrotain and ammonium sulfate (Norman et al., 2004) did. There was a significant yield increase at the DREC when the N rate was increased from 90 to 150 lb N/acre (Table 4).

The weather cooperated quite well at the LHRF in 2007 with only a trace of rain occurring between any of the N application times and flooding (Table 1). Similar to the DREC, rice grain yield was not significantly different between Nutrisphere-treated urea and urea at the LHRF (Table 5). Rice grain yield displayed a significant decrease when the time between N application and flooding was increased from 1 to 5 days and a nonsignificant grain yield decrease as the time increased from 5 to 11 days at the LHRF (Table 6). This indicates enough ammonia-volatilization loss occurred over the 11 days prior to flooding at the LHRF to cause the rice grain yield to decrease from 177 bu/acre to 156 bu/acre and Nutrisphere was not able to minimize the loss enough to significantly influence rice yields, let alone maintain them. Rice grain yield at the LHRF increased significantly from 139 bu/acre when no N fertilizer was applied to 161 and 170 bu/acre when 60 and 120 lb N/acre, respectively, were applied (Table 7).

The weather was not fully cooperative at the RREC location due to a 2-inch-plus rain occurring the day after the 10-day-prior-to-flooding N application (Table 1). However, the 10-day-prior-to-flooding N application at the RREC can be used to evaluate the nitrification inhibition abilities of Nutrisphere and of course there is the 6-day-prior-to-flooding N application for evaluating ammonia volatilization. Rice grain yields at the RREC were not significantly influenced by use of Nutrisphere with the urea (Table 5). Not at any of the three sites did Nutrisphere cause a significant grain yield increase. Grain yield at the RREC significantly decreased from 164 bu/acre to 144 bu/acre as the time between N application and flooding was increased from 1 to 6 days and decreased further to 114 bu/acre when the time between was increased to 10 days (Table 8). This indicates there was substantial ammonia-volatilization loss between 1 and 6 days prior to flooding that Nutrisphere was not able to significantly influence. It also indicates that Nutrisphere is probably not a good nitrification inhibitor either because there was a significant yield difference between the 10- and 6- or 1-day application times at the RREC. The 10-day-prior-to-flood N application at the RREC received a 2-inch rain the next day that would have effectively incorporated the N fertilizer and stopped any ammonia volatilization. Thus, nitrification 10 days prior to flooding followed by denitrification after flooding would have been the only N loss mechanism involved in the 10 day prior to flooding treatments. It seems that if Nutrisphere was indeed a nitrification inhibitor, then the 10-day-prior-to-flooding treatment should have been better than urea applied at the same time, but it was not. Nutrisphere applied at 10 days was not even as good as, let alone better than, the 6-day-prior-to-flooding urea application that lost yield because of ammonia volatilization. Further, Nutrisphere had no significant influence on yield at the 10-day application time, which indicates that it was not an effective nitrification inhibitor. Grain yield at the RREC was significantly increased when N fertilizer was applied and significantly increased when the N rate was increased from 60 to 120 lb N/acre (Table 7).

Because Nutrisphere did not have a significant influence on rice grain yield at any of the application times at all three site-years, a laboratory study was conducted. Shown in Table 9 are the cumulative ammonia-volatilization loss means from each of the N sources measured 3, 7, 11, and 15 days after N fertilizer application. Ammonium sulfate lost the least N to ammonia volatilization of all products tested with only 0.6% of the applied N lost over the 15-day incubation. The product with the second lowest amount of N lost via ammonia volatilization of all the products tested was Agrotain-treated urea. Agrotain-treated urea lost via ammonia volatilization essentially none of the applied N by day 3, 2.7% of the applied N by day 7, 12.7% of the applied N by day 11, and 18.3% of the applied N by day 15. Urea (check), on the other hand, lost via ammonia volatilization was 14.5% by day 3, 35.9% by day 7, 51.8% by day 11, and 56.9% by day 15. Nutrisphere-treated urea lost similar amounts of applied N via ammonia volatilization as untreated urea (check) by day 3 and day 15, but lost significantly more by day 7 and day 11. Nutrisphere-treated urea lost via ammonia volatilization 17.6% of the applied N by day 3, 42.2% of the applied N by day 7, 57.8% of the applied N by day 11, and 62.7% of the applied N by day 15. Thus, Nutrisphere was not an effective urease inhibitor like Agrotain.

SIGNIFICANCE OF FINDINGS

The rice field studies comparing urea with and without Nutrisphere indicated Nutrisphere, unlike Agrotain and ammonium sulfate, does not produce similar yields when applied from 5 to 10 days prior to flooding. When Nutrisphere-treated urea was the N source, grain yields decreased similar to untreated urea as the time between N application and flooding increased. No significant rain occurred at the DREC nor at the LHRF and no significant rain occurred after the 6-day-prior-to-flooding N application at the RREC; thus, any decrease in yield as the time between N application flooding was increased can be attributed to ammonia-volatilization loss that Nutrisphere did not significantly minimize. This finding agrees with the laboratory incubation study that showed Nutrisphere did not significantly decrease the ammonia volatilization loss of urea like Agrotain. The-10-day-prior-to-flooding N application at the RREC, which received the 2-plus inches of rain the day after N application, was used to evaluate Nutrisphere as a nitrification inhibitor. When Nutrisphere was applied 10 days prior to flooding at the RREC, a significant decrease in grain yield resulted that was not significantly different from urea. Consequently, the data indicate Nutrisphere was not any more effective as a nitrification inhibitor than it was as a urease inhibitor.

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Table 1. Pertinent agronomic information for the field studies conducted in 2006 at the Delta Research and Extension Center (DREC) in Stoneville, Miss., and in 2007 at the Lake Hogue Research Farm (LHRF), near Weiner, Ark., and the Rice Research and Extension Center (RREC) near Stuttgart, Ark.

Practices	DREC	LHRF	RREC
Planting dates	5/9	5/10/06	4/19
Emergence dates	5/19	5/19	4/28
Preflood N dates and rain dates	6/1 = 10 d before flood N applied 6/9 = 1 d before flood N applied	6/1 = 11 d before flood N applied 6/7 = 5 d before flood N applied 6/10 = trace of rain 6/11 = 1 d before flood N applied	5/14 = 10 d before flood N applied 5/15 = 2 inch rain 5/18 = 6 d before flood N applied 5/24 = 1 d before flood N applied
Flood dates	6/10	6/12	5/25
Harvest dates	9/9	9/14	8/29

Table 2. Influence of nitrogen (N) source on rice grain yield at the Delta Research and Extension Center in 2006.

N source	Grain yield
	(bu/acre)
Nutrisphere (0.5%) + urea	169
Nutrisphere (1.0%) + urea	167
Urea	172
$LSD_{(\alpha=0.05)}$	NS[z]

[z] NS = nonsignficant at the 0.05 probability level.

Table 3. Influence of nitrogen (N) application timing on rice grain yield at the Delta Research and Extension Center in 2006.

N application timing	Grain yield
(dpf[z])	(bu/acre)
1	174
10	165
$LSD_{(\alpha=0.05)}$	7

[z] dpf = number of days prior to establishment of permanent flood.

Table 4. Influence of nitrogen (N) rate on rice grain yield at the Delta Research and Extension Center in 2006.

N rate	Grain yield
(lb N/acre)	(bu/acre)
90	157
150	182
$LSD_{(\alpha=0.05)}$	7

Table 5. Influence of nitrogen (N) source on rice grain yield at the Lake Hogue Research Farm (LHRF) and the Rice Research and Extension Center (RREC) in 2007.

	Grain yield	
N source	LHRF	RREC
	-------- (bu/acre) -------	
Nutrisphere (1.0%) + urea	164	139
Urea	167	142
$LSD_{(\alpha=0.05)}$	NS[z]	NS

[z] NS = nonsignficant at the 0.05 probability level.

Table 6. Influence of nitrogen (N) application timing on rice grain yield at the Lake Hogue Research Farm in 2007.

N application timing	Grain yield
(dpf[z])	(bu/acre)
1	177
5	163
11	156
$LSD_{(\alpha=0.05)}$	8

[z] dpf = number of days prior to establishment of permanent flood.

Table 7. Influence of nitrogen (N) rate on rice grain yield at the Lake Hogue Research Farm (LHRF) and the Rice Research and Extension Center (RREC) in 2007.

	Grain yield	
N rate	LHRF	RREC
(lb N/acre)	------------------(bu/acre)------------------	
0	139	56
60	161	122
120	170	159
$LSD_{(\alpha=0.05)}$	8	10

Table 8. Influence of nitrogen (N) application timing on rice grain yield at the Rice Research and Extension Center in 2007.

N Timing	Grain yield
(dpf[z])	(bu/acre)
1	164
6	144
10	114
$LSD_{(\alpha=0.05)}$	10

[z] dpf = number of days prior to establishment of permanent flood.

Table 9. Ammonia volatilization of urea, ammonium sulfate, Agrotain-treated urea, and Nutrisphere-treated urea from a Dewitt silt loam soil during a 15-day laboratory incubation.

N sources	Day 3	Day 7	Day 11	Day15
	-------------------------(% of N applied)------------------------------			
Urea	14.5	35.9	51.8	56.9
$(NH_4)_2SO_4$	0.1	0.2	0.5	0.6
Agrotain + urea	0.006	2.7	12.7	18.3
Nutrisphere + urea	17.6	42.2	57.8	62.7
$LSD_{(\alpha=0.05)}$	6.6	3.5	5.9	6.0

Grain Yield Response Of Fourteen New Rice Cultivars To Nitrogen Fertilization

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ABSTRACT

The Variety x Nitrogen (N) Fertilizer Rate Study determines the proper N fertilizer rates for the new rice cultivars across the array of soil and climatic conditions that exist in the Arkansas rice-growing region. The fourteen rice cultivars evaluated for N fertilizer response in 2007 were: 'Bowman'; 'Jupiter'; 'Pirogue'; 'Presidio'; 'Trenasse'; Clearfield 'CL 171 AR'; the Arkansas experimental varieties 'RU0401182', 'RU0601170', and 'RU0601188'; the USDA-ARS experimental '4484-1693'; and the RiceTec hybrids Clearfield 'CL XL 729', Clearfield 'CL XL 730', 'XP 744', and Clearfield 'CL XP 745'. When the rice varieties were grown on silt loam soils, Bowman, CL 171 AR, and RU0401182 required 90 to 120 lb N/acre to maximize yield; Pirogue, Trenasse, and 4484-1693 always required 120 lb N/acre to maximize yield; and Jupiter, Presidio, RU0601170, and RU0601188 required 120 to 150 lb N/acre to maximize yield. A severe storm at the Northeast Research and Extension Center (NEREC) 2 weeks prior to harvest caused all of the rice varieties to shatter and lodge to some degree, with the damage most extreme at the N rates that typically maximize rice yield on the clay soils. Due to the lodging and shattering from the storm at the higher N rates, all of the rice varieties obtained maximal yield on the clay soil at the NEREC when 120 to 150 lb N/acre were applied. The three Arkansas experimental varieties displayed yield stability over a wide range of N fertilizer rates. The four RiceTec hybrids generally required 90 lb N/acre applied preflood to maximize grain yield. However, when an additional 30 lb N/acre were applied at late boot (LB), yields tended to increase in the absence of lodging and significantly increase in the presence of lodging due mainly to the LB application minimizing lodging.

INTRODUCTION

A major strength of the rice-soil fertility research program has been the delineation of N fertilizer response curves for promising new rice cultivars. This study measures the performance of the new cultivars over a range of N fertilizer rates on clay and silt loam soils and determines the proper N fertilizer rates across the array of soils and climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Fourteen cultivars were studied in 2007 at one to three locations, depending on seed supply. Louisiana had three new varieties in the studies: i) Jupiter, a semidwarf medium-grain; ii) Pirogue, a semidwarf short-grain; and iii) Trenasse, a semidwarf long-grain. Presidio, a semidwarf long-grain, was released by Texas. Mississippi released a new semidwarf long-grain named Bowman. Arkansas, in collaboration with Horizon AG, released CL 171 AR, a new Clearfield long-grain developed from the 'Wells' variety. Clearfield rice varieties are tolerant to the broad spectrum herbicide imazethapyr (Newpath). RiceTec Clearfield CL XL 729, CL XL 730, and CL XP 745 are long-grain hybrid varieties tolerant to Newpath. The other RiceTec hybrid, XP 744, is a long-grain. There were four experimental lines in the studies in 2007. The three experimental varieties, RU0401182, RU0601170, and RU0601188, are from Arkansas and 4484-1693 was from the USDA-ARS National Rice Research Center near Stuttgart, Ark.

PROCEDURES

Locations where the Variety x N-Fertilizer Rate Studies were conducted and corresponding soil series are as follows: Lake Hogue Research Farm (LHRF), in Poinsett County near Weiner, Ark, on a Hillemann silt loam (Thermic, Albic, Glossic Natraqualfs); Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized was a randomized complete block with four replications at all locations for all the rice cultivars studied. The split application scheme utilized for all cultivars, except the RiceTec hybrids, was a two-way split application method where the N fertilizer was split-applied at preflood and beginning internode elongation (BIE) in the following total N (preflood N + BIE N) rate splits: 0 (0+0), 60 (30+30), 90 (45+45), 120 (75+45), 150 (105+45), 180 (135+45), and 210 (165+45) lb N/acre. The studies on the two silt loam soils at the LHRF and the RREC received the 0 to 180 lb N/acre fertilizer rates and the study on the clay soil at the NEREC received the 0 to 210 lb N/acre N rates with the 60 lb N/acre rate omitted. Studies on the clay soil at the NEREC received the higher N rate of 210 lb N/acre and had the low N rate of 60 lb N/acre omitted, because 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 150 lb N/acre applied in an assortment of split applications at preflood, BIE, and LB. The rice was drill-seeded in plots nine-rows wide (row spacing of 7 inches), 15-ft. in length at a rate of 100 lb/acre on the silt loam soils and 130 lb/acre on the clay soil, except the RiceTec hybrids, which were seeded at a rate of 31 lb/acre on the silt loam soil at the LHRF. Rice was seeded on 19 April at the RREC, on 1 May at the NEREC, and on 10 May at the LHRF. 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

Bowman did not significantly increase in grain yield when more than 90 and 120 lb N/acre were applied on the silt loam soils at the LHRF and the RREC, respectively (Table 1). The high native soil-N at the LHRF is the reason why Bowman maximized yield when only 90 lb N/acre were applied and the RREC also had a good amount of native soil-N. This is probably why the grain yield of Bowman decreased significantly when the amount of N greater than the optimum rate was applied to the silt loams soils. However, Bowman did not lodge on the silt loam soils. When Bowman was studied on the clay soil at the NEREC, 150 lb N/acre were required to maximize grain yield. It is typical for rice to require 30 to 60 lb N/acre more to reach maximum yield potential when grown on clay soils compared to silt loam soils. There was some lodging and shattering of all varieties at the NEREC due to a weather event 2 weeks before harvest that included 4 inches of rain and high winds. The lodging and shattering lowered the yields of all varieties at the NEREC, some more than others, and the yields obtained should be viewed in that light. Bowman stood better than most varieties at the NEREC and did not began to lodge and display a decreasing trend in grain yield until more than 150 lb N/acre were applied. This was the first year Bowman was in the Variety x N Rate Studies and it will require one or two more years of study to determine the best N rates when grown on silt loam and clay soils.

Jupiter achieved maximum grain yields of around 200 bu/acre at the three study sites in 2007 (Table 2). Jupiter did not significantly increase in grain yield when more than 120 lb N/acre were applied on the silt loam soil at the LHRF and when more than 150 lb N/acre were applied on the silt loam soil at the RREC and the clay soil at the NEREC. Similar to in 2006 (Norman et al., 2007), Jupiter was able to maintain its grain yield when the N rate was increased by 30 to 60 lb N/acre over the optimum on the silt loam soils. When the N rate on the clay soil at the NEREC was increased above 150 lb N/acre, lodging and shattering from the storm right before harvest certainly contributed to the grain yield decline of Jupiter at the high N rates, although it is not atypical to have lodging on a clay soil at the optimal or higher N rates. The 2007 data along with the 2005 (Norman et al., 2006) and 2006 (Norman et al., 2007) data indicate Jupiter should have an N rate in the range of 120 to 150 lb N/acre when grown on silt loam soil and 150 to 180 lb N/acre when grown on clay soil. The higher N rates of 150 lb N/acre when grown on silt loam soils and 180 lb N/acre when grown on clay soils should probably be used since Jupiter had a stable grain yield when greater than the optimum N rate was applied.

Pirogue was able to achieve a maximum grain yield on the silt loams at the LHRF and the RREC when 120 lb N/acre were applied (Table 3). Due to the rather large native soil-N at these sites, only 120 lb N/acre required to maximize the yield of Pirogue. Unfortunately, Pirogue only yielded a maximum grain weight of 133 bu/acre on the silt loam soil at the RREC, but did achieve a maximum yield of 170 bu/acre at the LHRF. Pirogue was able to obtain a maximum grain yield of 174 bu/acre when 150 lb N/acre were applied to the clay soil at the NEREC, but this was not significantly higher than the 169 bu/acre yield obtained when 120 lb N/acre were applied. The lodging and shattering from the storm definitely lowered yields at the higher N rates at the NEREC and may have masked the N rate that resulted in the highest yield. Usually 150 lb N/acre are required by varieties like Pirogue to maximize yields when grown on clay soils. As the N rate on the clay soil was increased above 120 lb N/acre, lodging also steadily increased until finally reaching 100% when 210 lb N/acre were applied, which in turn resulted in a grain yield of only 103 bu/acre. This along with the 2006 data probably indicates that the N rate applied to Pirogue must be fairly exact for it to achieve full grain-yield potential. After 2 years of testing, it appears that 120 lb N/acre should be applied to Pirogue when grown on silt loam soil and 120 to 150 lb N/acre when grown on clay soil.

Presidio yielded well on the silt loam soil at the LHRF and obtained a maximum grain yield of 183 bu/acre when 150 lb N/acre were applied (Table 4). Similar to Pirogue, Presidio only obtained a maximum yield of 141 bu/acre on the silt loam soil at the RREC when 120 lb N/acre was applied. Presidio had quite stable yields on the silt loam soils when the N rate was 120 to 180 lb N/acre. When grown on the clay soil at the NEREC, Presidio obtained a maximum grain yield when only 120 lb N /acre were applied. The maximum grain yield of Presidio may have been higher at the 150 lb N/acre and higher rates, but the storm induced lodging and shattering of Presidio at these N rates and certainly lowered yields. Thus, Presidio probably obtained a higher maximum yield at the NEREC than 168 bu/acre and probably obtained it at a higher N rate than 120 lb N/acre. After 2 years of study it appears Presidio will require 120 to 150 lb N/acre when grown on silt loam soils and 30 lb N/acre more when grown on clay soils. Presidio should probably be studied one more year in the Variety X Nitrogen Rate Study.

Trenasse reached maximum grain yields on the silt loam soils at the LHRF and RREC when 120 lb N/acre were applied and displayed a significant grain yield decrease when 150 lb N/acre were applied (Table 5). Due to the rather high native soil-N at these sites, only 120 lb N/acre was required to maximize the yield of Trenasse, Trenasse has shown in the past to decline in yield significantly when a higher than optimum N rate was applied (Norman et al., 2007). Trenasse obtained a maximum grain yield of 188 bu/acre when only 120 lb N/acre were applied to the clay soil at the NEREC and maintained that yield when 150 lb N/acre were applied. In the past, Trenasse required

150 lb N/acre when grown on clay soils to maximize yield. The lodging and shattering caused by the storm right before harvest contributed to the large yield decrease at the 180 and 210 lb N/acre rates. After 3 years of testing, Trenasse should probably have an N rate between 120 and 150 lb N/acre when grown on silt loam soil and 150 to 180 lb N/acre when grown on clay soil (Norman et al., 2006, 2007).

The grain yield of CL 171 AR peaked at 166 and 162 bu/acre when 90 and 120 lb N/acre were applied on the silt loam soils at the LHRF and RREC, respectively (Table 6). The native soil-N was quite high at the LHRF in 2007 as indicated by the high grain yield (136 bu/acre) of CL 171 AR when no N fertilizer was applied. The high native soil N is the reason CL 171 AR had a peak grain yield at such a low N rate. CL 171 AR did not significantly increase in grain yield when more than 120 lb N/acre were applied to the clay soil at the NEREC. CL 171 AR performed the best at the NEREC location in 2007 by obtaining a yield of 179 bu/acre when 150 lb N/acre were applied. The storm at the NEREC did not cause CL 171 AR to lodge or shatter like the other varieties. As in 2006 (Norman et al. 2007), CL 171 AR had stable grain yields at all locations when higher than the optimum N rate was applied. After 2 years of study it appears CL 171 AR will require 120 lb N/acre when grown on silt loam soil and probably 150 lb N/acre when grown on clay soil.

RiceTec hybrid CL XL 729 obtained yields of over 200 bu/acre with no lodging at all fertilizer N rates applied on the silt loam soil at the LHRF, except when 150 lb N/acre were applied in a single preflood N application (Table 7). The grain yield of CL XL 729 did not significantly increase when more than 90 lb N/acre were applied in a single preflood application, but achieved a maximum numerical grain yield at the LHRF of 244 bu/acre when 90 lb N/acre were applied preflood followed by 30 lb N/acre at LB. Our current N recommendation for the RiceTec hybrids when grown on silt loam soils is 90 lb N/acre applied preflood followed by 30 lb N/acre at LB. Grain yields of CL XL 729 significantly decreased from the peak yield when less than 90 lb N/acre were applied preflood or when 120 lb N/acre were applied preflood with an application of 30 lb N/acre at IE or LB. The severe storm at the NEREC caused all of the RiceTec hybrids to lodge and shatter severely and thus the yields obtained were not reflective of the hybrids and will not be shown.

RiceTec hybrid CL XL 730 produced yields of over 200 bu/acre on the silt loam soil at the LHRF with most of the N fertilizer applications and achieved an amazing grain yield of 177 bu/acre when no N fertilizer was applied (Table 7). CL XL 730 achieved peak grain yields of over 220 bu/acre when 90 lb N/acre were applied preflood followed by 30 at IE and /or at LB, similar to our current N recommendation for the RiceTec hybrids when grown on silt loam soil. A respectable grain yield of 215 bu/acre was obtained by CL XL 730 when 90 lb N/acre were applied preflood followed by 60 lb N/acre at LB. When the preflood N rate was increased to 120 or 150 lb N/acre, the grain yield of CL XL 730 decreased to around 200 bu/acre and it displayed some slight lodging.

RiceTec hybrid XP 744 achieved numerically maximum grain yields and the least lodging on the silt loam soil at the LHRF in 2007 when 90 lb N/acre were applied preflood followed by 30 or 60 lb N/acre at LB (Table 7). Even with all the lodging, XP 744 still achieved grain yields of 195 bu/acre or more when the recommended N application scheme for the hybrids when grown on silt loam soil was utilized (i.e., 90 lb N/acre applied preflood followed by 30 or 60 lb N/acre at LB). Lodging appeared to generally worsen for XP 744 when 30 lb N/acre were applied at IE or when the preflood N rate was increased to 120 lb N/acre. Lodging was less severe within all preflood N rates when N was applied at LB.

RiceTec hybrid CL XP 745 achieved the highest numerical grain yield of 194 bu/acre and the least lodging on the silt loam soil at the LHRF in 2007 when 60 lb N/acre were applied preflood followed by 30 at IE (Table 7). CL XP 745 produced a grain yield of 189 bu/acre when 90 lb N/acre were applied preflood followed by 30 lb N/acre at LB. The next highest yields (i.e., 179 bu/acre) for CL XP 745 were obtained when 90 lb N/acre were applied preflood followed 30 lb N/acre at IE and LB or 60 lb N/acreat LB. The grain yield of CL XP 745 decreased below 170 bu/acre when 90 lb N/acre were applied preflood with or without 30 lb N/acre applied at IE and no N applied at LB; when 120 lb N/acre with or without N were applied at IE or LB; or when 150 lb N/acre were applied in a single preflood N application. Lodging of CL XP 745 was the least severe when the recommended preflood-N rate of 90 lb N/acrecre was applied with 30 or 60 lb N/acre at LB.

Overall, the 2007 data at the LHRF confirm the RiceTec hybrid N recommendation for silt loam soils of 90 lb N/acre applied preflood followed by 30 lb N/acre at LB. However, the new hybrids XP 744 and CL XP 745 appear to lodge worse than previously released RiceTec hybrids.

The USDA-ARS experimental variety 4484-1693 obtained its highest grain yield of 195 bu/acre when 120 lb N/acre were applied to the silt loam soil at the LHRF and maintained this yield when 150 lb N/acre were applied (Table 8). The 4484-1693 variety suffered severe lodging at the RREC and did not significantly increase in yield due to lodging when more than 60 lb N/acre were applied to this silt loam soil. The soil at RREC had high native soil-N, but not as high as at the LHRF where there was no lodging. Yield at the RREC peaked at 153 bu/acre when 90 lb N/acre were applied. The yield of 4484-1693 peaked at 182 bu/acre when 150 lb N/acre were applied to the clay soil at the NEREC. Lodging became severe at the NEREC when the N rate was increased to 180 lb N/acre or more and caused yields to decrease sharply. The severe storm was a major contributor to the lodging of all varieties at the NEREC in 2007. The lodging resulted in a large $LSD_{(0.05)}$ and the inability to distinguish significant yield differences between N rates. It appears rice variety 4484-1693 will require 120 lb N/acre when grown on silt loam soil and 150 lb N/acre when grown on clay soil.

A preliminary N fertilizer rate study was conducted on the silt loam soil at the RREC with the Arkansas experimental rice varieties RU0401182, RU0601170, and RU0601188 (Table 9). The RU0401182 variety did not significantly increase in yield when more than 90 lb N/acre were applied and reached a maximum yield of 168 bu/acre when 120 lb N/acre were applied. The Arkansas experimental varieties RU0601170 and RU060188 did not significantly increase in yield when more than 120 lb N/acre were applied and had peak grain yields of 195 and 199 bu/acre, respectively, when 150 lb N/acre were applied. All of the Arkansas experimental varieties displayed good grain yield stability through the highest N rate of 180 lb N/acre.

SIGNIFICANCE OF FINDINGS

Nitrogen fertilizer response studies were conducted on fourteen new rice varieties in 2007 and the resulting response curves will be used to determine the proper N fertilization rate to obtain maximum grain yield potential for each new variety. Bowman, Jupiter, Pirogue, Presidio, Trenasse, Clearfield CL 171 AR, the Arkansas experimental varieties RU0401182, RU0601170, and RU0601188; the USDA-ARS experimental variety 4484-1693; and the RiceTec hybrids XL 723, Clearfield CL XP 729, and Clearfield CL XL 730 were the new rice varieties evaluated for N fertilizer response in 2007. The conventional, self-pollinated rice varieties required 90 to 150 lb N/acre to achieve maximum grain yield when grown on silt loam soils. The variability of the N required to maximize yield is due to the difference between varieties and in native soil-N between silt loam sites and shows the need for Rice Soil-N Test. A severe storm at the NEREC 2 weeks prior to harvest caused all of the varieties to lodge and shatter, especially as the N rate increased. This caused all of the varieties to peak in grain yield when 120 to 150 lb N/acre were applied to the clay soil, about 30 lb N/acre lower than is typical. In general, the RiceTec hybrids required 90 lb N/acre applied preflood to maximize grain yield on the silt loam soil at the LHRF. Nevertheless, when the 90 lb N/acre preflood rate was combined with 30 lb N/acre applied at LB, yields tended to increase in the absence of lodging and significantly increase in the presence of lodging due to the LB application minimizing lodging. This supports our N recommendations for the RiceTec hybrids when grown on silt loams soils. The three Arkansas experimental varieties displayed good yield stability over a wide range of N fertilizer rates.

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Table 1. Influence of nitrogen (N) fertilizer rate on the grain yield of Bowman rice at three locations in 2007.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	133	51	85
60	172	---	113
90	183	150	130
120	165	153	167
150	151	174	144
180	143	167 [5x]	140
210	---	166 [10]	---
$LSD_{(0.05)}$	7.0	11.8	12.1

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

[y] A bushel (bu) of rice weighs 45 lb.

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

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Jupiter rice at three locations in 2007.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	142	52	98
60	171	---	162
90	185	140	172
120	205	177	177
150	200	196 [10x]	193
180	203	162 [50]	186
210	---	164 [55]	---
$LSD_{(0.05)}$	10.1	20.5	14.4

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

[y] A bushel (bu) of rice weighs 45 lb.

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

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Pirogue rice at three locations in 2007.

N Fertilizer rate	Grain yield LHRF[z]	NEREC	RREC
(lb N/acre)	(bu/acre[y])		
0	122	33	55
60	146	---	95
90	154	114	115
120	170	169	133
150	163	174 [15x]	129
180	156	167 [20]	129
210	---	103 [85]	---
$LSD_{(0.05)}$	9.4	27.7	10.8

[z] LHRF =Lake Hogue Research Farm, Wiener, Ark.; NEREC=Northeast Research and Extension Center, Keiser, Ark.; RREC=Rice Research and Extension Center, Stuttgart, Ark.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in superscript to the side of yield weight are lodging percentage.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Presidio rice at three locations in 2007.

N Fertilizer rate	Grain yield LHRF[z]	NEREC	RREC
(lb N/acre)	(bu/acre[y])		
0	115	75	64
60	147	---	109
90	159	152	127
120	171	168	141
150	183	150 [30x]	141
180	174	149 [55]	142
210	---	123 [90]	---
$LSD_{(0.05)}$	7.4	9.1	7.2

[z] LHRF =Lake Hogue Research Farm, Wiener, Ark.; NEREC=Northeast Research and Extension Center, Keiser, Ark.; RREC=Rice Research and Extension Center, Stuttgart, Ark.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in superscript to the side of yield weight are lodging percentage.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Trenasse rice at three locations in 2007.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	119	93	98
60	138	---	140
90	145	182	153
120	170	188 [5x]	176
150	155	185 [20]	157
180	142	129 [80]	146
210	---	116 [95]	---
$LSD_{(0.05)}$	11.5	23.3	15.6

[z] LHRF =Lake Hogue Research Farm, Wiener, Ark.; NEREC=Northeast Research and Extension Center, Keiser, Ark.; RREC=Rice Research and Extension Center, Stuttgart, Ark.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in superscript to the side of yield weight are lodging percentage.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL 171 AR rice at three locations in 2007.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	------------------------------ (bu/acre[y]) ------------------------------		
0	136	71	86
60	158	---	133
90	166	152	146
120	158	176	162
150	157	179	160
180	157	165	157
210	---	174	---
$LSD_{(0.05)}$	7.0	13.6	11.1

[z] LHRF =Lake Hogue Research Farm, Wiener, Ark.; NEREC=Northeast Research and Extension Center, Keiser, Ark.; RREC=Rice Research and Extension Center, Stuttgart, Ark.
[y] A bushel (bu) of rice weighs 45 lb.

Table 7. Influence of nitrogen (N) fertilizer rate and timing on the grain yield of the RiceTec hybrids CL XL 729, CL XL 730, XP 744, and CL XP 745 at the Lake Hogue Research Farm near Weiner, Ark., in 2007.

N fertilizer rate		Grain yield			
Total	Split[z]	CL XL 729	CL XL 730	XP 744	CL XP 745
-----(lb N/acre)-----		---------(bu/acre[y])---------			
0	0-0-0	169	177	139	141
90	60-30-0	216	208	168 [75x]	194 [70]
90	90-0-0	226	214	156 [98]	162 [83]
120	90-30-0	225	200	152 [100]	161 [75]
120	90-0-30	244	221	197 [38]	189 [48]
150	90-30-30	238	226	184 [100]	179 [20]
150	90-0-60	229	215	195 [35]	179 [53]
120	120-0-0	234	200 [10]	145 [100]	168 [95]
150	120-30-0	216	195 [5]	158 [100]	152 [90]
150	120-0-30	208	203 [15]	174 [78]	158 [73]
150	150-0-0	193 [20]	196 [25]	137 [100]	141 [100]
$LSD_{(0.05)}$		25	18	43	31

[z] Split = nitrogen applied at preflood-beginning internode elongation-late boot.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in superscript to the side of yield weight are lodging percentage.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of USDA-ARS experimental variety 4484-1693 rice at three locations in 2007.

N Fertilizer	Grain yield		
rate	LHRF[z]	NEREC	RREC
(lb N/acre)	---------- (bu/acre[y])----------		
0	139	73	101
60	159	---	147 [20]
90	179	162	153 [25]
120	195	164	149 [50]
150	193	182 [15x]	144 [55]
180	182	141 [70]	120 [80]
210	---	109 [90]	---
$LSD_{(0.05)}$	12.5	30.1	43.1

[z] LHRF =Lake Hogue Research Farm, Wiener, Ark.; NEREC=Northeast Research and Extension Center, Keiser, Ark.; RREC=Rice Research and Extension Center, Stuttgart, Ark.
[y] A bushel (bu) of rice weighs 45 lb.
[x] Numbers in superscript to the side of yield weight are lodging percentage.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Arkansas experimental rice varieties RU0401182, RU0601170, and RU0601188 at the Rice Research and Extension Center near Stuttgart, Ark., in 2007.

N Fertilizer	Grain yield		
rate	RU0401182	RU0601170	RU0601188
(lb N/acre)	(bu/acre[y])		
0	99	87	93
60	144	154	153
90	159	175	177
120	168	188	191
150	158	195	199
180	160	193	190
$LSD_{(0.05)}$	13.4	7.8	9.7

[z] A bushel (bu) of rice weighs 45 lb.

Evaluation of Two Soil-Based Nitrogen Tests to Enhance Fertilizer Recommendations in Arkansas Rice Production

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

ABSTRACT

Nitrogen (N) response trials were conducted in Arkansas to evaluate the Illinois Soil Nitrogen Test (ISNT) and Direct Steam Distillation (DSD) in measuring soil-N availability and as a tool for N fertilizer recommendations. Field studies were conducted on several silt loam soils at experiment stations and producer fields across the state. Six N fertilizer rates ranging from 0 to 180 lb N/acre were applied in split applications in a randomized complete block design with four replications. Total N uptake and grain yield were used for correlation and calibration of each soil test. Percent relative grain yield and N fertilizer rate to achieve 95% relative grain yield were regressed against the mean ISNT and DSD values for the 0 lb N/acre-rate plots at each location. Currently, 16 site-years have been used to develop soil-based N tests for rice with significant relationships between the two soil tests and percent relative grain yield and N rate to give 95% relative grain yield. Results show a strong correlation between percent relative grain yield and ISNT and DSD at the 0- to 18-inch depth. The coefficients of determination increased for percent relative grain yield and N rate to give 95% relative grain yield as depth increased until 18 inches, but then dropped significantly at the 0- to 24-inch depth. Coefficients of determination >0.80 for both methods at the 0- to 18-inch depth indicate the incorporation of either test for use in N fertilizer recommendations could improve N management for rice producers while lowering costs and environmental impacts.

INTRODUCTION

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

PROCEDURES

Field experiments were conducted in Arkansas from 2005 to 2007 on several silt loam soils around the state to evaluate the ability of the ISNT and DSD to predict N response characteristics in rice. Studies conducted on experiment stations were seeded with 'Wells' and producer fields were chosen with cultivars that had similar N fertilizer requirements and yield potential (i.e. 'Francis'). On station, rice was seeded at ~100 lb/acre in nine-row plots (7-inch spacing) of 15 feet in length. The rice was grown upland until the 4- to 5-leaf growth stage at which time a permanent flood (2- to 4-inch depth) was established and maintained until maturity. Nitrogen response trials were randomized complete block designs with four replications and fertilizer rates ranging from 0 to 180 lb N/acre as a 2-way split application. For each of the plots receiving N, the majority was applied prior to flooding with a small portion applied at midseason. Soil cores (4 replications) were taken prior to flooding from the 0 lb N/acre treatments in 6-inch increments to a depth of 24 inches and analyzed using either the ISNT or DSD. Following maturity, the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bushel (bu)/acre at 12% moisture. A bushel of rice weighs 45 pounds. Percent relative grain yield was determined by dividing the 0 lb N/acre plot yield by the maximum yield at that location and the N rate that resulted in 95% of maximum yield was used for calibration procedures. Percent relative grain yield was correlated to the average soil test value for each depth (0- to 6-inch, 0- to 12-inch, 0- to 18-inch and 0- to 24-inch). Calibration of the soil-based N tests was achieved by regressing the N rate to achieve 95% relative grain yield against the average soil test value for each depth (0- to 6-inch, 0- to 12-inch, 0- to 18-inch, and 0- to 24-inch). Correlations were determined using JMP 7.0 (SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

Rice producers in Arkansas apply a wide range of N fertilizer rates and at varying application times (preflood, midseason etc.). Current N fertilizer recommendations suggest that for the majority of cultivars grown in Arkansas, a top yield can be achieved by applying 150 lb N/acre. This number is achieved statistically using the mean N rate to achieve maximum yield over several locations around the state. Possible problems associated with this approach are the differences in native soil-N release from site to site or field to field. Unfortunately, not all producer fields are going to mimic the N mineralization potential that is seen within fertilizer rate trials held on experiment stations. To combat rising N fertilizer prices and eliminate potential environmental impacts from excessive N fertilizer application, a more precise soil-based approach to N fertilizer recommendations was evaluated.

Correlation of individual depth increments of 0- to 6-inch, 0- to 12-inch, 0- to 18-inch, and 0- to 24-inch resulted in a significant relationship between relative grain yield and ISNT and DSD at the p=0.01 level (Table 1). Coefficients of determination suggest that the best sampling depth is 0- to 18-inches for maximum predictive value. The strongest correlation is expressed in Fig. 1 where the relationship between relative grain yield and the DSD soil-N value at 0- to 18-inches resulted in an R^2=0.77 (p=0.01). Coefficients of determination for relative grain yield versus each of the soil tests increased with depth until 0- to 18-inches where a decrease was seen at the 0- to 24-inch increment (Table 1). The best relationship between relative grain yield and either of the two soil tests not being obtained until the 0- to 18-inch depth suggests that rice can access and utilize soil-N from a large portion of the soil profile. An improvement in the precision of each soil test to predict relative grain yield as the sampling depth increases was observed and conflicts with traditional thought that the majority of nutrients are taken up from the top 6 inches of the soil profile. Relative grain yield appears to be highly dependent on soil-N mineralization potential and sub-soil N availability.

Calibration of a soil-based N test is the most important step and is the most critical in determining its success. Soil test calibration involves using a soil test result to predict the amount of a particular nutrient that needs to be applied in order to achieve maximum yields. For purposes of this evaluation, the N rate to achieve 95% relative grain yield was regressed against results from each of the soil-based N tests to determine if they were capable of predicting N fertilizer needs. The strongest correlation is presented in Fig. 2, where the N rate to give 95% relative yield is regressed against the DSD value at the 0- to 18-inch soil depth. Similar to the results obtained with relative grain yield, the predictive quality of each soil test increased with depth until the 0- to 18-inch depth, with a decrease at the 0- to 24-inch depth. The 0- to 18-inch depth appeared to have the best correlation and predictive ability for each of the soil tests when comparing all of the depths (Table 2). The highest correlations for relative grain yield were also seen at the 0- to 18-inch depth increment, which strongly supports the calibration data. It is very important that the correlation for relative grain yield and the calibration of N fertilizer rate have similar relationships at the same depths within the soil profile.

Current recommendations for Wells and Francis on silt loams soils following soybean are 150 lb N/acre for a two-way split application. Under this assumption, an estimate of how well fertilizer is being applied can be obtained by evaluating the difference between the recommended rate of 150 lb N/acre and the N rate obtained from the calibration data at the 0- to 18-inch depth. All of the sites within the 16 site-years required less than 150 lb N/acre, resulting in no sites within the dataset being under-fertilized. The mean difference between the recommended rate and the rate based on soil test results at 0- to 18-inch depth increment was 81 lb N/acre for all sites. Differences between the recommended rate and the rate based on soil analysis ranged from 30 to 150 lb N/acre (Table 3), bringing up very interesting points. Some silt loam soils in Arkansas can produce a top yield with little or no fertilizer application, while others required almost the entire recommended rate. There was a five-fold difference in N rate recommendation across 16 site-years, demonstrating the high variability in soil-N availability from site to site. Based on current fertilizer recommendations with urea as the N source and the data presented, producers are over-applying N equal to roughly $40.50/acre on average, but as much as $75.00/acre when no N fertilizer is needed (assuming N as urea cost is $0.50/lb or $450/ton for urea).

Initial results indicate the strong need for a soil-based N test for fertilizer recommendations in Arkansas. Based on the results of this study, producers may be applying more N fertilizer than is necessary to achieve top yields in their particular field(s), but this problem will only become more of an issue as N fertilizer prices continue to rise. Saving money by applying less N is not the only concern; an emphasis should also be placed on the potential environmental impacts of applying too much N fertilizer. To insure the continued success of Arkansas rice producers, a soil-based N test should be developed. A soil-based N test will allow site-specific N-fertilizer recommendations, thereby avoiding excess N application and lowering potential lodging and disease problems, but ultimately keeping more money in producers' pockets.

SIGNIFICANCE OF FINDINGS

The long-term sustainability of Arkansas rice production hinges on the smart and efficient use of N fertilizer. Costs associated with all aspects of rice production have been on the rise, but the cost of urea has more than doubled within the last decade and can represent a significant portion of the producer inputs. Recommendations are based on the assumption that a few sites within the state represent the majority of silt loam soils across the state. Extreme differences in N quantity and availability can exist within a single farm on the same silt loam soil. A better understanding of N availability and how it impacts rice yield are important steps toward insuring the continued success of Arkansas rice producers. The results presented here show the potential for a soil-based N test specifically for rice produced on silt loam soils within Arkansas. The adoption of these soil-based N tests for use in N fertilizer recommendations could potentially save producers money by managing N fertilizer needs on a field-to-field basis. As demonstrated above, the current recommendation led to over-fertilization at all of the

16 sites utilized within the study, identifying the potential for increased incidence of disease and higher total input costs. Site-specific N management is a primary goal for all crops and is starting to become a reality for Arkansas rice producers.

ACKNOWLEDGMENTS

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Table 1. Comparison of Direct Steam Distillation (DSD) and Illinois Soil Nitrogen Test (ISNT) for predicting relative rice grain yield by depth for 16 sites in Arkansas.

	DSD			ISNT		
Soil depth	Slope	Intercept	R^2	Slope	Intercept	R^2
(inches)						
0-6	0.36	3.78	0.30	0.41	-0.68	0.37
0-12	0.61	-15.19	0.51	0.76	-28.18	0.57
0-18	0.97	-49.93	0.77	0.81	-26.02	0.73
0-24	0.67	-15.74	0.61	0.66	-5.88	0.61

Table 2. Comparison of Direct Steam Distillation (DSD) and Illinois Soil Nitrogen Test (ISNT) for predicting the N rate to give 95% relative rice grain yield by depth for 16 sites in Arkansas.

	DSD			ISNT		
Soil depth	Slope	Intercept	R^2	Slope	Intercept	R^2
(inches)						
0-6	-0.78	169	0.36	-0.87	175	0.43
0-12	-1.71	250	0.61	-1.66	231	0.70
0-18	-1.84	267	0.89	-1.74	223	0.85
0-24	-1.53	213	0.81	-1.42	190	0.77

Table 3. Difference between current N fertilizer recommendation and rate from soil-based N test results as well as the cost associated with over-application of N fertilizer.

Site no.	Rate of N over-applied[z]	Cost of excess N[y]
	(lb N/acre)	($/acre)
1	81	40.50
2	55	27.50
3	103	51.50
4	109	54.50
5	119	69.50
6	150	75.00
7	43	21.50
8	54	27.00
9	30	15.00
10	55	27.50
11	73	36.50
12	121	60.50
13	80	40.00
14	81	40.50
15	73	36.50
16	72	36.00
Average	81	40.50

[z] Difference between current recommended rate and the rate obtained from the calibration curve and soil test value.

[y] Cost based on fertilizer price of $0.50/lb N or $450.00/ton urea.

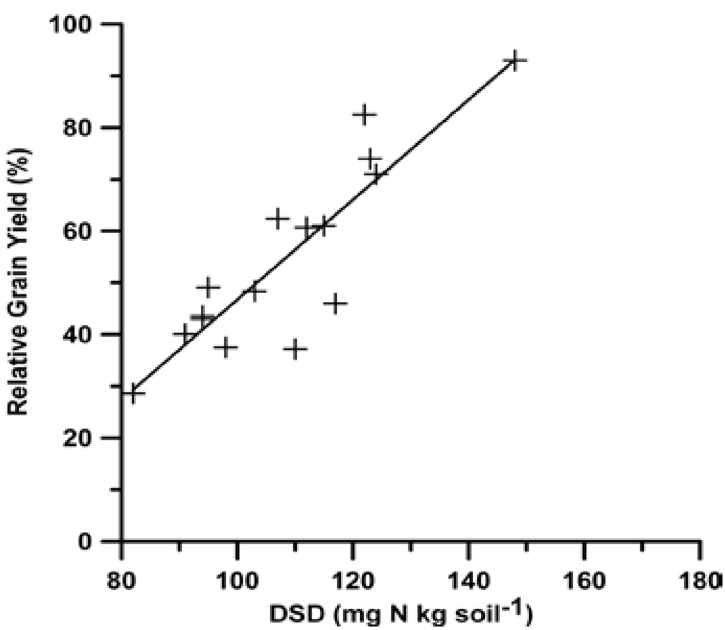

Fig. 1. Correlation of percent relative rice grain yield versus the Direct Steam Distillation (SDS) soil test value for the 0- to 18-inch depth increment.

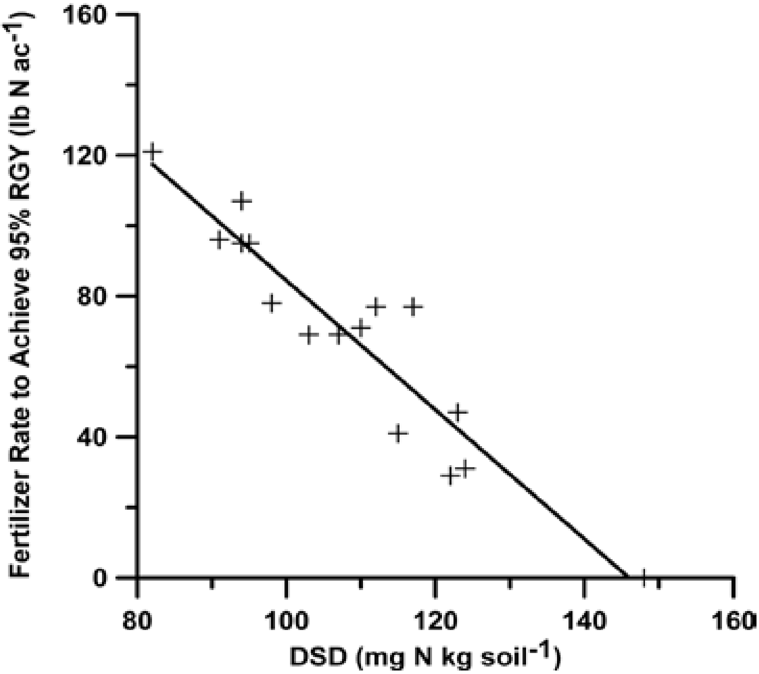

Fig. 2. Calibration of N rate to achieve 90% relative rice grain yield versus the Direct Steam Distillation (DSD) soil test value for the 0- to 18-inch depth increment.

Urea Persistence in Ponded Surface Water and a Silt-Loam Soil Used for Rice Production

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ABSTRACT

Urea is a common fertilizer in delayed-flood rice production in eastern Arkansas and its use worldwide has increased dramatically in recent decades. The movement of urea into soil is critical to retaining N in terrestrial ecosystems. However, urea itself is rarely measured directly because urea is assumed to undergo rapid hydrolysis to ammonia. Low levels of urea have been implicated as an N source for algae in aquatic ecosystems. To address the potential of urea to move out of terrestrial systems, urea was analyzed directly by a colorimetric method in surface water and 4-inch length soil cores that were ponded for 12, 24, 48, and 96 hrs. Dry and muddy soil was ponded immediately after urea application, and dry soil was ponded 5 days after urea or Agrotain application to the soil surface. Agrotain is urea treated with the urease inhibitor NBPT. Urea N was measured in floodwater after ponding dry and muddy soil, but concentrations decreased with increased ponding time after 24 hours. Floodwater urea-N concentrations were much higher when muddy soil was ponded as compared to dry soil. Little to no urea-N (≤1 μg N/mL) was measured in floodwater if there was a 5-day delay between urea or Agrotain application and ponding. The 5-day delay resulted in little detection of urea N in the soil (≤1 μg N/g) unless urea was applied as Agrotain. Agrotain urea-N concentrations ranged up to an average of 63 μg N/g at the 0.8- to 1.6-inch soil depth after 24 hrs of ponding, were about 12 μg urea-N/g at the 0- to 0.8-inch depth after 48 hrs, and were less than 1 μg N/g at all 0.8-inch depth intervals after 96 hrs of ponding. If untreated, urea remaining in floodwater may be a concern if applied to wet soil.

INTRODUCTION

Urea is a common N fertilizer in crop production, especially for rice in eastern Arkansas. Worldwide use of urea has also increased dramatically in recent decades (Glibert et al., 2006). In the mid-1960s, urea comprised less than 10% of the synthetic N fertilizer used for all crops globally, and its use is now over 50% (Glibert et al., 2006; Smil, 2001). Dependent upon management practices and environmental factors, between 20 and 70% of fertilizer N may be taken up by rice plants (DeDatta et al., 1988; Wilson et al., 1989).

Urea itself is rarely measured. Urea is assumed to hydrolyze rapidly to ammonia by activity of the enzyme urease. Urea may be treated to slow breakdown. One such urease inhibitor is Agrotain (i.e., NBPT), which is coated onto urea prills.

Urea movement is important for agricultural management decisions, but urea transport into aquatic ecosystems may contribute to algal growth in rivers and coastal outlets. Algae, specifically dinoflagellates and diatoms, can utilize urea as an N source for biomass growth, which can lead to harmful algal blooms (Carpenter et al., 1972; Glibert et al., 2006; Sonya and Anderson, 2003). Harmful algal blooms have been increasing in number of events, locations, and severity over the last few decades (NOAA, 2003). Therefore, it is important to determine the potential for urea to move out of terrestrial ecosystems into adjacent surface water bodies.

The objective of this research was to measure the extent to which floodwater applied to a silt-loam soil incorporates urea into the surface soil. Soil cores were ponded at the surface with 2 inches of water immediately after dissolution of fertilizer or following a 5-day delay between fertilizer dissolution and ponding. When there was no delay between urea dissolution and ponding, untreated urea was applied to dry and muddy soil. It was hypothesized that the extent to which urea remains in surfacewater or is incorporated into soil with infiltration of surface water depends on the fertilizer, antecedent soil moisture conditions, and the delay between fertilizer application and ponding of surface water.

PROCEDURES

DeWitt silt-loam soil (Typic Albaqualf; Table 1) was collected from the University of Arkansas Rice Research and Extension Center near Stuttgart, Ark., and was kept intact inside 2.8-inch diameter, 4-inch length cores for the series of experiments in this study. Fertilizers included untreated urea and urea treated with the urease inhibitor NBPT, trade name Agrotain. Controls received no N fertilizer. Fertilizer (202 mg urea or 90 mg N), added to approximate 178 lb/acre, was applied to the soil surface with just enough water to dissolve it. Mariotte bottles were employed to maintain 2 inches of water continually ponded on the surface of each core. Ponding times were 12, 24, 48, and 96 hours. Antecedent soil moisture conditions are labeled "dry," with an average soil moisture content of 18%, and "muddy," where cores were saturated by placing in a tub of standing water and adding water to the soil surface for 5 days prior to the initiation of an experiment. There was either no delay between urea prill dissolution and ponding or a 5-day delay between urea prill dissolution and ponding.

After a designated ponding time, surface water volumes were measured, collected, filtered, and kept at 39°F or frozen at -4°F until analyzed for urea N. Cores were capped, immediately placed in a -176°F freezer, and cut frozen with a band saw at 0.8-inch depth intervals, thawed, and mixed. Moisture content was determined gravimetrically after drying soil (5 g) at 220°F for 24 hours. Urea was extracted at a 1:10 (wt:vol) soil: extract ratio with 2 *M* KCl and analyzed colorimetrically using the microplate method (Greenan et al., 1995). Urea-N concentrations were compared in surface water and each soil depth using the general linear model and least significant differences to separate means ($P < 0.05$).

RESULTS AND DISCUSSION

When cores were immediately ponded with water after dissolution of fertilizer, regardless of whether soil was muddy or dry prior to flooding, urea (>1 µg N/mL) was measured in the surface water (Table 2). However, much higher urea-N concentrations were measured in the floodwater if soil was muddy rather than dry prior to surface ponding of water. Urea-N concentrations were highest 12 and 24 hours after establishment of surface water ponding and decreased with increased ponding time, but were still significant in muddy soil after 48 hours of surface water ponding. These results suggest that less urea moved into the soil if it was muddy prior to ponding. Furthermore, when applied to muddy soil, not only were high concentrations of urea measured in the floodwater, but little urea moved into soil beyond the surface 0.8 inches (Table 3).

Urea N (≤1 µg N/g) was not measured in surface water or at any of the 0.8-inch soil depths if there was a 5-day delay between dissolution of untreated urea and ponding of water (Tables 2 and 4). Any N applied was measured as the NH_4^+ hydrolysis product (Tomlinson et al., 2007). These results suggest that urea hydrolized over the 5-day delay between urea dissolution and flooding.

Similar to untreated urea, there was almost no urea measured in the floodwater when Agrotain was applied and there was a 5-day delay prior to ponding (Table 2). However, in contrast to untreated urea, urea N was measured in soil when applied as Agrotain (Table 4). Concentrations were variable and averaged 2.2 to 47 and 3.4 to 63 µg N/g at different 0.8-inch depth intervals after 12 and 24 hrs, but decreased to <1 µg N/g after 96 hrs of ponding. Urea hydrolyzes to ammonia/ammonium. Savin et al. (2007) found that when ammonium N was measured in dry soil receiving urea and immediately ponded with water, greater concentrations were often measured at 0.8- to 1.6-inch depth compared to the 0- to 0.8-inch depth. Similarly, greater concentrations of urea were measured at the 0.8- to 1.6-inch depth within the first 24 hrs of ponding as compared to the 0- to 0.8-inch depth when Agrotain was applied to soil in this study and the flood delayed 5 days.

The use of Agrotain retained N in urea form and allowed movement of N as urea into soil down to 3.2 inches within 24 hours. After 48 hours of ponding, some urea was measured at the 3.2- to 4-inch depth. This concentration largely reflects a high urea concentration in one core (84 µg N/g in one core and <1 µg N/g in three cores), suggesting that although it may not happen often, downward movement of urea to 4 inches can occur.

Essentially no urea was measured in the floodwater (≤1 µg N/mL) or soil (≤1 µg N/g) of control cores at any incubation time, indicating that all urea N was measured as a result of fertilizer addition and was not from a pre-existing source in the soil or water.

SIGNIFICANCE OF FINDINGS

Urea remains in floodwater up to 4 days, especially when applied to muddy rather than dry soil. High concentrations of urea measured in surface water and lack of movement of urea into muddy soil suggest that urea remaining in the floodwater could be lost from the terrestrial system either from transport (Glibert et al., 2006) or processes that result in ammonia volatilization. Therefore, possible movement out of the ecosystem in surface water flow or through ammonia volatilization may be a concern, especially if urea is applied to wet soil. Fertilizer N was not measured as urea in surface soil or ponded water if untreated urea was dissolved on the soil surface and the flood delayed 5 days, suggesting that much of the urea is hydrolyzed within those 5 days. Use of Agrotain minimized hydrolysis of urea, and did not result in urea being measured in the floodwater, but did result in N movement into the soil as urea within the first 24 to 48 hours of surface water ponding. These results are consistent with previous findings demonstrating the potential for N losses when there is a delay between application of untreated urea and flooding, or if untreated urea is applied to wet soil.

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Table 1. Properties of a DeWitt silt-loam soil (Typic Albaqualf; n = 3) collected from the Rice Research and Extension Center near Stuttgart, Ark.

pH	EC[z]	P	K	C	N	bulk density
	(μmhos/cm)	(μg/g)	(μg/g)	(%)	(%)	(g/cm^3)
5.6 (0.1)	337.3 (8.5)	49.6 (3.7)	115.5 (4.4)	0.73 (0.01)	0.08 (0.01)	1.31 (0.02)

[z] EC is electrical conductivity.

Table 2. Urea-N concentrations in surface water ponded on top of dry or muddy soil cores for 12 to 96 hours with or without a 5-day delay between fertilizer application and surface water ponding.

Delay before ponding	Fertilizer	Antecedent soil moisture	Urea 12 hrs	24 hrs	48 hrs	96 hrs
			----------------------	(µg N/mL)	----------------------	
None	None (control)	Muddy	0.01 c[z]	0.39 c	0.00 c	0.02 c
None	Urea	Muddy	561.5 a	573.5 a	232.4 b	66.6 bc
None	None (control)	Dry	0.09 b[y]	0.01 b	0.16 b	0.02 b
None	Urea	Dry	42.33 a	41.84 a	6.63 b	3.62 b
5-Day	None (control)	Dry	0.053[x]	0.00	0.00	0.08
5-Day	Urea	Dry	0.01	0.02	0.62	0.00
5-Day	Agrotain	Dry	0.27	0.59	0.05	0.13

[z] The same letter following water urea-N concentrations on muddy soil of the control indicates no significant difference (LSD 189.82).

[y] The same letter following water urea-N concentrations on dry soil of the control with no delay indicates no significant difference (LSD 20.47).

[x] There were no significant differences among water urea-N concentrations with a 5-day delay between fertilizer application and surface water ponding.

Table 3. Urea-N concentrations in muddy soil sectioned into 0.8-inch depth intervals after having been ponded with water for 12 to 96 hours, and with no delay between fertilizer application and surface water ponding.

Soil depth	Urea	Control
(inches)	(µg N/g)	(µg N/g)
0.0 - 0.8	6.34 a[z]	0.002
0.8 - 1.6	0.41 b	0.09
1.6 - 2.4	0.24 b	0.11
2.4 - 3.2	0.00 b	0.00
3.2 - 4.0	0.04 b	0.00

[z] The same letter following N concentrations among depths in soil receiving urea indicates no significant difference (LSD 2.97).

[y] There were no significant differences among depths in control soil (LSD 3.37).

Table 4. Urea-N concentrations in soil sectioned into 0.8-inch depth intervals after having been ponded with water for 12, 24, 48, or 96 hours and with a 5-day delay between fertilizer application and surface water ponding.

Soil	Urea				Agrotain				Control			
depth	12 hrs	24 hrs	48 hrs	96 hrs	12 hrs	24 hrs	48 hrs	96 hrs	12 hrs	24 hrs	48 hrs	96 hrs
(inches)	(µg N/g)											
0.0 - 0.8	0.10	0.0	0.0	0.00	5.55 b[z]	21.69 b	11.68 ab	0.26 a	0.00	0.00	0.0	0.00
0.8 - 1.6	0.69	0.5	0.0	0.03	41.38 a	62.66 a	2.99 b	0.65 a	0.00	0.00	0.0	0.27
1.6 - 2.4	0.91	0.0	0.0	0.06	46.62 a	11.80 bc	2.34 b	0.45 a	0.00	0.00	0.0	0.00
2.4 - 3.2	0.48	0.2	0.0	0.00	14.23 b	11.48 bc	1.02 b	0.63 a	0.05	0.00	0.0	0.00
3.2 - 4.0	0.10	0.0	0.0	0.00	2.18 b	3.40 c	21.11 a	0.00 a	0.00	0.11	0.0	0.00

[z] The same letter following N concentrations among depths in soil receiving Agrotain indicates no significant difference (LSD 14.58). There are no significant differences among depths in soil receiving urea or in control soil. To compare across ponding time and fertilizer use LSD 15.93.

Rice Response to Phosphorus and Potassium Fertilization

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ABSTRACT

Phosphorus (P) and potassium (K) must often be applied to maintain the productivity of cropped soils and prevent deficiencies of these nutrients from limiting crop yields. Fertilization trials were conducted with K at eight sites and P at three sites during 2007. Rice yields were not affected by P fertilization on two soils, and showed a strong but non-significant trend to be greater (167 vs 179 bu/acre) when P was applied at a third site. Rice yields responded to K fertilization at three of eight sites with yield increases ranging from 24 to 38 bu/acre. Whole plant K concentrations of rice receiving no K at responsive sites were <1.5% K at panicle differentiation and <1.2% K at early boot. At two responsive sites, the percentage of blank kernels per panicle and stem rot ratings were greater and total kernel number per panicle tended to be lower when K was not applied. Results all suggest that K deficiency decreases rice yields before K deficiency symptoms become visually prominent and increases the severity of stem rot.

INTRODUCTION

Phosphorus and K are essential macronutrients that must often be applied to maintain the productivity of cropped soils and prevent deficiencies of these nutrients from limiting crop yields. Deficiencies of P and K are sporadically observed in rice (*Oryza sativa* L.) and soybean [*Glycine max* (Merr.) L.] fields in Arkansas. Generally, rice grown on alkaline soils is susceptible to and shows P-deficiency symptoms during the seedling to tillering stages. In contrast, K-deficiency symptoms typically appear following panicle differentiation. Potassium-deficient rice has been documented on soils with a wide range of chemical properties in Arkansas, but deficiencies are most common on silt and sandy loams with pH <7.0 that have low soil-test K concentrations. Although P and K deficiencies of rice occur every year, they are relatively uncommon and research studies have not consistently shown significant rice yield increases from P and K fertilization, especially for soils that have a medium level of soil-test K.

Soil samples submitted to the University of Arkansas soil-test lab show that 54% of Arkansas soils cropped to rice have soil-test K <110 ppm (DeLong et al., 2006). Data shows that when soil-test K is <110 ppm, K fertilization will often increase rice yields with the magnitude and likelihood of yield increases becoming greater as soil-test K declines (Slaton et al., 2006). The importance of accurate soil-test based fertilizer recommendations is greater than ever because of increased fertilizer prices and the adoption of precision agriculture and variable-rate application technology. The primary objectives of these studies were to evaluate rice growth and yield responses to P and K fertilization rates on soils in eastern Arkansas to aid in developing accurate fertilizer recommendations and diagnostic nutrient concentrations that can be used to diagnosis K deficiencies of rice.

PROCEDURES

In 2007, P-fertilization trials were established at three sites and K-fertilization trials were established at eight sites. Selected soil and agronomic information is listed for each site in Table 1. Studies were established in grower fields as well as on the University of Arkansas Pine Tree Branch Station (PTBS) near Colt, Ark.; Rice Research Extension Center (RREC) near Stuttgart, Ark.; and the Lake Hogue Research Farm (LHRF) site near Weiner, Ark. The cooperating grower fields were in Poinsett (2) and Cross counties. Growers omitted P and K fertilizer from the part of the field designated for research.

For each site, before fertilizer treatments were applied, a composite soil sample (0- to 4-inch depth) was collected from each unfertilized control plot to determine soil chemical properties. Soil samples were dried at 50°C in a forced-draft oven, crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture by electrode, and subsamples of soil were extracted using the Mehlich-3 method. Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma spectroscopy (ICPS). Selected soil chemical properties for each experiment are listed in Table 2. Soybean was the previous crop grown (in 2006) at all sites except the RREC, which followed rice.

A long-grain cultivar was drill-seeded into conventionally tilled seedbeds at all sites, except for the Fisher site which was no-till. Management of rice with respect to stand establishment, pest control, irrigation, and other practices closely followed University of Arkansas Cooperative Extension Service guidelines for direct-seeded, delayed-flood rice production. Each plot was 6.5- to 8-ft wide and 16-ft long with a 1- to 2.5-ft wide alley surrounding each plot.

Phosphorus Trials

At the PTBS and Weiner sites, 0, 25 (PTBS only), 50, and 100 lb P_2O_5/acre were applied as triple superphosphate (46% P_2O_5) and diammonium phosphate (18-46-0) to the soil surface before or shortly after emergence. At the RREC, 0, 40, 80, 120, and 160 lb P_2O_5/acre were applied to the soil surface after seeding. If needed, K (60 lb K_2O/acre as muriate of potash) and/or Zn fertilizers (10 lb Zn/acre as $ZnSO_4$) were also broadcast to the soil surface several weeks before flooding. At the cooperating grower field site, N fertilization, pest control, and flooding were managed by the grower. Whole plant samples were collected in the first inside row in the 0 and 50 lb P_2O_5/acre treatments at Weiner and PTBS at the midtillering stage for tissue analysis. Samples were dried to a constant moisture, ground to pass a 2-mm sieve, and digested to determine nutrient concentration. At maturity, the middle rows from the center of each plot were harvested with a plot combine for grain yield determination. Harvest moisture content and weight of the harvested rice were determined immediately and yields were adjusted to 12% moisture for statistical analysis.

The experiment at the RREC was a randomized complete block with 6 replicates. At PTBS and Weiner, the experiments were arranged in a randomized complete block design with a 2 (Source) x 3 or 4 (P_2O_5 rate) factorial treatment structure plus an unfertilized control and four replicates per treatment. Locations were analyzed separately. Mean separations were performed by Fisher's Protected Least Significant Difference method at a significance level of 0.10.

Potassium Experiments

Potassium rates of 0, 40, 80, 120, and 160 lb K_2O/acre as muriate of potash (60% K_2O) were applied to the soil surface before or at rice emergence at eight sites. When needed, P (46 lb P_2O_5/acre as diammonium phosphate) and Zn (10 lb Zn/acre as $ZnSO_4$) fertilizers were also broadcast to the soil surface before flooding. At the PTBS, RREC, and LHRF, 130 lb N/acre as urea were applied at the 5-leaf stage and followed by flooding. At all grower field sites, N and flooding were managed by the cooperating growers. Whole-plant samples were harvested from a 3-ft section in the first inside row near panicle differentiation and the late boot to early heading stages. Plant samples were processed and harvest was performed as described previously for the P-rate trials. Rice panicles (25) were collected from the 0, 80, and 160 lb K_2O/acre treatments at the RREC, PTBS-39, and PTBS-40 sites before harvest. Panicles were assayed for total and filled kernels per panicle to evaluate how K deficiency influences total spikelet number and blanking. At maturity, whole plant samples from PTBS-39 and PTBS-40 were harvested from a 3-ft section of an inside row and each stem was assayed for stem rot on a scale of 1 to 5 where 1 is healthy (no stem rot) and 5 is dead from stem rot. Stem rot ratings were summed and divided by the number of culms to determine the overall stem rot rating.

All K-rate experiments were arranged as a randomized complete block design with treatments replicated six times. Locations were analyzed separately. Mean separations were performed by Fisher's Protected Least Significant Difference method at a significance level of 0.10. All statistical analyses were performed with SAS version 9.1.

RESULTS AND DISCUSSION

Phosphorus Trials

Soil pH was >7.0 and soil-test P values were *optimum* (36-50 ppm) at Weiner and *medium* at PTBS (26-35 ppm) whereas soil pH was 5.5 and soil-test P was *low* (16-25 ppm, Table 2) at the RREC. The recommended rates of P fertilizer were 0 lb P_2O_5/acre at Weiner, 30 lb P_2O_5/acre at RREC, and 50 lb P_2O_5/acre at PTBS. Based on the soil-test P and pH, little or no grain yield response to P fertilization was expected for any site, but moderate rates of P were recommended for two sites to help maintain soil-test P.

Whole-plant P concentrations at all three sites increased significantly as P rate increased (Tables 3 and 4), but only rice grown at the PTBS contained low- to deficient-P concentrations (<0.20% at midtillering). Rice receiving 50 lb P_2O_5/acre as DAP had greater tissue-P concentrations than rice receiving triple superphosphate and the unfertilized control. Although not statistically significant at the 0.10 level, rice grain yields at the PTBS also showed a trend to be numerically greater when P fertilizer was applied. Rice receiving no P fertilizer yielded 167 bu/acre compared to the average yield of 179 bu/acre for rice receiving 25 to 100 lb P_2O_5/acre (single-degree-of-freedom contrasts P=0.108).

Phosphorus source had no influence on grain yield at PTBS or Weiner. The yields of rice receiving preplant applications of DAP and TSP fertilizers both averaged 179 bu/acre at PTBS and differed by only 1 bu/acre (200 vs 201 bu/acre) at Weiner. These results suggest no yield benefit from the small amount of preplant N (10 to 40 lb N/acre) supplied by the DAP when sufficient preflood-N was applied. At PTBS no visual difference was observed in rice growth among DAP rates; however, at Weiner, rice receiving 100 lb P_2O_5/acre as DAP showed visually greater growth before flooding, which can be advantageous for rice management on alkaline soils.

At the RREC, rice yields were not affected by P rate, although early-season rice dry-matter accumulation and tissue-P concentrations both increased due to P fertilization (Table 4). Previous studies have also shown that rice growth on slightly acidic soils may be stimulated by P fertilization, but grain yield is usually not increased.

Potassium Rate Trials

Soil-test K concentrations were *very low* (<61 ppm) at PTBS-39 and PTBS-40; *low* (61-90 ppm) at Lake Hogue; *medium* (91 - 130 ppm) at PTBS, Fair Oaks, and Weiner sites; and *optimal* (131 - 175 ppm K) at the RREC and Fisher sites (Table 2). Potassium fertilization (60-120 lb K_2O/acre) was recommended for all sites except those with *optimal* K levels; however, little or no positive yield increase was expected at the sites testing *medium*. Visual symptoms of K deficiency were expressed only at the PTBS-39 and PTBS-40 sites, which are long-term K trial sites that have received a range of annual-K rates since 2001 or 2002, respectively.

Potassium fertilization had no influence on rice dry-matter accumulation by the panicle differentiation growth stage at any short-term trial site (Table 5), but significantly affected both long-term trial sites, PTBS-39 (Table 6) and PTBS-40 (Table 7). Dry-matter data at panicle differentiation indicate that vegetative rice growth is not generally affected by K fertilization on soils with *low* soil-test K (Table 5), but is significantly reduced when soil-K declines to a *very low* level (Tables 6 and 7). Tissue-K concentration at panicle differentiation significantly increased as K-rate increased at all sites (Tables 5 to 7). Whole-plant K concentrations of the unfertilized control at panicle differentiation were considered *low* or *deficient* (<1.8% K) only at Lake Hogue, PTBS-39, and PTBS-40. At PTBS-39 and PTBS-40, rice receiving annual applications of 40 to 80 lb K_2O/acre also contained *low* to *deficient* K concentrations.

By early heading, significant differences in dry-matter accumulation among K-rates were observed only at PTBS-39, PTBS-40, and Weiner (Tables 6 to 8). At PTBS-39 and PTBS-40, application of 80 to 160 lb K_2O/acre increased dry matter by 20 to 28% compared with the unfertilized control (Tables 6 and 7). At Weiner, rice receiving 80 lb K_2O/acre produced the greatest numerical dry matter, which was significantly greater than rice that received 40 or 160 lb K_2O/acre (Table 8). By late boot, whole-plant K concentrations of rice receiving no K fertilizer were *deficient* (<1.2%) at LHRF (Table 8), PTBS-39 (Table 6), and PTBS-40 (Table 7), and marginal at PTBS (Table 8), but sufficient at all other sites.

As predicted by tissue-K concentrations at panicle differentiation and early heading, significant grain yield increases from K fertilization occurred at LHRF (Table 9), PTBS-39 (Table 6), and PTBS-40 (Table 7). Potassium fertilization produced grain yield increases that ranged from 24 to 38 bu/acre at these responsive sites. Although rice yields were increased significantly with the lowest K rate, 120 to 160 lb K_2O/acre were needed to maximize yields at PTBS-39 and PTBS-40.

Potassium fertilization had no influence on total spikelet number or percent blank spikelets at the RREC (data not shown), which was expected since soil-K was sufficient to produce maximal yields. In contrast, experiments at PTBS-39 and PTBS-40 showed panicles collected from rice receiving no K had a greater percentage of blank kernels than when K was applied at moderate to high rates and had a strong trend for kernels per panicle to increase as K-rate increased (Table 10). Similar results were reported from a study conducted in 2004 that responded to K fertilization (Slaton et al., 2005). Stem rot (PTBS-39 and PTBS-40) was more severe on rice receiving no or low rates of K than on rice receiving 80 to 160 lb K_2O/acre annually (Table 10). These results all suggest that K deficiency decreases rice yields before K deficiency symptoms become visually prominent, which is usually after panicle differentiation, and increases the severity of stem rot.

SIGNIFICANCE OF FINDINGS

Soil-test recommendations for K correctly suggested that rice yields at four research sites would be affected only nominally or not at all by K fertilization, with the recommended K fertilizer serving to replace K removed by an above-average rice yield (i.e., maintain soil-K fertility). Soil-test-based P-fertilizer recommendations correctly predicted rice response to P fertilization at two sites. Although current soil-test-based P and K fertilizer recommendations are not always accurate, these data show that the recommendations often correctly identify nutrient-deficient soils and appropriately classify crop response to soils with *medium* or greater soil-test K levels. Furthermore, application of insufficient K fertilization for several years increases the severity of stem diseases like stem rot. Continued research and verification of soil-test-based recommendations will further improve our knowledge of crop response to fertilization and enable us to refine recommendations to aid in maximizing crop yields and net profits.

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Table 1. Agronomic and field information for field sites used to evaluate rice response to P and K fertilization on silt loam soils during 2007.

Site	Nutrients tested	Cultivar	Soil series	Plant date[z]
				(day - month)
Fair Oaks	K	RTXL 723	Henry	30 March
Weiner	K & P	Francis	Henry	23 April
Fisher	K	CL161	Hillemann	9 May
Lake Hogue	K	Francis	Hillemann	10 May
Pine Tree	K & P	Francis	Calhoun	10 April
Pine Tree (39 & 40)	K	Francis	Calhoun	30 April
RREC	K & P	Francis	Dewitt	7 May

[z] Estimated or actual seeding date.

Table 2. Selected soil chemical characteristics (0- to 4-inch depth) of sites used to evaluate rice response to P and K fertilization on silt loam soils in 2007. Values in () are the standard deviation of the mean.

Field name	Soil pH[z]	Mehlich-3 extractable soil nutrient concentrations[y, x] P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
		(ppm)								
Phosphorus trials										
PTBS	7.9	27 (4)	98	2298	380	9	214	211	2.1	1.2
RREC	5.5	19 (2)	123	936	144	11	340	175	1.1	0.9
Weiner	8.0	43 (6)	136	2953	235	32	126	26	24.1	1.1
Potassium trials										
Fair Oaks	6.8	29	92 (6)	1621	250	22	128	45	2.9	0.9
Weiner	8.1	34	101 (5)	2954	230	34	126	35	22.7	1.1
Fisher	6.3	26	132 (17)	1253	215	11	360	81	3.4	0.4
LHRF	7.1	8	81 (5)	874	211	9	179	188	2.4	0.9
Pine Tree	7.9	28	104 (15)	2295	377	11	197	228	1.7	1.2
RREC	5.5	27	150 (14)	1016	165	13	436	138	2.0	0.7
PTBS39	8.1	27	56 (10)	2587	373	11	258	205	5.2	1.2
PTBS40	8.0	24	54 (8)	1736	359	10	219	192	5.0	1.1

[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 six or more composite samples taken from the 0- to 4-inch depth.

Table 3. Effect of P-fertilizer source (DAP = diammonium phosphate and TSP = triple superphosphate) and rate on rice tissue P concentrations at the midtillering stage at two trials conducted in 2007.

P fertilizer source and rate	Site PTBS	Weiner
(lb P_2O_5/acre)	(% P)	
None - 0 lb P_2O_5	0.14	0.27
TSP - 50 lb P_2O_5	0.16	0.31
DAP - 50 lb P_2O_5	0.18	0.31
LSD0.10	0.019	0.018
P-value	0.012	0.011

Table 4. Effect of P-fertilizer rate on rice dry matter accumulation and whole plant P concentration at midtillering and grain yield for a P rate trial conducted at the RREC in 2007.

P fertilizer	Measurement		
rate	Dry matter	Tissue P	Grain yield
(lb P_2O_5/acre)	(lb/acre)	(%)	(bu/acre)
0	1470	0.30	176
40	1618	0.31	176
80	1779	0.32	176
120	1837	0.34	176
160	1981	0.34	176
LSD0.10	206	0.02	NS[z]
P-value	0.0039	0.0077	0.9943

[z] NS = not significant at 0.10.

Table 5. Effect of K rate, by location, on rice dry matter accumulation at the panicle differentiation (PD) stage for studies conducted in 2007.

	Site					
K rate	Fair Oaks	Fisher	LHRF	PTBS	RREC	Weiner
(lb K_2O/acre)	(lb dry matter/acre)					
0	4730	4054	2449	3631	8573	5354
40	4931	3890	2819	4041	8542	5288
80	4650	4219	2576	3950	9380	5456
120	4820	3796	2804	4286	8297	5490
160	4766	3897	2850	3691	8649	5428
$LSD_{0.10}$	NS[z]	NS	NS	NS	NS	NS
P-value	0.910	0.494	0.503	0.851	0.426	0.945
	(% K)					
0	2.00	2.79	1.46	1.81	2.78	2.21
40	2.33	2.90	1.72	2.03	2.79	2.39
80	2.56	3.17	1.92	2.26	2.97	2.46
120	2.74	3.24	2.18	2.44	3.02	2.47
160	2.87	3.32	2.39	2.48	2.89	2.63
$LSD_{0.10}$	0.25	0.19	0.22	0.21	0.14	0.16
P-value	<0.0001	0.0004	<0.0001	<0.0001	0.0329	0.0052

[z] NS = not significant at the 0.10 level.

Table 6. Effect of K rate on rice dry matter (DM) and K concentration at panicle differentiation (PD) and early heading (EH) and grain yield for a long-term study conducted in test 39 (PTBS-39) at the Pine Tree Branch Station test in 2007.

Annual K	Dry matter		K concentration		
rate	PD	EH	PD	EH	Grain yield
(lb K_2O/acre)	(lb dry matter/acre)		------- (% K) -------		(bu/acre)
0	3894	9741	1.14	0.81	155
40	4358	10135	1.34	0.92	171
80	4741	12314	1.68	1.05	185
120	4961	11766	1.92	1.42	187
160	4807	11725	1.96	1.48	193
$LSD_{0.10}$	668	1525	0.26	0.19	13
P-value	0.0718	0.0365	<0.0001	<0.0001	<0.0001
C.V., %	13.8	12.4	15.8	15.1	7

Table 7. Effect of K rate on rice dry matter (DM) and K concentration at panicle differentiation (PD) and early heading (EH) and grain yield for a long-term study conducted in test 40 (PTBS-40) at the Pine Tree Branch Station test in 2007.

Annual K	Dry matter		K concentration		
rate	PD	EH	PD	EH	Grain yield
(lb K_2O/acre)	(lb dry matter/acre)		------- (% K) -------		(bu/acre)
0	3894	9741	1.14	0.81	155
0	4237	9636	1.17	0.78	158
40	4758	9733	1.66	0.96	176
80	5559	11771	1.85	1.22	180
120	4466	12317	1.98	1.35	187
160	5068	11950	2.54	1.46	188
$LSD_{0.10}$	522	877	0.36	0.14	10
P-value	0.0056	0.0002	0.0004	<0.0001	0.0013
C.V., %	8.2	6.3	15.6	9.7	4.5

Table 8. Effect of K rate, by location, on dry matter accumulation and whole-plant K concentrations at the late boot to early heading stage for studies conducted in 2007.

	Site					
K rate	Fair Oaks	Fisher	LHRF	PTBS	RREC	Weiner
(lb K_2O/acre)	(lb dry matter/acre)					
0	--	13832	--	12594	15774	12090
40	--	13343	--	13259	16403	11133
80	--	14430	--	13057	16683	13049
120	--	14149	--	14481	15547	12211
160	--	14102	--	12361	15816	10428
$LSD_{0.10}$	--	NS[z]	--	NS	NS	1274
P-value	--	0.659	--	0.656	0.583	0.019
	(% K)					
0	1.33	1.78	1.16	1.26	2.03	1.62
40	1.56	1.84	--	1.41	2.09	1.77
80	1.70	1.94	--	1.49	2.16	1.81
120	1.68	2.00	--	1.56	2.12	1.80
160	1.89	1.98	--	1.75	2.16	1.88
$LSD_{0.10}$	0.17	NS	--	0.09	NS	0.09
P-value	0.0003	0.1749	--	<0.0001	0.2465	0.0015

[z] NS = not significant at the 0.10 level.

Table 9. Effect of K rate, by location, on rice grain yield for studies conducted in 2007.

	Site					
K rate	Fair Oaks	Fisher	LHRF	PTBS	RREC	Weiner
(lb K_2O/acre)	(bu/acre)					
0	222	--	159	178	175	212
40	222	--	176	190	179	208
80	230	--	175	188	174	199
120	225	--	183	190	177	205
160	227	--	183	185	176	209
$LSD_{0.10}$	NS[z]	--	9	NS	NS	NS
P-value	0.9214	--	0.0014	0.7032	0.6782	0.3418
C.V., %	7.8	--	5.2	9.0	3.9	5.2

[z] NS = not significant at the 0.10 level.

Table 10. The effect of annual K fertilizer rate, averaged across two sites, on stem rot disease index, total kernel number per panicle, and percentage blanks per panicle for long-term K studies conducted at Pine Tree Branch Station in 2007.

Annual K rate	Stem rot disease index	Kernel number	Percent blanks
(lb K_2O/acre)	(rating)	(#/panicle)	(%/panicle)
0	3.5	149	22
40	3.0	--	--
80	2.8	157	18
120	2.6	--	--
160	2.7	161	16
LSD0.10	0.2	NS[z]	3
p-value	<0.0001	0.12	0.0075
C.V., %	8.7	7.2	19.2

[z] NS = not significant at the 0.10 level.

Determining the Potential of Furrow-Irrigated Rice Using a 3- and 5-Day Irrigation Schedule in a Rice-Production System

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ABSTRACT

A field study was initiated to evaluate a 3- and 5-d furrow-irrigation schedule in a rice production system. Height of 'Cybonnet' and 'XL 723' was similar in June and July of the growing season. Furrow-irrigation schedule did not influence rice heights. Rice grown in the furrow of a raised bed was taller than rice grown on top of a raised bed in June, but no difference in July. No independent variable influenced panicle number. Total kernels and filled kernels/panicle were greater for XL 723 hybrid than Cybonnet and for rice grown on top of a raised bed. Furrow-irrigation schedule and soil moisture data collection site (200- or 400-ft of a 600-ft plot) slightly influenced yield components. Rough rice yields were greater for XL 723 than Cybonnet, but no differences were observed for furrow-irrigation schedule or soil moisture data collection site. Percent head rice was greater for Cybonnet compared to XL 723, 3-d compared to 5-d furrow-irrigation schedule, and for the 200-ft compared to the 400-ft soil moisture data collection site. Volumetric soil moisture content was 38.1 and 36.3 m^3/m^3 for Cybonnet and XL 723, respectively, indicating that XL 723 may have used more soil water than Cybonnet. Volumetric soil moisture content of a saturated clay soil is 48.4 m^3/m^3. Lower volumetric soil-moisture levels provided by both furrow-irrigation schedules may be the reason for depressed rough rice yields.

INTRODUCTION

A rice (*Oryza sativa*)-production system in the United States is predominately grown with flood-irrigation. In this system, the crop is usually flooded at approximately the V-4 (4- to 5-leaf) growth stage (Counce et al., 2000) and continuous flood is typically maintained until after rice heading. Vories et al. (2002) stated that producers and researchers have investigated the possibility of producing rice in a row-crop culture with other irrigation methods rather than a continuous flood and that potential benefits include water and energy savings, simplified flushing of the soil early in the growing season, savings in levee construction and destruction, and easier harvest due to soil drying.

Furrow-irrigated rice production systems have recently begun to receive increased attention among rice producers and media outlets. Furrow-irrigation can generally saturate the soil and may be similar to flood-irrigation (Vories et al., 2002). Nitrogen application timings and rates in furrow-irrigated rice have been investigated (Bollich et al., 1988; Hefner and Tracy, 1991; Wells et al., 1991). Vories et al. (2002) observed a 15.6% yield reduction in furrow-irrigated rice compared to flood-irrigated rice. Unfortunately, little information is available concerning the timing of furrow-irrigation. Therefore, research was initiated to investigate furrow-irrigation schedules on rice growth and yield, yield components, and the effect of soil moisture.

PROCEDURES

Research was initiated at the University of Arkansas Northeast Research and Extension Center (NEREC) in Keiser, Ark., in 2007 on a Sharkey clay loam (very-fine, smectitic, thermic Chromic Epiaquert). A factorial arrangement of treatments in a randomized complete block design with four replications was used. The first factor consisted of two rice cultivars (RC), a conventionally bred cultivar ,'Cybonnet,' and a hybrid, 'XL 723'. The second factor consisted of two furrow-irrigation schedules (FIS), three-day (3-d) and five-day (5-d). Plot size was 25.33-ft wide (eight 38-inch raised beds) by 600-ft long. A raised bed/hipping implement was used to establish raised beds parallel to the slope of the field site for drainage. Pest management was based on Arkansas Cooperative Extension Service recommendations. Cybonnet and XL 723 were direct-seeded into the top, shoulder, and furrow of the raised beds at 90- and 30-lb/acre, respectively, using a 7.5-inch row spacing on 19 April. Nitrogen fertility management consisted of a two-way split application of 126 lb nitrogen (N)/acre on 23 May followed by 40.5 lb N/acre on 12 July, with both applications applied as urea (45% N). To prevent volatilization of the urea, 0.18 oz Agrotain/lb N was applied to urea prior to both applications. No phosphorus or potassium fertilizer was required or applied.

An irrigation water-flow meter was installed to record water usage by the 3-d and 5-d FIS. Poly-pipe was attached to the flow meter and placed at high end of experiment area to facilitate the FIS treatments. Rice was direct-seeded over the entire 25.33-ft plot width; however, only 12.67-ft (four 38-inch raised beds) of each plot were furrow-irrigated to prevent cross-contamination of irrigation water from each plot. Following each FIS, irrigation water was allowed to drain from the field site. Similar to a flood-irrigation rice-production system (Counce et al. 2000), FIS irrigations were scheduled to begin when rice reached the 4- to 5-leaf growth stage. During the growing season, the 3- and 5-d FIS were terminated when one-inch or greater of rainfall was collected, because this amount typically saturated the soil at NEREC and each FIS was begun anew 2 days following each rainfall event.

During the growing season, rice plant heights were recorded periodically. At maturity, panicle number/3-row-ft, yield components, rough rice yield, and milling yield (percent head and total rice) were determined. Yield components were determined by collecting three panicles within 5 ft of the 200- and 400-ft soil moisture data collection locations (SMCL) in each plot to determine the total number of primary branches, kernels, and filled kernels/panicle. Rough rice yields were collected by harvesting two 3.13- by 20-ft segments around the 200- and 400-ft SMCL with a mechanical harvester. Soil moisture, recorded as volumetric moisture content in m^3 water/m^3 soil (m^3/m^3) with a Dynamax TH_2O thetaprobe, was collected twice weekly during the season. Soil moisture measurements were collected by inserting the thetaprobe 3 inches deep into the top and furrow of a raised bed to record variation in soil moisture within each plot during the growing season. All data were collected near each SMCL for comparison to soil moisture data. Additionally, plant heights, panicle number/3-row-ft, yield components, and soil moisture data were recorded for rice seeded on the top and furrow of a raised bed.

Data were subjected to ANOVA using PROC MIXED (SAS, 2006) with replication as a random variable. All dependent variables were analyzed separately. Rough rice yield was converted to 12% moisture prior to analysis. Main effects and all possible interaction means were separated with Fisher's protected LSD test at 0.05 probability level.

RESULTS AND DISCUSSION

Following seeding, rice was flush-irrigated on 24 May to aid in stand establishment and herbicide activation. Irrigation water amounts were not recorded for each flush-irrigation. Both cultivars reached the 4- to 5-leaf growth stage on 4 June; therefore, both FIS were begun this date.

No differences in plant height were observed between RC or FIS at either date (Table 1). At the 200- and 400-ft SMCL, no difference in rice height was documented on 12 June; however, rice located at the 200- and 400-ft SMCL was 42 and 58 inches, respectively, on 17 July (Table 1). Heights of rice located in the furrow (34 inches) were greater than rice located on the top (17 inches) of a raised bed on 12 June, but no difference was observed on July 17. Additionally, RC, FIS, SMCL, and rice position on a raised bed did not influence panicle number/3-row-ft with all variables averaging 48 panicles/3-row-ft.

The RC did not influence the number of primary branches/panicle (Table 2). However, total kernels and filled kernels/panicle were greater for XL 723 than Cybonnet. No yield component was influenced by FIS with number of primary branches, total kernel, and filled kernels/panicle averaging 13, 54.5, and 45, respectively. The SMCL influenced only the filled kernels/panicle with 49 for XL 723 and 42 for Cybonnet. Rice position on a raised bed affected total kernels and filled kernels/panicle, but not the number of primary branches/panicle. Total kernels and filled kernels/panicle were greater for rice located on top of a raised bed compared to rice located in the furrow.

Rough rice yield of Cybonnet and XL 723 was 78 and 107 bu/acre, respectively, and head rice percentages for Cybonnet were greater than XL 723 (Table 3). Yields were far less than those measured by the University of Arkansas Cooperative Extension Service Rice Performance Trials, which found that Cybonnet averaged 186 bu/acre and 61:71% head rice:total rice and XL 723 averaged 218 bu/acre and 59:70% head rice:total rice from 2004 through 2007 when grown in a continuous flood (UA-CES, 2007a). Averaged across RC, the 3- and 5-d FIS yielded 93 and 92 bu/acre, but head rice yield was greater for 3-d FIS compared to 5-d FIS. Rough rice yield was similar at the 200- and 400-ft SMCL, indicating that location of rice in a furrow-irrigation rice field may not affect the potential yield. The SMCL slightly affected head and total rice yield, but differences were within one percent difference.

Soil moisture was recorded as volumetric soil moisture content (m^3/m^3) in which the greater the m^3/m^3, the wetter the soil. Analysis indicated a significant RC and FIS main effect and a significant interaction of SMCL and rice location on raised bed for soil moisture (Table 4). Soil moisture for Cybonnet (38.1) was greater than XL 723 (36.3). These data indicated that XL 723 may actually use more soil water than Cybonnet during the growing season. Additionally, the soil moisture was greater for the 3-d FIS compared to the 5-d FIS, which would be expected due to increased frequency of irrigations. The interaction of SMCL and rice location on raised bed indicated that soil moisture was greater at 200-ft SMCL for rice located on top on a raised bed, but the opposite was observed at 400-ft SMCL. These data may be attributed to the flow of water down the furrows of each plot thus allowing the furrows of a raised bed at 400-ft SMCL to reach a higher soil moisture content. The 3- and 5-d FIS were initiated 24 and 16 times with a total irrigation water usage of 30.1- and 16.8-inches, respectively (data not shown). During the growing season, 11 inches of total rainfall were recorded at the experimental site. The combination of irrigation water and the rainfall totals for the 3- and 5-d FIS was 41.1 and 27.8 inches, respectively. Typical seasonal irrigation water usage for a flood-irrigation rice production on a clay soil in Arkansas is 36 inches (UA-CES, 2006).

Davis (2002) determined that saturated volumetric soil water content for a Sharkey clay soil at Keiser was 48.4 m^3/m^3. The maximum volumetric soil moisture content observed in this experiment was 38.1 m^3/m^3 (Table 4). Understanding that soil in a flood-irrigation rice production system is typically maintained in a saturated condition coupled with the low levels of rainfall amounts observed in 2007, a lack of water in this furrow-irrigation rice research may have been the primary reason for the depressed rough rice yields even though the total water amount (irrigation plus rainfall) for the 3-d FIS was greater than typical irrigation water usage for flood-irrigated rice, as reported by the University of Arkansas Cooperative Extension Service (UA-CES, 2006).

SIGNIFICANCE OF FINDINGS

Research indicates that irrigation water usage can be decreased in a furrow-irrigated rice production system compared to traditional flooded-rice at the NEREC.

However, rough rice yields and milling percentages were greatly depressed compared to flooded-rice. This research suggests that a 3- and 5-d FIS may not sufficiently provide adequate water amounts to maintain a level of soil moisture to produce acceptable rice yields when low levels of rainfall are experienced. Further research is needed to determine the potential of furrow-irrigation as a component of a rice production system.

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Table 1. Main effect of rice cultivar, furrow-irrigation schedule, soil moisture data collection location, and rice location on raised bed on 12 June and 17 July, plant height and panicle number/3-row-ft at physiological maturity.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture data collection location		Rice location on raised bed	
Parameter	Cybonnet	XL 723	3-d[z]	5-d	200-ft	400-ft	Top	Furrow
Plant height	(inches)							
12 June	26	25	25	26	25	26	17	34
LSD (0.05)[y]	NS[x]		NS		NS		3	
17 July	48	52	51	49	42	58	49	51
LSD (0.05)	NS		NS		4		NS	
	(number)							
Panicle number/3-row-ft	46	49	48	47	49	46	45	50
LSD (0.05)	NS		NS		NS		NS	

[z] d = days.
[y] LSD (0.05) = least significant difference at the 0.05 probability level.
[x] NS = not significant at the 0.05 probability level.

Table 2. Main effect of rice cultivar, furrow-irrigation schedule, soil moisture data collection location, and rice location on raised bed on primary branch number, kernels, and filled kernels per panicle.

	Rice cultivar		Furrow-irrigation schedule		Soil moisture data collection location		Rice location on raised bed	
Parameter	Cybonnet	XL 723	3-d[z]	5-d	200-ft	400-ft	Top	Furrow
	------------(number							
Primary branch/ panicle	13	13	13	13	13	13	13	13
LSD (0.05)[y]	--------NS[x] ------		----------NS -------		--------NS --------		------- NS -------	
Kernels/panicle	47	62	54	55	52	56	59	49
LSD (0.05)	--------- 8 --------		----------NS -------		--------NS --------		---------4---------	
Filled kernels/panicle	36	53	44	46	42	49	48	41
LSD (0.05)	--------- 7 --------		----------NS -------		---------4----------		---------5---------	

[z] d = days.
[y] LSD (0.05) = least significant difference at the 0.05 probability level.
[x] NS = not significant at the 0.05 probability level.

Table 3. Main effect of rice cultivar, furrow-irrigation schedule, and soil moisture logger location on rough rice yield and percent head and milled rice yield.

Parameter	Rice cultivar		Furrow-irrigation schedule		Soil moisture data collection location	
	Cybonnet	XL 723	3-d[z]	5-d	200-ft	400-ft
	(bu/acre)					
Rough rice yield	78	107	93	92	87	98
LSD (0.05)[y]	13		NS[x]		NS	
	(%)					
Head rice yield	64.5	57.8	61.6	600.7	61.5	60.8
LSD (0.05)[y]	0.5		0.5		0.5	
	(bu/acre)					
Total rice yield	71.3	71.2	71.2	71.3	71.0	71.5
LSD (0.05)[y]	NS		NS		0.4	

[z] d = days.
[y] LSD (0.05) = least significant difference at the 0.05 probability level.
[x] NS = not significant at the 0.05 probability level.

Table 4. Main effect of rice cultivar and furrow-irrigation schedule, and the effect of the interaction of soil moisture data collection location and rice location on raised bed on volumetric soil moisture measurements.

Parameter	Rice cultivar		Furrow-irrigation schedule	
	Cybonnet	XL 723	3-d[z]	5-d
	(m^3/m^3)[z]			
Soil moisture content	38.1	36.3	37.9	36.4
LSD (0.05)[y]	0.7		0.8	

Rice location on raised bed	Soil moisture data collection location: 200-ft	400-ft
	(m^3/m^3)	
Top	37.1	36.9
Furrow	36.5	38.2
LSD (0.05)	0.7	

[z] d = days; m^3/m^3 = volumetric moisture content in m^3 water/m^3 soil.
[y] LSD(0.05) = least significant difference at the 0.05 probability level.

Rice Irrigation-Water Management for Water, Labor, and Cost Savings

P. Tacker

ABSTRACT

Field demonstrations of rice irrigation methods were conducted in 10 counties with 14 producers on 32 different fields. A field comparison of Multiple Inlet Rice Irrigation (MIRI) to conventional irrigation on three sets of fields showed an average of 15% less water pumped on the MIRI fields over the season. Another field comparison of MIRI to a zero-grade field showed 27% less water pumped on the zero-grade field. A MIRI demonstration resulted in a grower being able to keep his field flooded with three small wells without having to use a relift pump like he had been doing in previous years. The MIRI was used on a flat field that was 4000 feet long and it made it much easier to get water to the bottom of the field initially and it also helped with maintaining the flood at the bottom through the season. A grower was better able to deal with a levee problem that occurred in a field and save water and labor because the MIRI provided more water-management flexibility. A comparison of furrow-irrigation to conventional flood-irrigation showed that from 26 June to the end of the season, 7 inches more irrigation was required with furrow-irrigation. Field work was done on investigating the use of a water-level sensor that can send a wireless signal on the status of the water depth in a rice field so that decisions can be made on whether or not to stop pumping.

INTRODUCTION

Multiple Inlet Rice Irrigation (MIRI) offers several potential advantages over the conventional-irrigation method: (1) reduced cold water rice, labor, runoff, and pumping costs, (2) improved water management and conservation, and (3) improved herbicide and nitrogen (N) fertilizer efficiency. The mechanics of MIRI systems need to be introduced to growers and adequately evaluated on production-size fields with varying soil, water, and topographical conditions. Rice production on zero-grade fields is becoming more popular because of its potential for significant water savings and because it doesn't require levees. Furrow-irrigated rice also alleviates the need for levees but thus far, minimum production and irrigation data have been collected. The evaluation and collection of data on MIRI, zero-grade, and furrow-irrigated systems 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 with several miles separating them. Managing these units becomes time and labor intensive. This can result in someone spending a lot of driving time and labor to determine if the pumping units are working properly. Many times a pumping unit may shut off soon after it is has been checked. When this happens critical pumping time is lost and the crop may suffer. A unit that provides a method for remote monitoring of pumps can be used to address this problem. The pump monitor can send a text message to a cell phone or pager or it can send an e-mail to a computer indicating that the water has stopped. This could save valuable pumping time and possibly reduce the amount of time and labor required for checking pump units. The units also have the ability to remotely shut a pumping unit down if needed. Efforts are ongoing to work with producers and the company manufacturing the pump monitors to look for future on-farm demonstration possibilities. This will help determine the practicality, dependability, and affordability of this technology in agriculture.

An accurate measurement of pump flow is critical to effective water management. Few growers know the actual flow delivered by their pump units or how to determine it. The plumb-bob method and/or a flow meter are two practical approaches for measuring pump flow. On-farm demonstrations offer the opportunity to instruct growers on how to use the two methods. This provides very useful information to the grower involved.

On-farm demonstrations cannot be conducted on every farm. However, experience and information gained on one farm 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 are coordinated with interested county extension agents and growers. Priority is given to opportunities that allow for comparison of a conventionally irrigated field to a zero-grade field or to a field that has MIRI or furrow-irrigation.

Measurements are made to determine water savings, cost savings, and other impacts of different irrigation-water management efforts. Information and experience gained from on-farm irrigation demonstrations are distributed through field tours, meetings, presentations, and publications.

RESULTS AND DISCUSSION

Project investigators and county extension agents worked directly with 14 producers in 10 counties on 32 different field demonstrations of rice irrigation methods (Table 1). Many of the counties are either designated or pending designation as critical groundwater usage areas.

Three field comparisons of MIRI to conventional rice irrigation were conducted in Arkansas, St. Francis, and White counties (Table 2). The producer involved with the Arkansas County MIRI field that showed an 18% water savings was pleased with how this allowed him to use his reservoir to irrigate more acres and avoid the significantly higher cost of using his irrigation wells. The White County comparison showed only 5% less water pumped on the MIRI field, but for most of the season right after the MIRI was pumped the conventional field would receive a rain just as it was starting to be pumped. The county agent and grower both commented that if this had not occurred, there would have been more water savings with the MIRI. The St. Francis County producer that achieved 23% water savings also used MIRI on another field. On this field he had a problem with a paddy in the middle of the field that he was able to better deal with because he could use the irrigation tubing to put water directly into the paddy.

A producer in Prairie County had been very resistant to using MIRI on his farm even though he had heard other farmers comment that it worked well for them. The county agent offered to help him set up MIRI on one of his fields. After the farmer saw how it was working he asked for help in setting it up on another field that he had a hard time keeping watered. He had three small wells that supplied the field but in the past he had always had to use a relift a lot during the season to keep the field flooded. The MIRI allowed him to keep the field flooded by using only the three wells and he was able to use the relift to irrigate some soybeans. The farmer commented that he was now a believer and that he would be using MIRI on most of his fields from now on.

A Poinsett County producer was interested in using MIRI for the first time and he contacted the county agent for help in setting it up. He was given assistance with installing a 3800-foot run of tubing on a 4000-foot long field. In addition to the field being long, it was very flat and it had always been difficult to get water to the end of the field and to keep it flooded with conventional-flood irrigation. The grower was very pleased with how it worked on the field and he estimated that it probably reduced his pumping time by about 20% from what was usually required. After setting MIRI up on this field, he was able to install it on another field without any assistance and he commented that he had other fields he would be using it on in the future.

In Craighead County a comparison was made on the water use of a MIRI field to a zero-grade field and the zero grade required 27% less irrigation (Table 2). The grower and his consultant had felt like there was significantly less irrigation water required with the zero grade and this demonstration helped them better document the difference.

The irrigation water used on a furrow-irrigated rice field was compared to a conventionally irrigated rice field in Arkansas County. Early-season pumping data on the conventional field were not obtained because of a flow-meter problem. The irrigation comparison from 27 June to the end of the season showed the furrow-irrigated field required 7 inches more irrigation during this period. Even though the furrow-irrigated field required 40 inches of irrigation for the season, the grower indicated that the water use for this field is always relatively high even for conventional irrigation. He felt like furrow-irrigation on this field was still more profitable than conventional because of the savings associated with not having levees.

Flow measurements were conducted on several wells used for the irrigation demonstrations. The producers were interested in how to measure flow and they were appreciative of having this information but most were disappointed to find that their wells were pumping less than they thought. A Monroe County producer used the flow information to determine that even though he had installed a new well, the flow was being restricted by old, underground transite irrigation pipe. The flows for six wells were determined for a farmer in Poinsett County so that he could work with the landlord to determine the best options for getting more irrigation capacity on the farm.

Evaluations of remotely monitored pump installations were conducted through coordination with the company and producers on several different farms. This involved the monitoring of previously installed systems and assistance with the placement of four new systems on farms. The evaluations have resulted in the company making improvements on converting the sensor equipment to digital-type communication so it will not be affected when the mandatory removal of analog-type communication is implemented. Discussions have also caused the consideration of the potential for using the technology to monitor the advance of water across the rice field as another notification that the grower can use to better manage the irrigation water. The company was assisted with the on-farm pilot testing of this application of the technology. There is also an ongoing effort with USDA-ARS staff in Mississippi and Missouri to design, develop, and field test a less-expensive version of the monitoring equipment so that it might be more affordable. The cooperators seem to have a positive opinion of the technology and its application to agriculture and have provided valuable feedback that is being used to inform other producers about the technology.

Experience from this years' work indicates that there is still a need for the evaluation and collection of data on MIRI, zero-grade, and furrow-irrigated systems. There continues to be a demand from growers for assistance in making field measurements of flow rates from irrigation wells to assist them in water management decisions. There are still certain areas and counties in the state that are not informed on the technology for remotely monitoring pumps and irrigation water flow. These needs and opportunities can be best addressed through on-farm demonstrations in various rice-producing areas of the state.

SIGNIFICANCE OF FINDINGS

Many Arkansas rice growers are experiencing increasing difficulty in effectively managing their irrigation water. Contributing factors are declining water tables, reduced pumping capacity, increased production acres, lack of skilled/dependable labor, decreased irrigation equipment efficiency, increasing pumping costs, and extended drought periods. All of these factors cannot be controlled, but there are water-management efforts that many growers could implement to reduce the impact of many of these factors. On-farm demonstrations are very effective in encouraging growers to implement different water-management recommendations that address these factors.

Cooperating growers involved in on-farm demonstrations learn irrigation water-management techniques for reducing water use, labor, and pumping costs. The field experience and information gained from the demonstrations are provided to other growers through field tours, meetings, and publications.

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Table 1. Rice irrigation field demonstration sites in 2007.

County		Fields	Farmers
Arkansas		8	2
Craighead		3	1
Cross		6	2
Lawrence		1	1
Mississippi		4	1
Monroe		2	1
Poinsett		2	2
Prairie		1	1
St. Francis		2	1
White		3	2
Total:	10	32	14

Table 2. Results of Multiple Inlet Rice Irrigation (MIRI) field comparison studies in 2007.

Arkansas County	18% less water for season with MIRI compared to conventional irrigation
Craighead County	27% less water for season with zero grade compared to MIRI
St. Francis County	23% less water for season with MIRI compared to conventional irrigation
White County	5% less water for season with MIRI compared to conventional irrigation

Using Kernel Strength to Estimate Rice Milling Quality

R.C. Bautista, T.J. Siebenmorgen, and R.M. Burgos

ABSTRACT

This study is a preliminary attempt to investigate the use of rice individual kernel breaking force (BF) and hardness index (HI) distributions as methods to estimate milling quality. Specifically, the percentage of strong kernels (kernels with BF greater than 20 N) and HI was correlated to head rice yield (HRY). Rice cultivars 'Bengal', 'Cheniere', 'Cocodrie', 'Francis', 'Wells', and 'XP 723' were harvested at various harvest moisture contents (MCs) from Arkansas, Mississippi, and Missouri in 2004 and 2005. Samples were cleaned and gently dried at 20°C and 56% RH to approximately 12% moisture content (MC), then analyzed for kernel BF, HI, and HRY. Results indicated a strong correlation (R=0.81) between HRY and percentage of strong kernels across the cultivars tested. Average kernel BF and average kernel HI showed weak, yet linear correlations with HRY across cultivars.

INTRODUCTION

Head rice yield is an index of milled rice quality and is defined as the ratio of the mass of head rice (kernels with length at least three-fourths of the original kernel length) to the mass of unmilled rough rice, expressed on a percentage basis. Head rice yield determination involves several time-consuming and labor-intensive steps: cleaning, hulling, milling, and separation of head rice from brokens. It would be a great advantage to anyone routinely conducting milling analyses to have a method that would rapidly determine HRY. With this end goal in mind, rice kernel mechanical properties are being investigated as potential predictors of HRY.

Kernel hardness can be measured by several methods, including the amount of force required to compress a kernel, or by the BF, the amount of force required to break a kernel in a three-point bending test (Lu and Siebenmorgen, 1995). Lu and Siebenmorgen (1995) did not observe good correlation between HRY and the average kernel compressive force for long-grain rice cultivars ‘Lemont’ and ‘Tebonnet’, but instead reported a highly significant correlation between HRY and BF distributions of individual rough rice kernels. Siebenmorgen and Qin (2005a) and Qin and Siebenmorgen (2005) attributed low kernel BFs to the presence of chalky kernels, immature and thin kernels, and fissured kernels resulting from moisture adsorption by low-MC kernels. Qin and Siebenmorgen (2005) showed a strong linear correlation between the percentage of “strong” kernels in samples and the sample HRY for three long-grain cultivars; strong kernels were defined as those that sustained a force greater than 20 N in bending without breaking. This definition was based on a study (Siebenmorgen and Qin, 2005b) that showed a significant relationship between HRY and the percentage of kernels that withstood a BF greater than 20 N.

Utilization of kernel BF as an indicator of milling quality presents some significant advantages over laboratory milling procedures, provided that a technology to rapidly measure individual kernel BFs is available. A single kernel-property measurement system, the SKCS 4100 (Perten Instruments, Stockholm, Sweden) has been developed for determining wheat kernel hardness and texture (Gaines et al., 1996). The SKCS 4100 isolates individual kernels, weighs them, and crushes them in a progressively narrower gap formed by a toothed rotor and a crescent (Perten Instruments, 2007). This device measures kernel hardness by crushing kernels one at a time while recording the crush force-time profile. After crushing 300 kernels, the average crushing force is calculated and recorded as the HI, a value that increases with increasing kernel hardness. The system can complete a 300-kernel test in 3 to 5 min, including reporting kernel weight, diameter, MC, and HI means and standard deviations.

The SKCS 4100 is commercially available; however, its utilization for measuring kernel properties has been limited to wheat. Its application for use in the prediction of rice milling quality was deemed promising, based on the relationship of rice kernel BF distributions to rice milling quality described above. The objectives of this study were to measure rice individual kernel HIs using the SKCS 4100, determine the degree of correlation of HIs to individual kernel BF measurements obtained using three-point bending tests, and test the possibility of using HI distributions to predict HRY.

PROCEDURES

Panicles of medium-grain Bengal and long-grain cultivars Cheniere, Cocodrie, Francis, Wells, and a long-grain hybrid XP 723 were collected in 2004 and 2005 from selected Arkansas, Mississippi, and Missouri farm trials at 12 to 26%[1] harvest MCs. A summary of rice samples used for this study is shown in Table 1. Each lot sample comprised approximately 200 hand-harvested panicles, which yielded at least 2 kg of rough rice. Immediately after harvest, five panicles were randomly selected from each

[1] Moisture contents are expressed on a wet basis.

lot for individual kernel MC measurements. The kernels from these five panicles were stripped by hand and the MCs of 300 of these kernels were measured using a single kernel moisture meter (CTR 800E, Shizuoka Seiki, Shizuoka, Japan). The average MC of the 300 individual kernel MCs was used as the lot harvest MC. Panicles remaining from those selected for individual kernel MC measurement were mechanically threshed (SBT, Almaco, Nevada, Iowa) to remove kernels. The rough rice was subsequently cleaned and dried to 12.5% MC in a chamber maintained at 21°C and 56% RH.

Three-Point Bending Tests (Kernel Breaking Force)

Two hundred dried kernels were randomly selected from each location/cultivar/HMC lot and dehulled by hand. A three-point bending test was conducted on each brown rice kernel using a texture analyzer (TA.TX2i, Texture Technologies Corp., Scarsdale, N.Y.) with a flat-faced loading head having a thickness of 1.5 mm and a width of 9.9 mm. The distance between the two kernel supporting points was set at 3.4 mm and the deformation rate was 0.5 mm/s. After placing a kernel across the supports, a bending test was initiated and the maximum force attained before the kernel broke was recorded as the BF.

Single Kernel Hardness Index Measurements

The HIs of 300 randomly selected, dried rough-rice kernels from each sample lot were measured using the single kernel characterization system. Data collected during the measurement of HI were processed by SKCS 4100 software to yield kernel mass, dimensions, MC, and HI means and standard deviations, as well as kernel HI distributions.

Milling Analysis

The remaining rough rice from each lot was cleaned and used for milling analyses. Two 150-g rough-rice samples from each lot were dehulled using a laboratory huller (Rice Machine, Satake Engineering Co., Hiroshima, Japan). The resulting brown rice was milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) for 30 s. A 1500-g mass was placed on the mill lever arm, 15 cm from the center of the milling chamber. Head rice was separated from brokens using a sizing machine (Model 61-115-60, Grain Machinery Manufacturing Corp., Miami, Fla.) with screen size #10 (4.0 mm, 10/64 in) for medium-grain and #12 (4.8 mm, 12/64 in) for long-grain cultivars. Statistical analyses were performed using JMP® (SAS Institute, version 6).

RESULTS AND DISCUSSION

Breaking Force Distribution Trends

Figure 1 shows the kernel BF distributions (left-side column) for selected cultivar lots with high, medium, and low harvest MCs. Kernel breaking forces ranged from 10 to 55 N across harvest MCs and generally exhibited a uni-modal distribution that was slightly skewed to low breaking-force levels. Among the tested cultivars, Wells showed a slightly greater peak BF mode than Cocodrie, Cheniere, Francis, and XP 723. At mid-range harvest MCs, Wells and XP 723 tended to have greater BFs than Cocodrie, Cheniere, and Francis. At low-range harvest MCs, the BF mode of Cocodrie and Wells was greater than BFs of Francis and XP 723.

Table 1 shows average BFs, which ranged from 25.6 to 37.8 N, over the harvest MC range of the samples. Generally, kernel average BF tended to decrease as harvest MC decreased. These findings are analogous with those of Qin and Siebenmorgen (2005), who reported a decreasing kernel BF as the harvest MC decreased to low harvest MC levels for rice cultivar XL 8. An exception to this observation was Wells from Hunter in 2004 wherein kernel average BF increased with a decrease in harvest MC (Table 1). In the case of Bengal from Brinkley in 2004, the average kernel BF peaked at 22.4% to 24.3% harvest MC, which indicated a lower average kernel BF at high harvest MC (26.5%) and at low harvest MCs (19.1 and 15.9%). The decrease in average kernel BF at high harvest MC could be due to immature kernels, which normally are thinner and, thus, weaker in bending strength. For the low harvest MCs, the decrease in average kernel BF could be the result of fissured kernels; fissured kernels are weak and break at low bending forces. Similar results were reported by Qin and Siebenmorgen (2005) who found that low harvest MC kernels showed decreased average kernel BF for long-grain cultivars 'Cypress' and 'Drew'.

Kernel Hardness Index Distribution Trends

Figure 1 also shows plots of kernel HI (right-side column) for the indicated rice cultivars from different locations. There was a wide distribution in kernel HIs that ranged from approximately 30 to 110 and were generally uni-modal and skewed to lower HIs. Kernel HI values are unit-less values that are based on algorithms that attempt to segregate kernels on a numeric scale. For wheat, an "algorithmic' value of 75 represents hard wheat kernels and soft wheat kernels generally correspond to a value of 25. No algorithmic value has been established for rough-rice kernel hardness classification.

Overall levels of HIs varied among cultivars. Wells had greater peak mode than Cocodrie at high HMC. At low HMC, Wells and XP 723 had similar peak modes. A strong correlation was observed between kernel BF and HI distributions (data not shown). For this reason, an attempt was made to correlate HRY to breaking force and HI as discussed below.

Correlation of Head Rice Yield to Percent Strong Kernels, Average Kernel BF and HI

Figure 2 shows a strong correlation (R=0.81) of HRY to percent strong kernels (kernels with BF greater than 20 N) for all lot samples harvested. Though there was a correlation (R=0.51) between HRY and average kernel BF, no correlation was established between HRY and average kernel HI. This observation showed that average kernel HI was not a good indicator of milling quality. This result also indicated that application of HI, which is largely dependent on compressive force, as an indicator of milling quality, was not sensitive to kernel parameters such as fissured or chalky kernel percentages, which are known to affect HRY.

The percentages of HI values greater than 60, 56, 52, 48, and 44 were determined in an attempt to determine if the distribution of HI values was correlated with HRY, in an effort to mimic the approach of using the percent strong kernels using BF. It is noted that these HI values are within the corresponding range of strong kernels in the kernel BF distributions for the same sample. Correlation analysis showed that none of these HI groups of 'strong kernels' was correlated with HRY. This result is speculated to be due to the inability of compressive load to detect either the presence of fissures in rice kernels or the presence of immature kernels that could have caused breakage in milling and reduction in HRY. No correlation was established between average HI values of individual rice kernels and HRY. Thus, continued research efforts are necessary to investigate other possible parameters of the individual kernel crushing profiles in an attempt to determine if such a parameter adequately differentiates strong from weak kernels as a means of predicting HRY.

SIGNIFICANCE OF FINDINGS

This study aimed to develop a strategy to rapidly estimate rice milling quality without having to actually mill a sample. An individual kernel characterization system (SKCS 4100, Perten Instruments) offers the possibility of predicting HRY using its crushing force profile. In this preliminary investigation, the average kernel BF, determined by three-point bending tests, correlated well with strong kernels and thus, HRY. However, no correlation was established between HI and HRY, indicating that using the average HI of the SKCS 4100 is not a good indicator of milling quality. To further investigate the adaptability of the SKCS 4100 as a milling quality indicator, efforts are underway to determine the slope and the values of the first peak of individual kernel crushing profiles in an attempt to investigate possible correlation with HRY. It is believed that some parameters of the crushing force profile better represent the BF of kernels, which adequately predicts milling quality. Thus, continued research into the adoption of the SKCS 4100 for milling quality prediction is being undertaken.

ACKNOWLEDGMENTS

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Table 1. Rice lots harvested at the indicated harvest moisture contents (HMCs) and the corresponding head rice yields (HRYs), average kernel breaking forces, and hardness indices in 2004 and 2005.

Year	Variety	Location	HMC	HRY	Avg. breaking force	Avg. hardness index
			(% w.b.)	(%)	(N)	
2004	Bengal	Brinkley, Ark.	26.5	70.9	33.0	81.2
			24.3	71.9	37.8	78.7
			22.4	71.2	37.1	81.1
			19.1	68.3	35.2	81.3
			15.9	69.6	33.3	80.6
	Bengal	Lodge Corner, Ark.	20.0	69.1	32.3	79.4
			18.5	68.1	31.1	80.4
			11.6	61.4	30.1	78.5
	Cocodrie	Essex, Mo.	23.9	62.8	30.7	70.8
			20.3	68.0	30.8	73.5
			13.5	60.5	30.5	71.5
	Cocodrie	Newport, Ark.	24.0	68.8	33.1	76.1
			21.0	68.2	30.6	73.2
			14.9	67.0	30.1	72.9
	Wells	Hunter, Ark.	25.7	65.3	30.6	72.3
			19.2	66.9	32.0	73.5
			15.2	63.2	33.8	73.6
2005	Cheniere	Osceola, Ark.	23.2	57.0	26.2	77.8
			21.0	60.9	26.6	77.5
			14.2	64.2	25.6	77.7
	Francis	Stuttgart, Ark.	24.4	60.8	32.0	79.9
			21.7	65.3	32.1	82.8
			16.7	63.2	32.1	83.1
			15.3	66.9	29.5	81.5
	Wells	Qulin, Mo.	24.9	61.8	35.6	76.4
			18.9	64.4	32.6	78.6
			15.8	61.0	31.3	75.7
	XP 723	Stuttgart, Ark.	24.5	65.5	34.4	81.8
			18.7	64.5	34.2	80.6
			17.2	64.7	32.4	79.0
			15.8	63.6	32.2	80.0
			14.6	60.2	30.3	80.0
	XP 723	Cleveland, Miss.	23.5	59.9	32.0	80.2
			18.0	63.5	32.7	80.5
			12.8	63.2	30.8	79.1

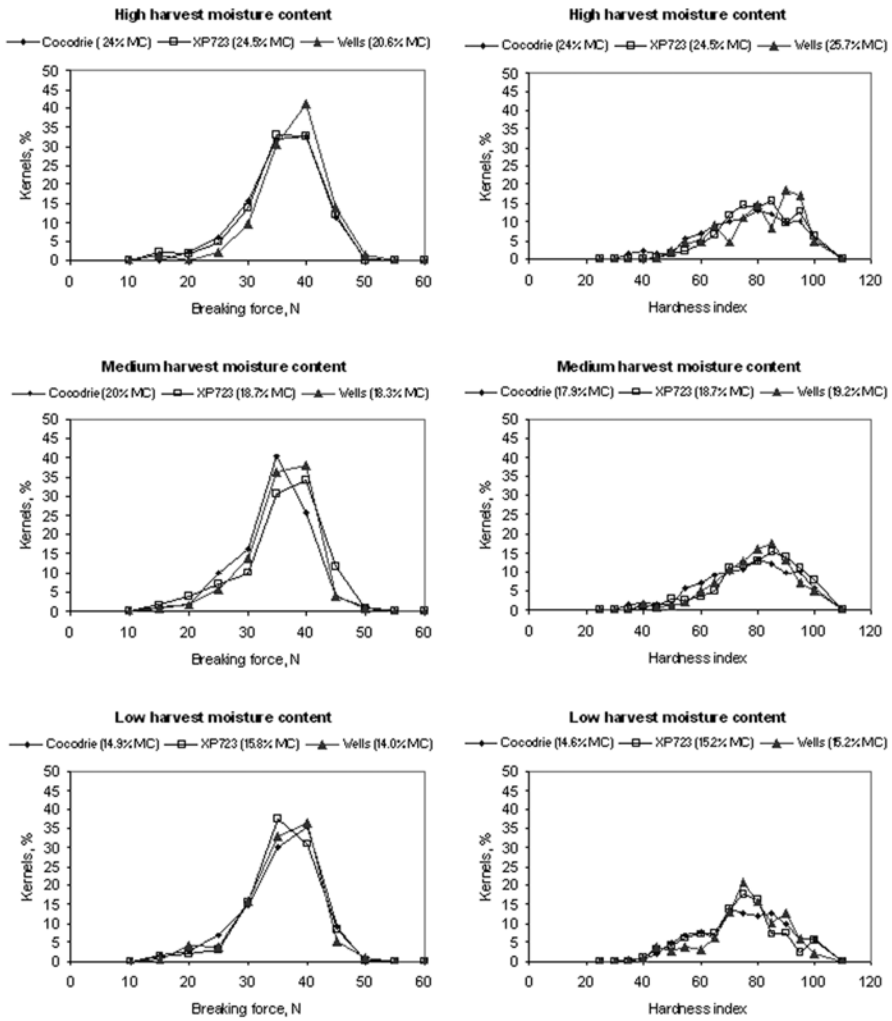

Fig. 1. Kernel breaking force and hardness index distributions at selected high, medium, and low harvest moisture contents of selected rice cultivar (harvest location, year) lots: Cocodrie (Newport, Ark., 2004), Wells (Hunter, Ark., 2004), and hybrid XP 723 (Stuttgart, Ark., 2004). Each distribution for kernel breaking force and hardness index was generated from 200 brown rice kernels and 300 rough rice kernels, respectively.

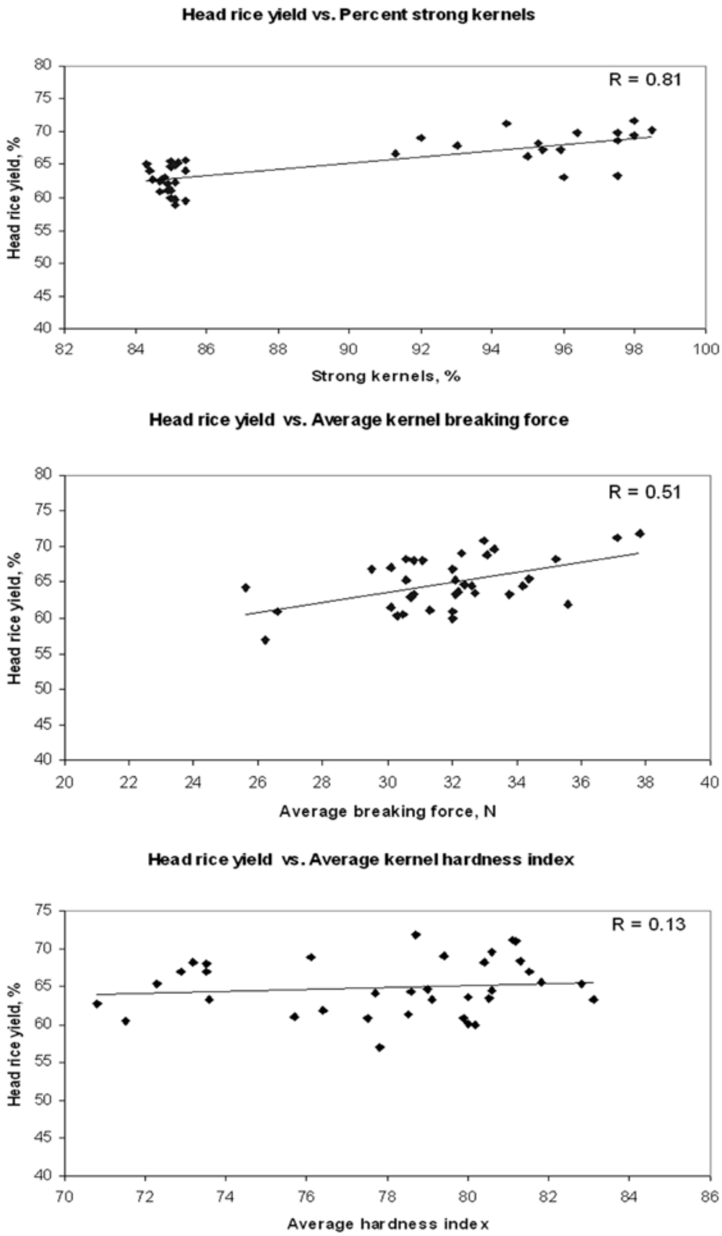

Fig. 2. Correlation of head rice yield to percent strong kernels (defined as those kernels that sustained a force greater than 20 N in bending without breaking), average breaking force, and average hardness index for sample lots indicated in Table 1. Each breaking force and hardness index data point was generated as the average of 200 brown rice and 300 rough rice kernels, respectively.

Drying Small Samples of Rough Rice Using Silica Gel - System Development

G.O. Ondier, T.J. Siebenmorgen, and J. Gibbons

ABSTRACT

The objective was to develop a procedure that could be used for drying small rice samples to 12.5% moisture content (MC)[1]. Specifically, the adsorptive capacity of silica gel in closed samples of rough rice and the duration required to dry rice samples were measured. Experiments comprised mixing moisture-permeable, silica gel packets with rough rice in plastic bags. Drying was carried out at 21 to 26°C, simulating ambient laboratory temperatures. The average adsorptive capacity of the silica gel packets in closed samples of rough rice was measured to be 0.27 g of water/g of silica gel. There was minimal variation in final rice MCs when using the packets.

INTRODUCTION

It is common practice to dry small samples of rice (1 to 5 kg) in air-conditioned labs or open warehouses, exposing the samples to air until the MC is reduced to safe storage levels (usually below 13%). Laboratory-scale driers are also available but require expensive relative humidity (RH) controls to be effective in controlling final sample MCs. Variation in drying air conditions is manifested in final sample MCs, consequently introducing variability in milling quality and subsequent functional property measurements. An effective drying method that will minimize the variation in the final MCs of small rough rice samples is thus needed. Sorption drying, whereby a desiccant material adsorbs moisture from wet grains when the two solids are mixed together, is a method that could be used for drying small grain samples. Zhangyong et al. (2002)

[1] Moisture contents are expressed on a wet basis unless specified otherwise.

reduced the MC of soybeans to safe levels and showed potential for improved seed germination by using intimate mixtures of soybean and silica gel in static beds. Sturton et al. (1983) and Graham et al. (1983) found the drying of corn, wheat, and oats using desiccants to be promising based on drying kinetics and seed quality. Danziger et al. (1972) demonstrated superiority in product quality when corn was dried using desiccants at ambient temperature.

Silica gel is a desiccant that has potential for grain drying. Silica gel is inert, has a high adsorbency, and is available in various packet sizes that would be ideal for drying small samples of rice. Silica gel held in moisture-permeable packets offers excellent handling properties, reduces separation cost, and minimizes the risk of product contamination. The objectives of this study were to establish procedures that could be used in drying small samples of rough rice using desiccant packets.

PROCEDURES

Four rice cultivars, 'Francis', 'Wells', 'Bengal', and 'Cybonnet', harvested at 21.2, 18.0, 18.1, and 20.9% MC, respectively, from the Rice Research and Extension Center near Stuttgart, Ark., in the fall of 2007 were used. The lots were cleaned immediately after harvest using a dockage tester (XT4, Carter-Day Co., Minneapolis, Minn.). The lots were stored in sealed plastic bins at 5°C for two weeks between harvest and the conduct of experiments. Sample MCs were determined by drying two, 20-g sub-samples from each lot in a convection oven (1370 FM, Sheldon Inc., Cornelius, Ore.) for 24 h at 130°C (Jindal and Siebenmorgen, 1987).

The study incorporated the use of 1- and 5-g silica gel packets (Sud-chemie, Albuquerque, N.M.), which had an initial MC of 0.05% with a manufacturer's adsorptive capacity rating of 30% by mass of silica gel. Sealable quart-volume plastic bags were used as drying containers because they are readily available, affordable, and easy to handle/store. To develop a method that minimized drying costs, experiments were carried out at 21 to 26°C. The study was conducted as a series of experiments; the procedures and results are presented accordingly.

Use of Plastic Bags as Drying Containers

The effectiveness of plastic bags as drying containers was determined. Four 150-g samples each from Francis, Bengal, and Wells cultivars at 21.0, 18.1, and 18.0% MC, respectively, were dried; two of the samples were dried using 1-g packets, one in a plastic bag and one in a quart glass jar, while the other two were dried similarly, except using 5-g packets. Glass jars were used for comparison because they were deemed to be impermeable to moisture. For purposes of calculating the amount of silica gel to use, a dry matter mass balance was used to determine the amount of moisture to be removed in drying. Equation 1 was first used to determine the mass of the rice samples after drying; Equation 2 was then employed to calculate the amount of water to be removed during drying:

$$m_1 (1- MC_1) = m_2 (1- MC_2) \quad \text{(Eq. 1)}$$

$$m_3 = m_1 - m_2 \quad \text{(Eq. 2)}$$

where m_1 is the mass of rough rice at the initial moisture content MC_1; m_2 is the mass of rough rice at the desired storage moisture content MC_2, which was taken to be 12.5%; m_3 is the mass of moisture to be removed in drying a rice sample from MC_1 to MC_2.

Given an assumed adsorptive capacity, the mass of silica gel (m_{sg}) required to dry a rough rice sample was then determined as:

$$m_{sg} = m_3/\text{assumed adsorptive capacity} \quad \text{(Eq. 3)}$$

The packets were not intimately mixed with the rice samples, but were placed directly on top of the rice bulk for ease of separation. The samples were dried for eight days in a chamber maintained at 26°C; a slightly higher than normal room temperature was used to test the integrity of the plastic bags in relation to moisture permeability. The final MCs of the rough rice samples were determined using the oven method previously described. The experiment was replicated.

Adsorptive Capacity of Silica Gel Packets in Rough Rice

A procedure was used in which silica gel adsorptive capacities ranging from 25 to 45% were assumed in calculating the mass of silica gel required to dry rough rice to the desired 12.5% MC. Ten 150-g samples were obtained from each of the cultivars Francis, Wells, Bengal, and Cybonnet. The excess moisture to be removed in drying the rough rice to 12.5% MC was determined using Eq. 1 and 2. Equation 3 was then used to calculate the mass of silica gel required to adsorb the excess moisture, using assumed adsorptive capacities of 25, 30, 35, 40, and 45%. Five of the ten samples of each cultivar were dried in plastic bags using 1-g silica gel packets and five were dried similarly, but using 5-g packets. Drying was conducted in a chamber maintained at 26°C. The final rice MC was determined by the oven method previously described.

After drying, the final rice MC was plotted against the assumed adsorptive capacities. Regression analysis yielded the silica gel adsorptive capacity that produced a dried MC equal to 12.5%. The experiment was replicated.

Drying Rate

The rate of moisture removal from rough rice when drying using 1- and 5-g silica gel packets was determined using twelve 150-g samples of Cybonnet cultivar. The samples were dried in plastic bags in a chamber maintained at 26°C. Six of the samples were dried using 1-g packets, while the other six were dried using 5-g packets. The packet adsorptive capacity was assumed as 25% of the initial packet mass. Two bags of rice, one with 1-g packets and another with 5-g packets, were removed from the drying chamber at daily intervals over a period of six days and the rice MC determined using the oven method described previously.

Milling Quality

To determine if milling quality was affected by drying using silica gel packets, head rice yields (HRYs) were determined. Sixteen representative samples, four from each rice cultivar dried in the previous stages, were obtained for HRY determination. Only samples dried to the desired 12.5% MC (± 0.1 pp) were assessed for processing quality, as rice MC at the time of milling affects HRY (Reid et al., 1998). Samples of rough rice (150 g) rice were passed through a dehulling machine (THU, Satake Engineering Co., Tokyo, Japan) to remove hulls and then milled for 30 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas). Head rice was separated from broken kernels using a sizing machine (61-115-60, Grainman Machinery Co., Fla.) and the HRY calculated as the ratio of the head rice mass to the initial rough rice mass (150 g). Head rice yields of replicate samples dried using silica gel were compared to HRYs of samples dried to 12.5% MC on screens in a chamber maintained at 26°C and 55% RH.

RESULTS AND DISCUSSION

Use of Plastic Bags as Drying Containers

Table 1 shows the final rice MCs obtained when drying using plastic bags and glass jars. There were no significant differences in final MCs of samples dried using 1- or 5-g packets (p-value of 0.7560). Additionally, there were no significant differences in final MCs when drying in plastic bags or glass jars (p-value of 0.4860). Therefore, migration of moisture through the plastic bags was considered negligible and plastic bags were deemed acceptable as a drying container.

Adsorptive Capacity of Silica Gel Packets in Rough Rice

Regression lines relating the final rice MC to the assumed adsorptive capacities of the silica gel (Fig. 1) showed that to attain the desired final MC of 12.5%, the adsorptive capacities of the 1-g silica gel packets used in Eq. 3 would need to be 25.7% in Bengal and 27.7% in Cybonnet, Wells, and Francis samples. Fig. 2 shows that the adsorptive capacities needed to dry samples from Cybonnet, Francis, Wells, and Bengal cultivars to the desired 12.5% MC were 24.5, 25.6, 26.6, and 27.3%, respectively, when drying with 5-g packets. The wider range of silica gel adsorptive capacities with the 5-g packets may be attributed to a decrease in the surface-area-to-volume ratio resulting from the fewer number of packets used when drying rice using the 5-g (Fig. 2) compared to the 1-g (Fig. 1) silica gel packets.

Selected data from Figures 1 and 2 were used to illustrate the final rice MC variability incurred when drying to near the 12.5% MC level. Table 2 data were taken from the final MC values of Figures 1 and 2 in which samples were dried with packet masses calculated assuming an adsorptive capacity of 25%. The within-cultivar variability in the final MC of the replicated rice samples was minimal, with maximum deviation of ± 0.1 percentage points MC.

Drying Rate

The drying rate was initially great due to the low RH developed within the drying containers resulting from the silica gel adsorption (Fig. 3). Moisture from the outer kernel layers was easily removed, thus leading to the initial, fast drying rate. As drying progressed, the moisture removal rate lessened due to the internal resistance to moisture transfer within the kernel.

Figure 3 shows that rice samples can be dried from a high initial MC (20.9%) to the desired 12.5% MC within six days. The rate of moisture exchange between the rice kernels and the silica gel packets was limited due to the lack of drying air circulation. The use of low temperatures also reduced the rate of moisture diffusion from the kernel, further extending the drying duration.

Milling Quality

Table 3 shows the averages of HRYs from samples dried using the silica gel packets and from samples air-dried in a control chamber. There were no significant differences in HRYs of samples dried with 1- or 5-g packets (p-value 0.7195). Additionally, there were no significant differences in HRYs between desiccant-dried and control-dried samples (p-value 0.9911).

SIGNIFICANCE OF FINDINGS

This preliminary work shows that small samples of rough rice of the mass often generated by rice scientists can be dried effectively to a desired storage MC using silica gel packets in plastic bags, without incurring milling quality reductions. Using these packets for drying small rice samples is convenient in that drying is carried out at ambient conditions, requires a relatively short duration, and produces little variation in final MC. Validation through field testing of this system is being planned.

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Table 1. Final moisture contents (MCs) of Francis, Wells, and Bengal rice samples dried for eight days in glass jars and plastic bags at 26°C. The final MCs are averages of four measurements comprising replicate samples dried using 1- and 5-g silica gel packets; there were no statistical differences between samples dried with the 1- or 5-g packets.

		Final rice MC	
Rice cultivar	Initial rice MC	Plastic bag	Glass jar
	----------(%)----------		
Francis	21.2	13.3	13.2
Wells	18.0	12.8	12.8
Bengal	18.1	12.9	12.8

Table 2. Final moisture contents (MCs) for Bengal, Wells, Francis, and Cybonnet rice samples dried in plastic bags at 26°C using 1- and 5-g silica gel packets. The mass of silica gel packets was calculated using an adsorptive capacity of 25%.

		Final MC			
		1-g		5-g	
Rice cultivar	Initial MC	Rep 1	Rep 2	Rep 1	Rep 2
	----------(%)----------				
Bengal	18.1	12.0	12.5	12.5	12.4
Wells	18.0	12.4	12.5	12.4	12.5
Francis	18.1	12.6	12.6	12.5	12.5
Cybonnet	20.9	12.6	12.5	12.4	12.4

Table 3. Head rice yields (%) of Francis, Bengal, Wells, and Cybonnet rice samples dried for eight days using 1- and 5-g silica gel packets in a chamber maintained at 26°C. There were no significant differences in HRYs between samples dried with 1-g or 5-g packets; as such the head rice yields from the desiccant-dried rice samples are averages of four measurements. There were no statistical differences between desiccant-dried and control-dried samples.

Drying condition	Francis	Bengal	Wells	Cybonnet
Desiccant-dried	58.3	55.4	56.7	59.8
Control-dried	59.3	55.5	56.7	60.1

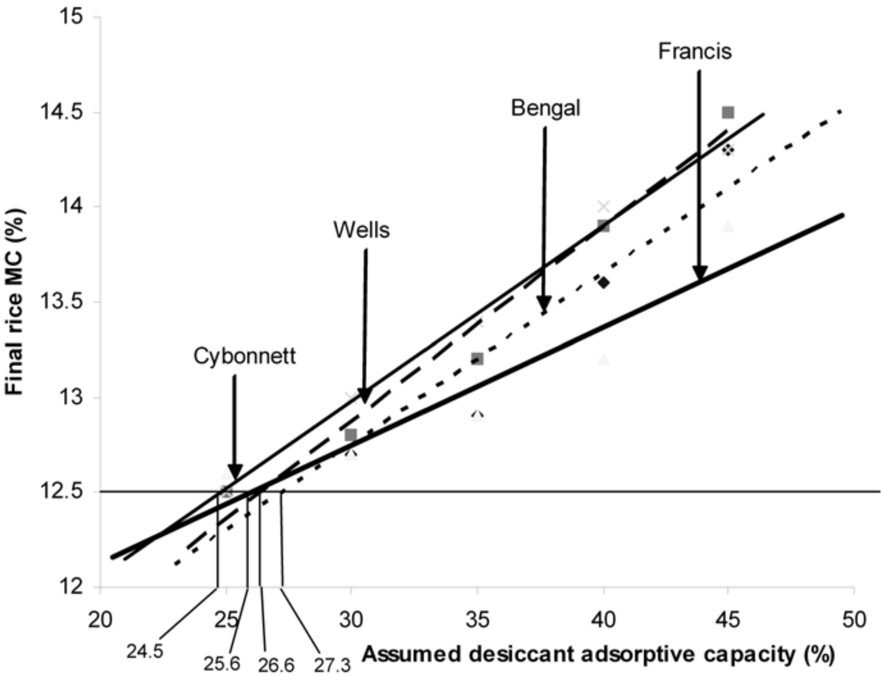

Fig. 1. Final rice moisture contents (MCs) by assumed desiccant adsorptive capacities for Bengal, Cybonnet, Francis, and Wells rice cultivars dried using 1-g silica gel packets for a period of eight days. Each data point is an average of two measurements.

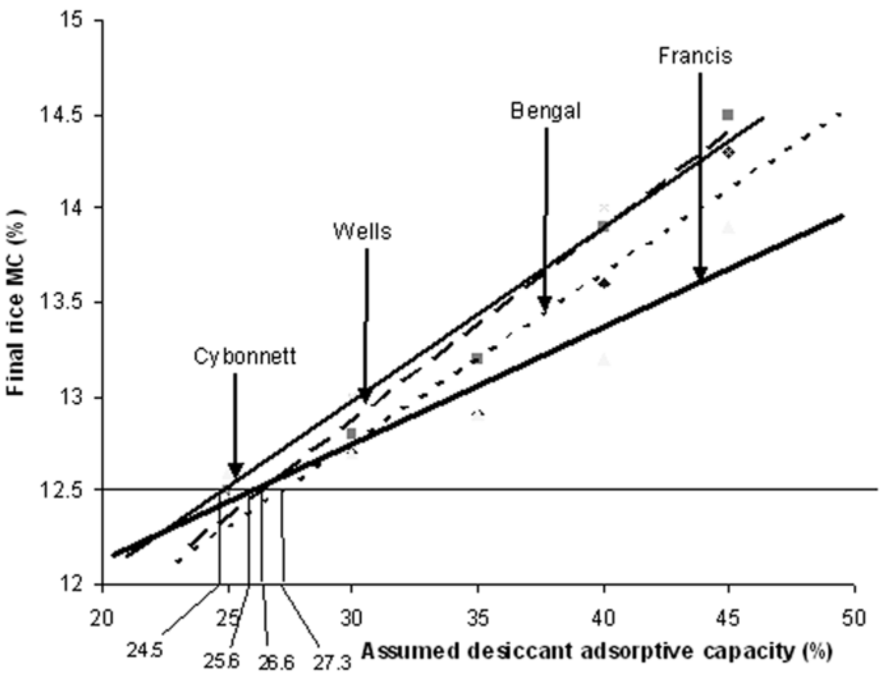

Fig. 2. Final rice moisture contents (MCs) by assumed desiccant adsorptive capacities for Bengal, Wells, Cybonnet, and Francis rice cultivars dried using 5-g silica gel packets for a period of eight days. Each data point is an average of two measurements.

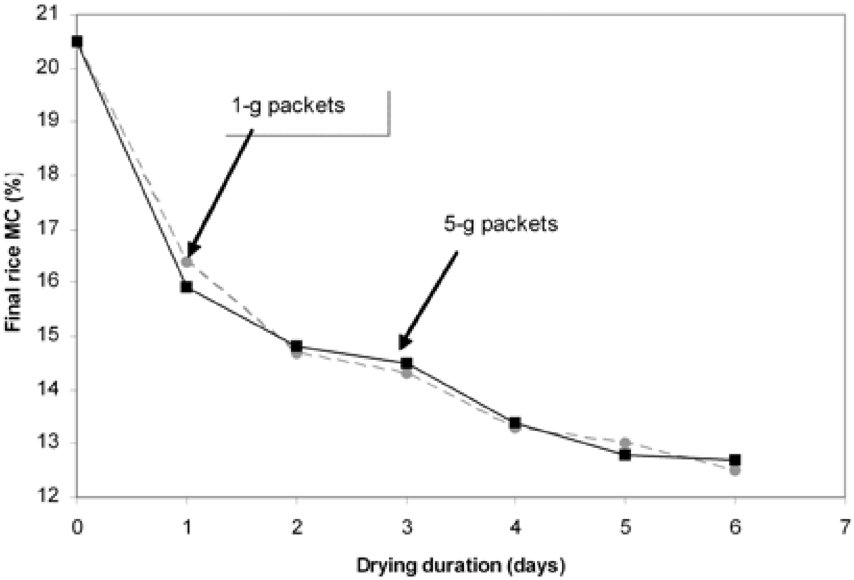

Fig. 3. Moisture content reduction determined at daily intervals in Cybonnet rice samples dried using 1- and 5-g silica gel packets (adsorptive capacity estimated as 25%). Each data point is an average of two measurements.

Effect of Long-Grain Rice Degree of Milling, Moisture Uptake, and Solids Leach During Cooking on Rice Textural Properties

M. Saleh and J.-F. Meullenet

ABSTRACT

Two long-grain rice cultivars/hybrids ('Wells' and 'CL 161') harvested from locations in Arkansas were used in this study. Rice samples were milled for 20, 30, 40, and 50 seconds. Milled whole-rice samples were cooked in excess water for 16, 18, 20, and 22 minutes and in a 2:1 water-to-rice ratio for 20 minutes (WR_{20}). Cooked rice texture and solid leach were determined. Results indicated that longer cooking duration resulted in softer rice as a result of fuller hydration of rice kernels. Increased milling duration also resulted in significant ($P<0.05$) decrease in cooked rice hardness. Milling and cooking duration significantly ($P<0.05$) affected total solid leached out during cooking.

INTRODUCTION

Rice texture is a key indicator of rice quality as it affects cooked rice acceptance by consumers (Lyon et al., 2000). Unlike other cereals, rice is consumed largely as cooked whole kernels, which is produced after de-hulling and milling processes. Although cooking methods for rice vary widely worldwide, rice-cooking methods are mostly subtle variations of two basic cooking techniques: namely (1) Excess or American method, where rice is usually cooked in a large amount of water then drained and (2) the Oriental method, where rinsed rice is usually cooked in a measured amount of water (Crowhurst and Creed, 2001). Optimum cooking degree of rice is usually determined when rice reaches an end cooking point where it either absorbed a maximum amount of water or until the core of the cooked rice kernels gelatinized (Kasai et al., 2005). Rice hydration upon cooking has, therefore, a great impact on rice textural properties.

Rice-kernel surface area and chemical composition also affect cooked-rice moisture uptake during cooking (Bhattacharya and Sowbhagya, 1971; Bergman et al., 2004). For example, high-amylose cultivars have been reported to turn out firmer and less sticky rice when cooked than low-amylose cultivars (Juliano and Perez, 1983). In addition, slender rice varieties have been found to uptake greater amounts of water during cooking than short and rounder varieties (Bergman et al., 2004). Although several researchers have studied the effect of water-to-rice ratio for rice cooking and resultant textural properties (Srisawas and Jindal, 2007; Bett-Garber et al., 2007), a universal way of selecting a water-to-rice ratio to obtain optimal cooked rice texture does not exist. In addition, there is a lack of information on the effect of cooking rice in an excess amount of water on cooked-rice textural characteristics. Therefore, this study was initiated to investigate the roles moisture uptake, solid leaching, and degree of milling play in determining cooked-rice instrumental textural properties.

PROCEDURES

Rice Sampling

Wells and CL 161 rice cultivar/hybrid were harvested from Keiser, Ark., at moisture contents (MC) of 16.0 and 21.2% (wet bases (wb)), respectively. Rice samples were brought to the University of Arkansas Rice Processing Program laboratories where the rice was cleaned and air dried at ambient temperature to a MC of ~12.5% (wb). Dried rough-rice samples were stored in air-tight plastic storage containers at 22 ±3°C for two months before milling.

Rice Milling and Preparations

Duplicate 150-g rough-rice samples were de-hulled using a de-husker (THU-35, Satake, Hiroshima, Japan) and milled for 20, 30, 40, and 50 seconds using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas). A double-tray sizing device was used to separate whole from broken kernels and head rice yield (HRY) was calculated. Only full rice kernels were used in this study. Rice surface lipid content (SLC) was determined using a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, Minn.) according to Matsler and Siebenmorgen (2005). Protein content in milled rice flour was determined in duplicate for each treatment using the Kjeldahl procedure, AACC method 46-11A (AACC, 2000).

Rice Cooking and Instrumental Texture Measurements

Rice was cooked using a miniature rice cooker, consisting of a glass-cooking vessel with a glass top and a heating mantle, the temperature of which was controlled by a temperature regulator (89000-10, Eutech Instruments, Pte Ltd, Singapore). For excess water cooking, 100 ml water was brought to a boil before 20 gram of milled rice were added. Rice was cooked for 16, 18, 20, and 22 minutes to a maximum cooking temperature of 98.5±1°C, after which the excess water was drained. Rice samples were also cooked in a water-to-rice ratio of 2:1 (w/w) (W/R_{20}) for 20 minutes. Cooked rice was conditioned for 5 minutes and kept warm (50°C) before texture measurements. The cooking conditions were identical for all rice treatments to eliminate differences in cooked-rice textural properties due to the cooking. Cooked-rice textural properties were determined by a uniaxial, single compression method using a Texture Analyzer (TA-XT2 plus, Texture Technologies Corp., Scarsdale, N.Y./Stable Micro Systems, Godalming, Surrey, United Kingdom). Ten whole cooked-rice kernels were compressed using a 50-Kg load cell to leave a 0.3 mm gap between two compression plates at the bottom of the compression cycle. The maximum compression force was used as an indicator of cooked rice hardness while the adhesion energy measured during the upward travel of the compression plate was used as an indicator of cooked rice stickiness. Rice treatments were cooked in duplicate and five measurements were taken for each cook.

Moisture Content, Solids Leach, and Cooking Test

Approximately 5 g of cooked rice was weighed, in triplicate, and dried at 130°C for 24 hours using a drying oven (Precision, Winchester, Va). Cooked rice MC was calculated as percentage of moisture weight in the cooked rice sample. The total amount of solids leached out during cooking was also determined for each milling and cooking duration. The disappearance of the cooked rice starchy core was evaluated by placing five cooked rice kernels between two glass-slides and compressing gently (Gujral and Kumar, 2003).

RESULTS AND DISCUSSIONS

Milled Rice Quality Characteristics

Milled rice SLC ranged from 18 to 44% for CL 161 and from 19 to 52% for Wells, respectively (Table 1). Increasing milling degree (i.e., lower SLC) resulted in an increase in apparent amylose and in a significant ($P<0.05$) decrease in protein content. This was credited to the removal of the outermost layers of rice kernels (i.e., layers rich in lipids and proteins) during milling. The increase in apparent amylose content was attributed to the disproportional losses of protein and lipids of rice kernels with milling. HRY ranged from 53.10 to 55.17% and from 55.23 to 57.53% for CL 161 and Wells, respectively. The decrease in HRY with milling (Table 1) was attributed to the removal of a greater amount of bran as well as due to the increased breakage of weak rice kernels with longer milling durations (Saleh and Meullenet, 2007; Siebenmorgen and Sun, 1994).

Cooked Rice Textural Properties

Results indicated that cooked rice hardness was affected by cooking and milling duration. Milling to a greater degree produced significantly ($P<0.05$) softer cooked rice (Table 2). Cooking for longer durations also resulted in softer rice texture for rice samples milled to the same degree, with rice samples milled for 50 seconds and cooked for 22 minutes having the lowest hardness value. For example, CL 161 rice treatments milled for 20 and 50 seconds had hardness values ranging from 84.22 N to 89.27 N, 68.54 N to 80.98 N, and from 63.91 N to 78.90 N when cooked for 18, 20, and 22 min, respectively. A similar trend was also reported for Wells. The decrease in hardness with milling is in agreement with previous work and was attributed to the restriction of moisture migration in rice kernels during cooking of lightly milled rice (Saleh and Meullenet, 2007). Limited hydration of a cooked rice kernel's core during cooking, as presented in Fig. 2, appears to affect cooked rice hardness. Moreover, the negative correlation between cooked rice hardness and moisture uptake during cooking, -0.86.and -0.84 for CL 161 and Wells, respectively, provides more evidence of the significant role moisture uptake plays in determining cooked rice hardness. Although not significant ($P>0.05$), results pointed toward an increase in cooked rice stickiness with the increase in milling degree across cultivars and cooking water-to-rice ratio. Further investigation on the role leached solids play in cooked rice stickiness is required.

Cooked Rice Moisture Content and Solids Leach During Cooking

Cooking and milling duration significantly ($P<0.05$) impacted cooked rice moisture uptake. The removal of bran layers that are richer in proteins and lipids, compared to the rest of the kernel, probably facilitates water migration into rice kernels during cooking. This is in line with Yadav and Jindal (2007) findings that high-protein rice requires longer cooking and greater moisture compared to low-protein rice, and also with Juliano (1993) who reported that high-amylose rices have higher capacity of absorbing moisture during cooking than lower-amylose samples. Other researchers (Bhattacharya and Sowbhagya, 1971) have proposed that the ability of rice kernels to uptake moisture during cooking is correlated to the variation in kernel surface area. However, results obtained in this study did not show significant differences ($P>0.05$) in rice physical dimensions as a result of milling degree (results not shown). This indicates that changes reported in rice functional properties are probably in this case a result of the differences in rice chemical composition caused by milling degree.

Milling degree and cooking duration of rice also impacted the amount of solids leached out with a significant interaction ($P<0.05$) between milling and cooking duration. During cooking, starch in the cooking rice kernel usually absorbs moisture and swells due to its gelatinization. Continued heating in the presence of water usually results in leaching of starch solids into the cooking gruel. Solids leached and cooked rice MC were highly correlated ($R^2= 0.61$) (Fig. 2), demonstrating that solids leached are proportional to the amount of water absorbed by rice during cooking.

SIGNIFICANCE OF FINDINGS

Milling and cooking of rice affected cooked rice texture, solids leaching, and water uptake. Changes in cooked rice hardness were related to the hydration of the rice kernel's core during cooking. Lightly milled rice samples resulted in lower moisture uptake of rice during cooking, thus harder cooked rice. Longer cooking duration, on the other hand, resulted in greater moisture uptake of rice producing softer cooked rice. Solids leached during cooking and moisture uptake of rice during cooking depend on rice milling and cooking durations.

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Table 1. Milled rice (CL 161 and Wells) HRY and chemical composition during milling for various durations[z, y].

Cultivars	Milling	HRY	SLC	AAC	Protein
	(s)	-------------------	------------(%)	-------------------	-------------------
CL 161	20	55.17 [a]	0.44 [a]	23.93 [a]	7.68 [a]
	30	54.13 [a]	0.33 [b]	24.04 [a]	7.47 [b]
	40	53.33 [a]	0.24 [c]	24.66 [a]	7.37 [bc]
	50	53.10 [a]	0.18 [d]	24.95 [a]	7.26 [c]
Wells	20	57.53 [a]	0.52 [a]	24.85 [ab]	6.65 [a]
	30	57.50 [a]	0.38 [b]	24.12 [b]	6.32 [b]
	40	55.87 [a]	0.27 [c]	24.92 [ab]	6.25 [bc]
	50	55.23 [a]	0.19 [d]	26.18 [a]	6.19 [c]

[z] HRY, SLC, and AAC represent head rice yield, surface lipid content, and apparent amylose content, respectively.
[y] Means of HRY, SLC, AAC, and protein content of the same cultivar/hybrid milled to different durations with different letters are significantly ($P<0.05$) different according to LSD.

Table 2. Cooked rice texture, moisture content and solid leach during cooking of long-grain rice samples (Wells and CL 161) milled to various degrees[z, y].

Milling durations	CL 161 Hardness	CL 161 Stickiness	CL 161 Moisture content	CL 161 Solids	Wells Hardness	Wells Stickiness	Wells Moisture content	Wells Solids
(s)	(N)	(N.s.)	-------------(%)	------------	(N)	(N.s.)	------------ (%)	-----------
Cooking in excess water								
				16 minutes				
20	89.88 a	7.11 a	68.43 b	1.26 b	94.85 b	8.72 a	70.26 a	1.43 a
30	90.06 a	7.63 a	70.38 a	1.08 c	95.00 b	9.54 a	70.48 a	1.46 a
40	89.70 a	8.35 a	70.55 a	1.28 b	102.21 a	11.06 a	67.11 b	1.35 b
50	91.99 a	9.26 a	69.73 ab	1.44 a	95.15 b	9.99 a	69.80 a	1.26 c
				18 minutes				
20	89.27 a	6.70 a	71.18 b	1.53 a	81.30 c	7.15 a	74.12 a	1.87 a
30	78.84 c	8.04 a	71.38 ab	1.26 d	87.32 b	7.84 a	70.97 b	1.49 c
40	77.78 c	8.05 a	71.01 b	1.30 c	98.04 a	10.08 a	69.69 b	1.32 d
50	84.22 b	8.22 a	71.84 a	1.46 b	82.05 c	8.42 a	72.36 ab	1.67 b
				20 minutes				
20	80.98 a	5.97 ab	72.50 ab	1.61 a	79.93 ab	7.58 a	75.53 a	2.05 a
30	78.30 a	6.79 a	71.30 c	1.30 b	82.91 a	8.20 a	73.05 b	1.75 b
40	71.15 b	6.84 a	71.63 bc	1.35 b	83.68 a	8.33 a	72.67 b	1.79 b
50	68.54 b	5.70 b	73.05 a	1.55 a	76.76 b	7.41 a	72.86 b	1.81 b
				22 minutes				
20	78.90 a	6.66 bc	73.59 a	1.83 a	82.58 a	7.73 a	74.54 b	2.02 a
30	69.77 b	8.33 ab	73.07 a	1.77 b	78.55 ab	7.58 a	74.64 b	1.56 c
40	68.06 b	9.50 a	72.71 a	1.48 d	80.09 ab	8.14 a	74.98 ab	1.83 b
50	63.91 c	5.27 c	73.97 a	1.63 c	76.40 b	8.76 a	75.38 a	1.73 b
W/R_{20}				W/R_{20}				
20	99.30 a	7.30 c	67.73 c	NA	109.06 a	10.25 a	67.80 c	NA
30	88.10 b	8.79 bc	69.09 ab		103.84 b	8.85 a	69.36 b	

continued

Table 2. Continued.

Milling durations	CL 161 Hardness	CL 161 Stickiness	CL 161 Moisture content	CL 161 Solids	Wells Hardness	Wells Stickiness	Wells Moisture content	Wells Solids
(s)	(N)	(N.s.)	-------------(%)------------		(N)	(N.s.)	------------ (%) -----------	
W/R_{20}					W/R_{20}			
40	86.57 [b]	8.97 [b]	69.66 [a]		101.21 [bc]	9.73 [a]	68.33 [bc]	
50	5.35 [a]	11.03 [a]	68.21 [bc]		100.97 [c]	11.37 [a]	71.42[a]	

[z] Solids, W/R_{20}, and NA represent percent of solids leached during cooking, water-to-rice ratio of 2:1 cooked for 20 min. and no results available, respectively.

[y] Means of hardness, stickiness, moisture content, and solid leach during cooking of the same cultivar/hybrid and cooking duration milled to different durations with different letters are significantly ($P<0.05$) different according to LSD.

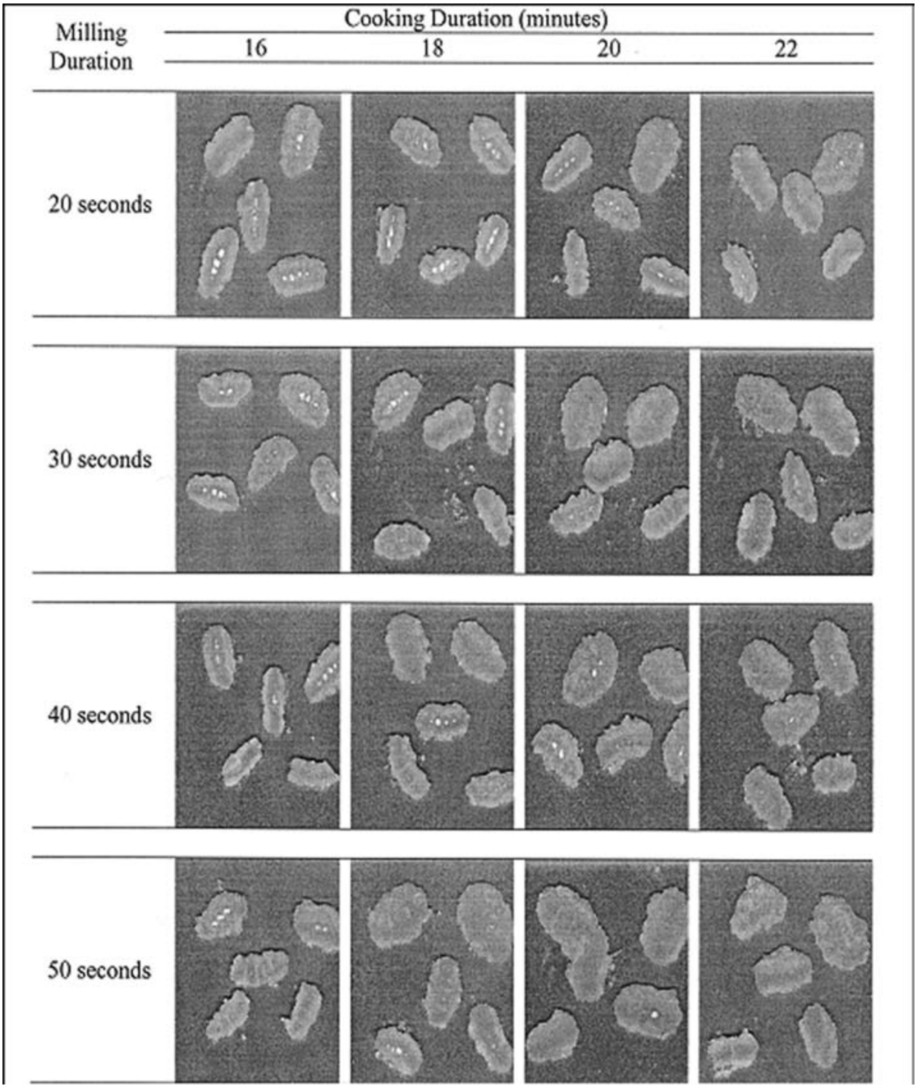

Fig. 1. Cooked rice kernels (CL 161), milled to different degrees and cooked in excess water for various durations, pressed between two microscope glass slides.

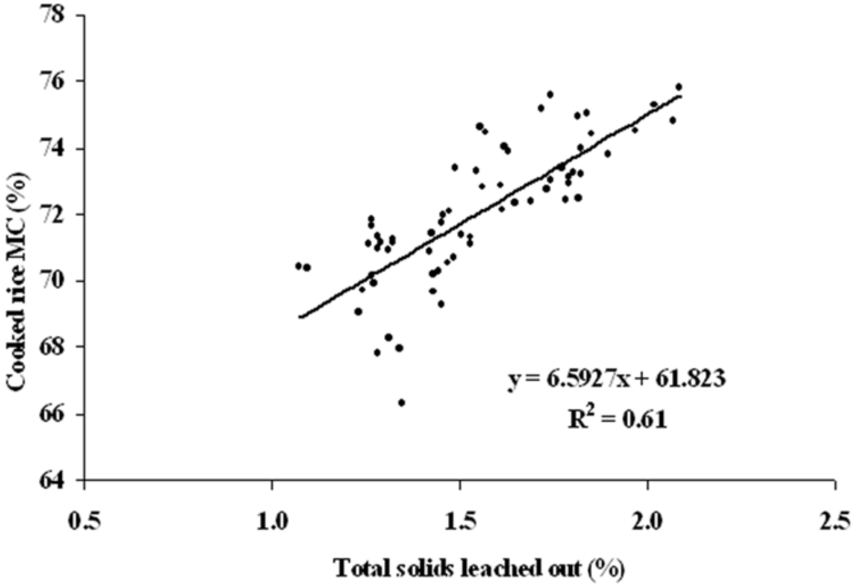

Fig. 2. Cooked rice (CL 161 and Wells) moisture content vs. solids leached during cooking.

Estimating the Economic Value of Rice as a Function of Harvest Moisture Content

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ABSTRACT

The net value (NV) of rice, as affected by drying costs and milling quality changes associated with harvesting rice at various moisture contents (MCs), was studied using a five-year dataset comprising eight cultivars harvested over a range of MCs from 11 southern USA locations. A quadratic relationship was used to characterize the change in NV across harvest MC (HMC); this relationship was due to the progressively increasing fee structure for drying costs and the quadratic nature of head rice yield (HRY) changes with HMC. The HMCs at which the peaks of the NV curves occurred were less than those at which HRY was maximum. The amount of change in NV between that achieved at harvesting at optimal HMCs and at lower HMCs, such as 14%, varied with the price of brokens and the amount of HRY reduction with HMC, but could be greater than \$0.80/cwt.

INTRODUCTION

Determining the appropriate time to harvest is a crucial decision for rice producers. Upon maturity, the average MC and the distribution of individual kernel moisture contents (MCs) vary dramatically according to environmental conditions (Bautista and Siebenmorgen, 2005). These MC changes can correspond to milling quality changes. For example, if the harvest date is delayed and the rice field MC is allowed to decrease to ≤15%[1], there is a risk that environmental humidity could cause dry kernels to rap-

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

idly absorb moisture, which causes fissuring (Kunze, 1978; Siebenmorgen and Jindal, 1986), resulting in decreased HRYs. At high HMCs, HRY can also decrease, as many long-grain kernels are immature, thin, and weak and thus increasingly prone to breakage (Siebenmorgen and Qin, 2005; Siebenmorgen et al., 2006).

The objective of this study was to determine the net economic value of rice, accounting for milling quality changes and drying charges associated with harvesting rice at various MCs. From these relationships, the HMC at which maximum NV occurred was quantified.

PROCEDURES

Rice Samples

During 1999, 2000, 2004, 2005, and 2006, 139 rice lots of 'Bengal' (medium-grain cultivar), 'Cypress', 'Drew', 'Cheniere', 'Cocodrie', 'Francis', 'Wells' (long-grain cutivars), and 'XP723' (long-grain hybrid) were collected from locations across Arkansas (7 locations), Missouri (2 locations), and Mississippi (2 locations). Each field, which was either a research or a farm trial plot, was sampled four to seven times during each harvest season to collect rice at HMCs ranging from 12% to 27%, determined using a single kernel moisture meter (CTR 800E, Shizuoka Seiki, Shizuoka, Japan). Table 1 summarizes the sample lots collected.

Samples were dried to 12.5% MC in a chamber in which air conditions were maintained at 21°C and 56% relative humidity. Husks were removed from two duplicate 150-g samples from each lot using a laboratory huller (Rice Machine, Satake Engineering Co., Hiroshima, Japan). The resultant brown rice was milled for 30 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas), and aspirated (Grain Blower, Seedburo Equipment Co, Chicago, Ill.), after which the milled rice was weighed. The milled rice mass percentage of the original 150-g mass of rough rice was recorded as the milled rice yield (MRY). Head rice was then separated from brokens using a sizing device (Grainman Model 61-115-60, Grain Machinery Manufacturing Corp., Miami, Fla.). Head rice yield was determined as the mass percentage of the original 150-g of rough rice that remained as head rice. The results of each duplicate were averaged before subsequent statistical and cost analyses.

Cost Analyses - Drying Charges

In the US rice industry, rice is traded based on its "dry" mass, commonly taken as the mass at approximately 12.5% MC. The pricing unit typically used is the cwt, or hundredweight, which is equal to 100 lb (avoirdupois, US). However, drying charges in the US are typically applied based on the number of "green", or freshly harvested, bushels. The conventional technique involved in the computation of the number of green bushels of incoming, non-dried rice is to assume a bulk density of 45 lb/bu (Henderson and Perry, 1976). Drying charges are thus calculated according to equation 1.

$$DC = \frac{M_G}{BD} \ X \ DF \qquad \text{(Eq. 1)}$$

Where:

DC = drying charge, $

M_G = mass of green rough rice at a given HMC, lb

BD = bulk density of rough rice, conventionally taken as 45 lb/bu

DF = drying fee, $/bu

The drying fee (DF) schedules were assumed to be typical of those used in Arkansas. Table 2 presents the drying fee schedule that was used in this study.

Cost Analyses -Net Value

The relationship between the mass of dried rice at 12.5% MC (M_D) and that at HMC (M_G) is given by equation 2.

$$M_D = \frac{M_G}{\left(\frac{(100-12.5)}{(100-\mathbf{HMC})}\right)} \quad \text{or, equivalently:} \quad MG = MD\,\frac{(100\text{-}12.5)}{(100\text{-}HMC)} \qquad \text{(Eq. 2)}$$

Where

M_D = mass of dry rice at 12.5% MC, lb

HMC = moisture content of undried rice, %

The gross values of head rice and brokens were calculated by equations 3 and 4, respectively. Note that in order to convert to more commonly traded units, pounds (lb) must be divided by 100 to convert to hundredweight (cwt).

$$GV_{HR} = (M_D) \ X \ HRY \ \ X \ P_{HR} \qquad \text{(Eq. 3)}$$

$$GV_{BR} = (M_D) \ X \ (MRY - HRY) \ X \ P_{BR} \qquad \text{(Eq. 4)}$$

Where

GV_{HR} = gross value of head rice, $

GV_{BR} = gross value of brokens, $

M_D = mass of dry rice at 12.5% MC, cwt

P_{HR} = price of head rice, $/cwt

P_{BR} = price of brokens, $/cwt

HRY = mass proportion of rough rice remaining as head rice after milling, decimal

MRY = mass proportion of rough rice remaining as milled rice (head rice + brokens), decimal

The gross value of a mass of dried rice (GV_{Rice}) was taken as the sum of GV_{HR} and GV_{BR}. The NV of rice was calculated according to equation 5.

$$NV = GV_{Rice} - DC \qquad \text{(Eq. 5)}$$

Where

NV = net value of rice, \$/cwt

The approach used in this analysis was to establish a basis of comparison as one cwt at 12.5% MC; as such, M_D = 1 cwt. For each of the 139 sample lots analyzed, the green mass (M_G) at the HMC of each lot was calculated from the one cwt base (M_D) using equation 2. For example, if a sample HMC were 18.0%, the M_D of one cwt would correspond to a M_G of 106.7 lb, or 2.37 green bushels. At 18.0% MC, a drying fee of \$0.30/bu would have applied, based on the drying fee schedule listed in Table 2, which would equate to a drying charge of \$0.71, essentially \$0.71/cwt of dried rice. After milling, if the sample had a MRY of 70% and a HRY of 60%, the one cwt of dry rough rice would produce 0.7 cwt of milled rice, of which 0.6 cwt would have been head rice and 0.1 cwt brokens. If the price of head rice were \$16.50 /cwt and the price of brokens were 60% of the value of head rice, according to equations 3 and 4, the GV_{Rice} would total \$10.89/cwt. By subtracting the drying costs, the NV, through equation 5, would equal \$10.18/cwt of dried rice. In this manner, the NV of each of the 139 sample lots was calculated and each year/location/cultivar sample lot then had associated HMC, HRY and NV values, which were related with regression equations.

RESULTS AND DISCUSSION

The trend between HRY and HMC for all year/location/cultivar sample lots was parabolic, caused by two HRY-reducing factors: moisture adsorption in the field at low HMCs, and the presence of weak, immature kernels at high HMCs (Siebenmorgen et al. 2007). The peak of each HRY vs HMC regression line corresponded to the optimal HRY (HRY_{opt}) and the associated HMC $HMC_{opt\text{-}HRY}$. The peak of each NV vs. HMC regression line corresponded to the optimal NV (NV_{opt}) and the HMC at which NV was maximized ($HMC_{opt\text{-}NV}$). The $HMC_{opt\text{-}HRY}$ differed depending on cultivar, year, and location; additionally, HRY usually decreased rapidly at low HMCs; however, for some sample sets, it did not respond as drastically. Several examples will illustrate the effects of varying HRY vs. HMC patterns on the NV of rice. For this analysis, head rice prices (P_{HR}) of \$16.50, 18.00, and 19.50/cwt were used and brokens prices (P_{BR}) were calculated as 60, 70, and 80% of the head rice price, based upon USDA, 2007.

Parabolic HRY vs. HMC Relationship

Figure 1 shows the relationship between NV, HRY, and HMC for Wells rice harvested in 2006 from Osceola, Ark. The corresponding tabular values of NV_{opt} and $HMC_{opt\text{-}NV}$ for all sample sets used in this study are given in Tables 3, 4, and 5. For the five samples collected at this location during this year, the peak of the HRY vs. HMC regression line corresponded to a HRY_{opt} of 66.3%, which would have been achieved if the rice had been harvested at an $HMC_{opt\text{-}HRY}$ of 21.2% (Table 1). However, the peaks of the NV regression lines indicate that in order to achieve NV_{opt}, Wells rice from Osceola, Ark., during 2006 would have had to have been harvested at lower MCs, from 18.0% to 19.2% (HMC_{opt-NV}), depending on the price of head rice and brokens (Tables 3, 4, and 5).

The NV curves in Figure 1 were developed assuming a head rice price (P_{HR}) of \$18.00/cwt and brokens prices (P_{BR}) of 60, 70, and 80% of the head rice price. As the P_{BR} increased, the peaks of the NV vs HMC curves shifted toward lesser HMCs. For this sample set, the HMC_{opt-NV} decreased from 19.1% HMC at 60% brokens value, to 18.7 and 18.1% HMC at 70 and 80% brokens values, respectively (Fig. 1 and Table 4). However, though the P_{BR} varied a total of \$3.60/cwt, from \$10.80/ cwt to \$14.40/cwt (60 and 80%, respectively, of the head rice price of \$18.00/cwt), NV_{opt} increased a total of only \$0.29/cwt, from \$11.76/cwt at 60% value, to \$12.05/cwt at the 80% value (Table 4).

At higher HMCs, the NV vs. HMC regression lines decreased at a greater rate than the HRY vs. HMC curve due to progressively increasing drying fees. The shape of the NV curves show that as the P_{BR} increased from 60% to 80% of the value of head rice, there was little difference in NVs at higher HMCs due to the correspondingly high HRYs and thus the relative absence of brokens. At lower HMCs, the lower HRYs and increased brokens masses caused the NV curves to separate. Therefore, an increase in the price of brokens had a more pronounced effect at lower HMC ranges.

From Figure 1 and Table 4, the consequences of delayed harvesting caused by logistics or equipment limitations can be quantified. If the Wells rice had been harvested at 14% HMC ($NV_{14\%HMC}$) as opposed to HMC_{opt-NV}, there would have been a \$0.82/cwt loss if the P_{BR} had been at 60% of the head rice price, and \$0.59/cwt and \$0.38/cwt at 70% and 80% values, respectively. As the price of brokens decreases, the NV of the rice at lower HMCs is greatly affected, but at greater HMCs, the price of brokens had little effect on NV, owing to the relative absence of brokens.

Declining HRY vs. HMC Relationship

Figure 2 (and Table 4) shows the relationship between NV, HRY, and HMC for medium-grain rice cultivar Bengal grown in Stuttgart, Ark., in 2000, assuming a head rice price of \$18.00/cwt. Head rice yields decreased dramatically from 68.4% to 51.0% as HMC decreased, but did not correspondingly decrease at the higher HMCs as with the parabolic relationship example (Fig. 1). According to the HRY versus HMC regression equation, the $HMC_{opt-HRY}$ would have been 26.0% with a corresponding HRY_{opt} of 69.9% (Table 1). If samples had been collected with a greater range of HMCs, the $HMC_{opt-HRY}$ may have been closer to the expected range of 22% to 24% (Siebenmorgen et al., 2007). Table 4 indicates that if the Bengal rice had been harvested at 14% HMC as opposed to HMC_{opt}, there would have been a \$0.52/cwt loss if the price of brokens had been at 60% of the head rice price, and losses of \$0.32/cwt and \$0.17/cwt at 70% and 80%, respectively.

Static HRY vs. HMC Relationship

Figure 3 (and Table 4) shows the relationship between NV, HRY, and HMC for long-grain cultivar Cypress grown in Stuttgart, Ark., in 2000, assuming a head rice price of $18.00/cwt. Head rice yield did not drastically change with HMC, but instead remained relatively static with only a 4.8 percentage point difference in HRY throughout the harvest season. Though it is more common that HRY decreases with decreased HMC, for some years, locations, and cultivars, low HMCs do not necessarily relate to low HRYs.

As a result of the fairly static HRYs, the shape of the NV curves in Figure 3 did not change appreciably with the price of brokens, compared to the previously exemplified sample sets. While HRY for this sample set was at a maximum at 21.1% HMC, Figure 3 and Table 4 show that NV was at maximum at 17.9, 17.6, and 17.2% HMC at 60, 70, and 80% brokens values, respectively; thus a HMC difference of at least 3.2 percentage points when considering the optimization of NV rather than HRY. The difference between $NV_{14\%HMC}$ and NV_{opt} was small relative to the parabolic and the declining HRY vs HMC relationships. If the rice had been harvested at 14% MC as opposed to HMC_{opt}, there would have been a $0.21/cwt loss if the price of brokens had been at 60% of the head rice price, and $0.16/cwt and $0.11/cwt at 70% and 80%, respectively.

SIGNIFICANCE OF FINDINGS

To date, studies relating HMC and HRY have focused on the optimal MC at which to maximize HRY. However, the current study revealed that the optimal economic MC was considerably less when considering maximizing NV rather than HRY. The HMC at which NV peaked was dependent on the HRY vs HMC relationship, as well as the price of head rice and brokens.

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Table 1. Summary of 139 rice lots from which data were used for this study. A parabolic function was used to describe the relationship between head rice yield (HRY) and harvest moisture content (HMC) for each year/location/cultivar lot.[z]

Year	Location	Cultivar	Harvest moisture contents							HRY_{opt}	$HMC_{opt\text{-}HRY}$	R^2
			(%, w.b.)							(%)[y]		
1999	Keiser, Ark.	Bengal	14.7	17.7	19.3	22.6	23.9	25.9		67.1	24.2	0.97
		Cypress	12.5	14.2	14.9	18.9	19.2	21.5	22.8	69.7	19.2	0.82
		Drew	12.8	14.8	16.1	18.3	20.1	22.6	25.5	70.6	21.0	0.86
	Stuttgart, Ark.	Bengal	12.2	14.7	17.7	19.3	22.6	23.9		66.3	23.8	0.98
		Cypress	12.5	14.2	16.0	18.9	19.2	22.8		67.9	22.5	0.97
		Drew	12.6	14.8	16.1	18.3	20.0	22.0	24.0	69.0	23.4	0.93
2000	Keiser, Ark.	Bengal	13.1	14.2	16.0	17.8	20.0	22.6	24.0	68.7	21.5	0.96
		Drew	13.9	15.6	17.6	21.2	23.7			69.4	20.3	0.94
	Stuttgart, Ark.	Bengal	12.5	14.5	16.3	18.4	20.1	22.1	23.6	69.9	26.0	0.98
		Cypress	13.7	14.2	16.8	18.0	21.6	23.6		65.4	21.1	0.71
		Drew	14.5	15.6	20.2	21.6	24.4			67.1	21.6	0.77
2004	Essex, Mo.	Cocodrie	13.5	20.1	20.3	23.9				67.6	19.2	0.97
	Hunter, Ark.	Wells	15.2	17.6	19.2	25.7				67.5	21.3	1.00
	Lodge Corner, Ark.	Bengal	11.6	18.5	20.3	25.5	27.1			69.1	22.4	0.99
	Newport, Ark.	Cocodrie	14.9	17.1	18.2	21.3	24.4			69.3	32.8	0.82
2005	Cleveland. Miss.	XP 723	12.0	14.0	17.3	18.0	23.5			63.8	19.5	0.98
	Osceola, Ark.	Cheniere	14.4	16.0	20.6	21.1	23.2			64.8	18.8	0.81
	Qulin, Mo.	Wells	15.4	16.8	18.8	19.0				63.0	18.7	0.46
	Stuttgart, Ark.	Francis	15.5	16.5	21.3	21.8	24.4			67.1	18.7	0.76
		XP 723	14.7	16.0	18.1	18.5	18.5	20.0		69.7	19.6	0.93
2006	Des Arc, Ark.	Cheniere	14.7	15.8	17.9	19.3	24.1			70.6	18.7	0.99
	Osceola, Ark.	Wells	13.7	18.9	19.4	21.2	24.2			66.3	21.2	1.00
	Shaw, Miss.	XP 723	14.2	16.3	20.1	24.7				67.9	20.4	0.85
	Stuttgart, Ark.	Wells	12.3	14.5	16.7	20.0	21.8	23.6	26.8	69.0	21.2	0.89
		XP 723	12.4	16.2	17.8	18.4	20.1	26.8		68.7	20.1	0.97

[z] The peak of each curve corresponded to the optimum HRY (HRY_{opt}) and the HMC at which HRY was optimized ($HMC_{opt\text{-}HRY}$).
[y] These data were reported by Siebenmorgen et al. (2007).

Table 2. Fee schedule that was used to compute drying charges in Equation 1.

Harvest moisture content (MC)	Drying fee (DF in Eq. 1)
(w.b.)	
≤13.5% MC	\$0.25/bu
13.6% to 18.9% MC	\$0.30/bu
19.0% to 21.9% MC	\$0.35/bu
≥22.0 % MC	\$0.50/bu

Table 3. Summary of optimal net values (NV_{opt}) and corresponding optimal harvest moisture contents ($HMC_{opt\text{-}NV}$) of the 25-year/location/cultivar lots that were used for this study, as calculated from the NV vs HMC quadratic regression equations.[z]

			$HMC_{opt\text{-}NV}$			NV_{opt}			$NV_{14\%HMC}$		
Year	Location	Cultivar	60%	70%	80%	60%	70%	80%	60%	70%	80%
			(%, w.b.)			($/cwt)					
1999	Keiser, Ark.	Bengal	21.8	21.1	19.9	10.43	10.56	10.70	9.25	9.76	10.28
		Cypress	17.8	17.5	17.2	11.03	11.08	11.15	10.60	10.76	10.92
		Drew	19.5	19.1	18.4	11.00	11.06	11.14	10.15	10.49	10.82
	Stuttgart, Ark.	Bengal	19.4	18.7	17.8	10.50	10.64	10.79	10.09	10.36	10.63
		Cypress	18.7	18.1	17.3	10.54	10.62	10.71	10.18	10.38	10.58
		Drew	20.5	19.9	19.0	10.69	10.80	10.93	9.73	10.14	10.54
2000	Keiser, Ark.	Bengal	19.5	19.0	18.2	10.79	10.88	10.98	9.98	10.33	10.68
		Drew	19.2	18.9	18.5	10.76	10.79	10.83	9.64	9.97	10.30
	Stuttgart, Ark.	Bengal	19.4	18.5	17.4	10.54	10.66	10.80	10.09	10.37	10.65
		Cypress	17.8	17.5	17.1	10.45	10.53	10.60	10.25	10.38	10.50
		Drew	20.5	20.3	20.1	10.53	10.59	10.66	8.84	9.21	9.58
2004	Essex, Mo.	Cocodrie	17.6	17.5	17.3	11.01	11.12	11.23	10.62	10.79	10.96
	Hunter, Ark.	Wells	18.2	17.6	16.8	10.86	10.98	11.10	10.64	10.84	11.03
	Lodge Corner, Ark.	Bengal	17.2	16.0	14.1	10.91	11.00	11.12	10.85	10.98	11.12
	Newport, Ark.	Cocodrie	17.0	16.8	16.6	11.06	11.16	11.27	10.97	11.09	11.20
2005	Cleveland, Miss.	XP 723	17.1	16.6	15.8	10.37	10.50	10.64	10.16	10.38	10.60
	Osceola, Ark.	Cheniere	17.7	17.5	17.2	10.46	10.54	10.63	9.87	10.08	10.28
	Qulin, Mo.	Wells	16.5	16.0	15.6	10.51	10.67	10.85	10.30	10.55	10.77
	Stuttgart, Ark.	Francis	18.1	18.0	18.0	10.73	10.82	10.90	10.24	10.36	10.48
		XP 723	17.9	17.7	17.4	10.58	10.69	10.79	10.19	10.37	10.57
2006	Des Arc, Ark.	Cheniere	17.7	17.5	17.3	10.97	11.04	11.13	10.53	10.68	10.82
	Osceola, Ark.	Wells	19.0	18.6	18.0	10.71	10.85	10.98	9.97	10.31	10.64
	Shaw, Miss.	XP723	18.9	18.5	18.1	10.60	10.70	10.80	9.81	10.11	10.42
	Stuttgart, Ark.	Wells	18.8	18.2	17.4	10.60	10.74	10.89	10.21	10.48	10.76
		XP723	15.6	14.4	12.8	10.64	10.78	10.94	10.62	10.78	10.94

[z] The $NV_{14\%HMC}$ values represent the NVs of the rice if it had been harvested at 14% HMC. Table values were calculated using a head rice price of $16.50/cwt and brokens prices of 60, 70, and 80% of the head rice price. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

Table 4. Summary of optimal net values (NV_{opt}) and corresponding optimal harvest moisture contents ($HMC_{opt\text{-}NV}$) of the 25-year/location/cultivar lots that were used for this study.[z]

Year	Location	Cultivar	$HMC_{opt\text{-}NV}$			NV_{opt}			$NV_{14\%HMC}$		
			60%	70%	80%	60%	70%	80%	60%	70%	80%
			(%, w.b.)			($/cwt)					
1999	Keiser, Ark	Bengal	21.9	21.2	20.2	11.48	11.61	11.76	10.14	10.70	11.26
		Cypress	17.8	17.6	17.3	12.10	12.16	12.22	11.62	11.80	11.97
		Drew	19.6	19.3	18.6	12.08	12.15	12.22	11.13	11.49	11.86
	Stuttgart, Ark.	Bengal	19.6	19.0	18.1	11.53	11.68	11.84	11.06	11.36	11.66
		Cypress	18.8	18.3	17.5	11.57	11.65	11.75	11.16	11.38	11.59
		Drew	20.6	20.0	19.2	11.75	11.86	12.00	10.67	11.11	11.55
2000	Keiser, Ark.	Bengal	19.6	19.1	18.4	11.85	11.94	12.06	10.94	11.33	11.71
		Drew	19.3	19.0	18.6	11.81	11.83	11.88	10.58	10.94	11.30
	Stuttgart, Ark.	Bengal	19.7	18.7	17.6	11.58	11.69	11.84	11.06	11.37	11.67
		Cypress	17.9	17.6	17.2	11.46	11.54	11.63	11.25	11.38	11.52
		Drew	20.6	20.4	20.2	11.56	11.63	11.70	9.70	10.11	10.52
2004	Essex, Mo.	Cocodrie	17.7	17.5	17.3	12.07	12.18	12.30	11.64	11.82	12.01
	Hunter, Ark.	Wells	18.3	17.8	17.0	11.92	12.04	12.17	11.67	11.88	12.09
	Lodge Corner, Ark.	Bengal	17.5	16.2	14.4	11.97	12.06	12.17	11.89	12.03	12.17
	Newport, Ark.	Cocodrie	17.0	16.8	16.5	12.13	12.24	12.36	12.04	12.17	12.29
2005	Cleveland. Miss.	XP 723	17.2	16.7	15.8	11.38	11.51	11.67	11.14	11.37	11.62
	Osceola, Ark.	Cheniere	17.7	17.5	17.2	11.47	11.56	11.66	10.83	11.05	11.28
	Qulin, Mo.	Wells	16.4	16.1	15.6	11.52	11.71	11.90	11.32	11.56	11.82
	Stuttgart, Ark.	Francis	18.1	18.0	18.0	11.77	11.86	11.95	11.24	11.39	11.52
		XP 723	18.0	17.8	17.5	11.61	11.72	11.84	11.18	11.39	11.60
2006	Des Arc, Ark.	Cheniere	17.7	17.6	17.4	12.03	12.12	12.20	11.55	11.71	11.87
	Osceola, Ark.	Wells	19.1	18.7	18.1	11.76	11.90	12.05	10.94	11.31	11.67
	Shaw, Miss.	XP723	18.9	18.6	18.1	11.63	11.74	11.85	10.77	11.10	11.43
	Stuttgart, Ark.	Wells	18.9	18.4	17.5	11.64	11.79	11.95	11.19	11.49	11.79
		XP723	15.8	14.5	12.9	11.67	11.82	11.99	11.64	11.82	11.99

[z] The $NV_{14\%HMC}$ values represent the NVs of the rice if it had been harvested at 14% HMC. Table values were calculated using a head rice price of $18.00/cwt and brokens prices of 60, 70, and 80% of the head rice price. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

Table 5. Summary of optimal net values (NV_{opt}) and corresponding optimal harvest moisture contents ($HMC_{opt\text{-}NV}$) of the 25-year/location/cultivar lots that were used for this study.[z]

Year	Location	Cultivar	$HMC_{opt\text{-}NV}$ 60%	$HMC_{opt\text{-}NV}$ 70%	$HMC_{opt\text{-}NV}$ 80%	NV_{opt} 60%	NV_{opt} 70%	NV_{opt} 80%	$NV_{14\%HMC}$ 60%	$NV_{14\%HMC}$ 70%	$NV_{14\%HMC}$ 80%
			(%, w.b.)			($/cwt)					
1999	Keiser, Ark.	Bengal	22.0	21.4	20.4	12.53	12.66	12.82	11.04	11.64	12.25
		Cypress	17.9	17.7	17.3	13.16	13.23	13.30	12.64	12.83	13.02
		Drew	19.7	19.4	18.7	13.16	13.23	13.31	12.11	12.50	12.90
	Stuttgart, Ark.	Bengal	19.8	19.2	18.3	12.57	12.73	12.90	12.03	12.36	12.68
		Cypress	19.0	18.5	17.7	12.60	12.69	12.79	12.14	12.38	12.61
		Drew	20.8	20.2	19.3	12.81	12.93	13.07	11.61	12.09	12.56
2000	Keiser, Ark.	Bengal	19.7	19.3	18.5	12.91	13.01	13.13	11.90	12.32	12.73
		Drew	19.3	19.0	18.6	12.85	12.89	12.92	11.52	11.91	12.30
	Stuttgart, Ark.	Bengal	19.9	18.9	17.8	12.62	12.74	12.89	12.03	12.36	12.69
		Cypress	18.0	17.7	17.3	12.47	12.56	12.66	12.24	12.39	12.53
		Drew	20.6	20.5	20.3	12.60	12.67	12.75	10.58	11.02	11.46
2004	Essex, Mo.	Cocodrie	17.8	17.6	17.4	13.14	13.26	13.38	12.66	12.86	13.05
	Hunter, Ark.	Wells	18.5	18.0	17.1	12.98	13.11	13.25	12.70	12.92	13.16
	Lodge Corner, Ark.	Bengal	17.7	16.5	14.6	13.03	13.12	13.24	12.93	13.09	13.24
	Newport, Ark.	Cocodrie	17.1	16.8	16.6	13.20	13.32	13.44	13.09	13.24	13.37
2005	Cleveland. Miss.	XP 723	17.3	16.8	15.9	12.38	12.53	12.70	12.11	12.37	12.64
	Osceola, Ark.	Cheniere	17.8	17.5	17.3	12.48	12.58	12.68	11.79	12.04	12.28
	Qulin, Mo.	Wells	16.4	16.0	15.6	12.55	12.74	12.95	12.32	12.59	12.87
	Stuttgart, Ark.	Francis	18.1	18.1	18.1	12.81	12.91	13.01	12.24	12.39	12.54
		XP 723	18.1	17.9	17.5	12.64	12.76	12.89	12.17	12.39	12.62
2006	Des Arc, Ark.	Cheniere	17.7	17.6	17.4	13.09	13.19	13.28	12.57	12.74	12.92
	Osceola, Ark.	Wells	19.2	18.7	18.1	12.80	12.95	13.11	11.91	12.30	12.70
	Shaw, Miss.	XP723	19.0	18.7	18.2	12.67	12.78	12.91	11.72	12.09	12.44
	Stuttgart, Ark.	Wells	19.0	18.5	17.7	12.68	12.83	13.01	12.18	12.50	12.82
		XP723	16.0	14.8	13.0	12.70	12.85	13.04	12.66	12.85	13.03

[z] The $NV_{14\%HMC}$ values represent the NVs of the rice if it had been harvested at 14% HMC. Table values were calculated using a head rice price of $19.50/cwt and brokens prices of 60, 70 and 80% of the head rice price. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

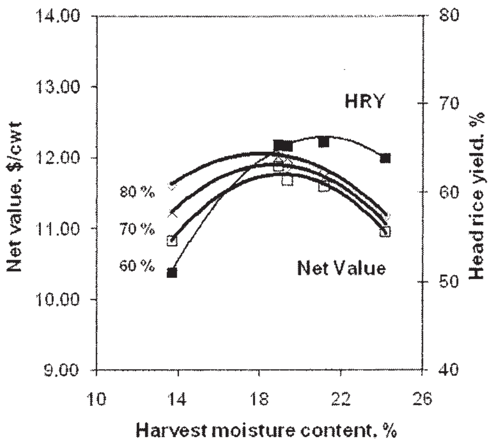

Fig. 1. Net value (eq. 5) and head rice yield (HRY) (■) of Wells rice harvested from Osceola, Ark., in 2006. Net value was calculated assuming that head rice had a value of $18.00/cwt, and brokens had values of 60 (□), 70 (x), or 80% (◊) of the head rice value. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

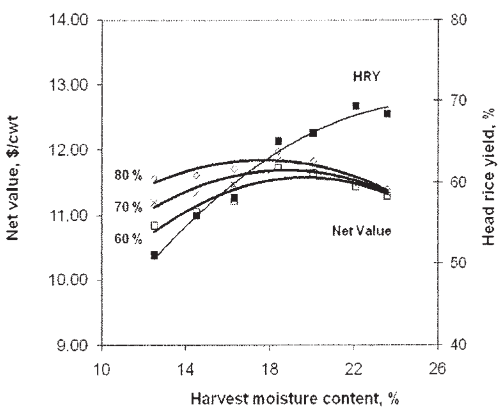

Fig. 2. Net value (eq. 5) and head rice yield (HRY) (■) of Bengal rice harvested from Stuttgart, Ark., in 2000. Net value was calculated assuming that head rice had a value of $18.00/cwt, and brokens had values of 60 (□), 70 (x), or 80% (◊) of the head rice value. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

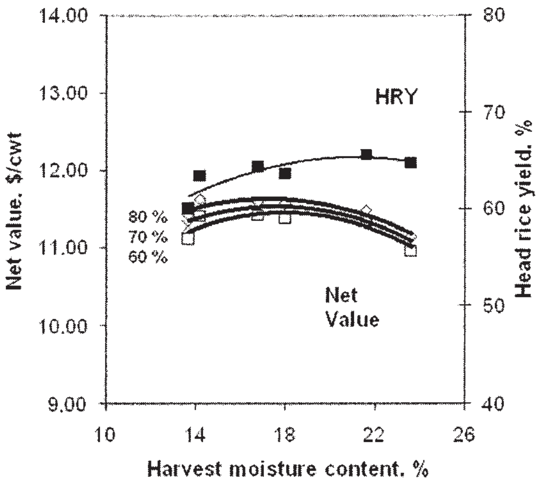

Fig. 3. Net value (eq. 5) and head rice yield (HRY) (■) of Cypress rice harvested from Stuttgart, Ark., in 2000. Net value was calculated assuming that head rice had a value of $18.00/cwt, and brokens had values of 60 (□), 70 (x), or 80% (◊) of the head rice value. Drying charges were calculated per equation 1 using the drying fee structure detailed in Table 2.

Kinetics of Milled Rice Fissure Formation

T.J. Siebenmorgen, N.T.W. Cooper, L.E. Estorninos, Jr., and R.C. Bautista

ABSTRACT

Environmental conditions can cause fissuring in milled rice that will subsequently lead to undesirable kernel breakage. The effects of cultivar ('Wells', 'CL 161', and 'Bengal'), milled rice kernel moisture content (11, 12, 13, and 14% MC), air relative humidity (10, 20, 30, 45, 60, 75, and 90% RH) and temperature (5, 10, 15, 20, and 30°C) on fissure formation in milled rice were investigated. Tests were conducted within a specialized chamber that controlled temperature and relative humidity and was equipped with a video camera and monitor system that observed fissure formation for up to 24 h. Cultivar had little effect on the rate of fissure formation. For a given air temperature, kernel MC affected fissuring in relation to the RH of the environment; fissures formed most readily in 11% MC kernels when exposed to 90% RH air and in 14% MC kernels in 10% RH air. In general, fissures appeared most quickly in low (10%) and high (90%) RH air conditions, with the fissuring rate increasing with temperature. Little to no fissuring occurred in environments of 45 to 75% RH. These findings have very significant implications for processing applications or systems in which milled rice is exposed to air.

INTRODUCTION

Fissured, milled rice kernels cause great financial losses to food processors in terms of both product waste and processing-plant production limitations. Understanding the causes and rates of fissure formation in rice kernels at all stages of rice milling, transportation, and end-use processing is necessary in order to design equipment and implement procedures to minimize fissure formation.

Fissures form within rice kernels when internal stresses exceed the material tensile strength of the kernel. Internal stress can be caused by intra-kernel MC gradients that result from moisture transfer between the kernel and the surrounding environment (Kunze and Hall, 1965; Kunze and Choudhury, 1972; Banazek and Siebenmorgen, 1990). The moisture adsorbing or desorbing potential of an air environment is determined by a given grain or grain component's equilibrium MC (EMC), which is associated with the temperature and RH of that air environment. As such, the rate and magnitude of intra-kernel MC gradient formation results from the difference between the kernel MC and the grain EMC associated with the surrounding air.

Given that milled rice shipments can be exposed to a wide range of air conditions for varying durations during transport and conveyance, this study was conducted to measure the rate (kinetics) at which fissures appear in milled rice exposed to a wide range of environments, particularly low-temperature environments.

PROCEDURES

The overall procedure comprised exposing milled rice at a range of MCs to given air conditions. Each air condition temperature and RH was maintained by a specialized chamber. While within the chamber, kernel images were recorded over a 24-hour duration using a video camera.

Rice Samples

Bengal (medium-grain cultivar), Wells, and CL161 (long-grain cultivars) were harvested at MCs ranging from 18% to 22% from Stuttgart, Jonesboro, and Pocahontas, Ark., respectively. Samples of each cultivar were dried to approximately 14% MC in a walk-in chamber maintained at 22°C and 55% RH by a temperature and RH controller (AA5582, Parameter Generation & Control, Inc., Black Mountain, N.C.). Sample MCs were determined by drying triplicate, 15-g samples for 24 h in a convection oven (Model 1370FM, Sheldon Manufacturing, Inc., Cornelius, Ore.) set at 130°C.

Chamber and Fissure Detection

All exposure tests were conducted using a chamber (Platinous Sterling Series T and RH Chamber, ESPEC North America, Hudsonville, Mich.) capable of controlling temperature from -35°C to 150°C (±0.5°C) and RH from 10% to 90% (±3%). Open petri dishes containing milled rice samples were mounted on a 0.51-m diameter plexiglass platform, mounted to a stepper motor (Sherline Products, Inc., Vista, Calif.). The stepper motor was controlled by a motion controller (Sherline Products, Inc.) interfaced to a timing system (Mumford Micro Systems, Santa Barbara, Calif.). Petri dishes were fastened 2.5 cm from the edge of the platform at an equidistant spacing of 22.5°. The motion controller was programmed to cause the stepper motor to incrementally rotate the platform every 15 s. One complete revolution (360°) of the platform was completed every 4 min, which also corresponded to the frequency that each petri dish sample was positioned under a camera (Scopeman MS-803, Moritex Corp., San Jose, Calif.) with

10X magnification. The camera was interfaced to a computer with a monitor and a video cassette recorder located outside the chamber. Rice kernels viewed under the camera were illuminated using two fiber-optic light sources, which were oriented to illuminate kernels from opposite directions so as to allow fissures to be detected in the camera images. Kernel images, along with the associated exposure duration, were simultaneously recorded onto the video cassette recorder. The video tapes were subsequently reviewed to quantify the number of kernels fissured after exposure durations of 4, 8, 16, 32, and 60 min; and then after 2, 4, 8, 12, and 24 h.

Procedure

For each cultivar, four 150-g, 14% MC samples were dehulled using a laboratory huller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) and then milled for 30 s with a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas). Broken kernels were separated from head rice using a shaker table (Grainman, Grain Machinery Mfg. Corp., Miami, Fla.). The four head-rice samples were then dried, each to a desired MC of 11, 12, 13, or 14%, by spreading the samples on screened trays and placing the trays in the above-mentioned walk-in chamber with air conditions maintained at 28°C and 48% RH. Once each desired MC was attained, as measured by the oven-drying procedure, the samples split, were sealed in plastic bags, placed in a 68-L container, and stored at 4°C for approximately 3 weeks until testing.

At the initiation of testing, sub-samples of each of the 12 (three cultivars x four MCs) lots were transferred from the 4°C storage to a room at ~ 22°C and allowed to equilibrate for 24 h while still sealed in the storage bags. For each rep, kernels from each lot were randomly selected and examined for fissures using a fissure-inspection box (TX-200 Grainscope, Kett Electric Laboratory, Tokyo, Japan) inside the 26°C and 55% RH walk-in chamber. For a given experimental design air setting, thirty non-fissured kernels from each of the 12 lots were selected and placed in petri dishes, which were randomly placed around the periphery of the rotary platform. An insulated shroud was placed over the rotary platform, which was then placed inside the test chamber. Once the temperature and RH conditions within the chamber were reached, the shroud was remotely removed and the fissure observation procedure was initiated.

The above procedure was conducted for thirty-five control-chamber air conditions, comprising five temperatures (5, 10, 15, 20, and 30°C) and seven RHs (10, 20, 30, 45, 60, 75, and 90%). A replication of tests using the second set of split samples was started immediately after the first replication was completed, approximately three months after the initiation of the experiment.

RESULTS AND DISCUSSION

The results obtained from reps 1 and 2 were not always similar. Figure 1a demonstrates that while the initial fissure formation rate was similar, after 24 h of exposure at 5°C and 20% RH, there was approximately 45 percentage points difference between the amount of fissuring in rep 1 and rep 2. However, at 5°C and 90% RH, the two reps reacted similarly in terms of the rate and extent of fissuring (Fig. 1b). It is speculated that fissuring was affected by the 3-month aging period that occurred between rep 1 and rep 2, causing rep 2 to be more susceptible to fissuring. As such, the results from the reps were not averaged and only the findings from rep 1 are presented. A study is currently underway with the intent of elucidating the effects of storage duration on the fissuring rate of rice kernels.

Little cultivar effect was observed, though Bengal fissured slightly more than the long-grain cultivars (data not shown), which corroborates with the studies of Jindal and Siebenmorgen (1994) who reported that thick-kernel cultivars were more susceptible to moisture adsorption damage than thinner-kernel cultivars.

Figure 1 shows that kernels of 11% MC fissured more readily and to a greater extent in high-RH environments (90% RH) (Fig. 1b) whereas kernels at 14% MC were more susceptible to fissuring in low-RH environments (Fig. 1a). Subsequent data will only show the results involving Bengal rice at 12% kernel MC, in order to isolate the effects of RH and temperature on kernel fissuring.

Relative Humidity Effects on Fissure Kinetics

Figure 2 demonstrates the effect of RH on kernel fissuring at 10, 20, and 30°C. At all temperatures, fissuring was most severe in the 10% RH environment, with 100% fissuring occurring after 24 h of exposure (Fig. 2a). As RH increased from the 10% level, the MC gradient between the rice kernels and the EMC associated with the air decreased; this resulted in dramatically less fissuring at 20 and 30% RHs. Minimal or no fissuring was observed at 45 and 60% RH at all tested temperatures. At 90% RH, fissuring increased, though to a lesser extent and at a slower rate than at 10% RH. These findings corroborated those of Lloyd and Siebenmorgen (1999), who showed that fissuring in medium-grain cultivars occurs to a greater extent at both low and high RHs.

Most fissuring occurred at low (10%) and high (90%) RH, with the fissuring rate increasing with temperature. At 10% RH and 30°C, fissures had formed in 68% of the kernels at time 4 min (Fig. 2c), as opposed to 7% and 28% fissuring at 10°C (Fig. 2a) and 20°C (Fig. 2b), respectively.

Temperature Effects on Fissure Kinetics

Figure 3 shows the effect of temperature on the rate of kernel fissuring at 10, 75, and 90% RH. The rate of fissuring increased with temperature; after 4 min at 10% RH, the milled rice showed 0% fissuring at 5°C, increasing to 7, 7, 27, and 67% fissuring at 10, 15, 20 and 30°C, respectively. After 24 h at 10% RH, almost all kernels had fissured at all temperatures. At 75% RH, the greatest amount of fissuring was observed at 15°C, with 30% of kernels having fissures after 24 h of exposure. At 90% RH, the amount of fissuring increased with temperature but at a slower rate than at 10% RH. After 4 min at 90% RH, the milled rice showed 0, 0, 7, 28, and 30% fissuring at 5, 10, 15, 20, and 30°C, respectively.

SIGNIFICANCE OF FINDINGS

This study showed that fissuring of milled rice kernels can occur extremely rapidly, at low and high RHs, especially at warmer temperatures (30°C). These findings have very significant implications for processing applications or systems in which milled rice is exposed to air. Monitoring of air temperatures and RHs during conveyance is suggested as a means of explaining the occurrence of fissures and ultimately as a means of preventing fissure formation.

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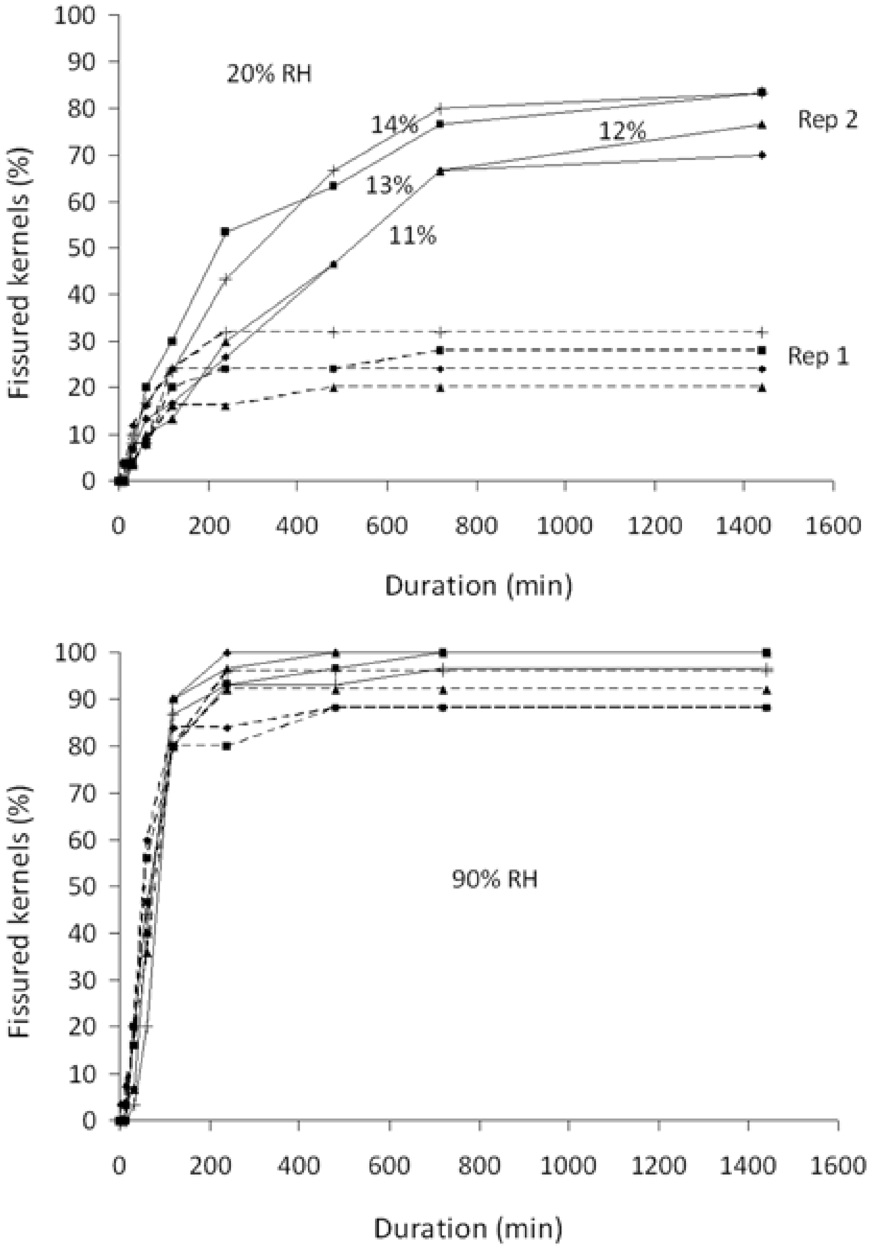

Fig. 1. Fissured kernel percentages of Bengal milled rice at the indicated moisture contents when exposed to environments of 5ºC and 20% or 90% relative humidity (RH). Rep 1 is represented by dashed lines (20% RH test conducted 1/3/2007, 90% RH test conducted 1/10/2007) while rep 2 is represented by solid lines (20% RH test conducted 4/3/2007; 90% RH test conducted 4/4/2007).

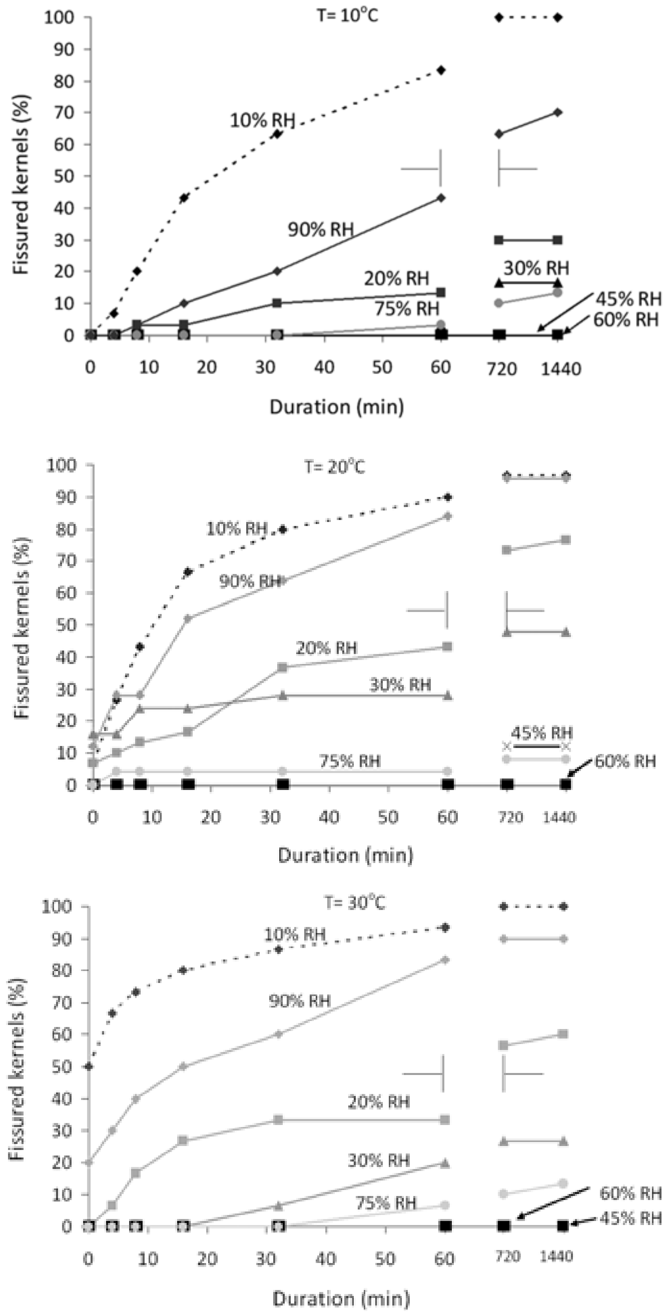

Fig. 2. Effects of relative humidity on the fissuring rate of milled Bengal rice (12% MC) at the indicated temperatures.

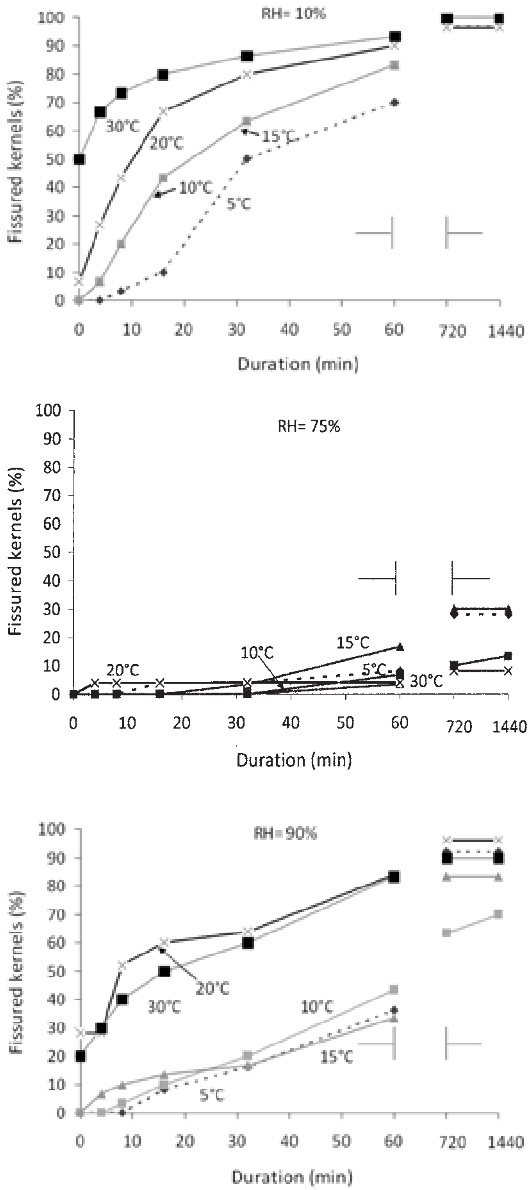

Fig. 3. Effects of air temperature on the fissuring rate of milled Bengal rice (12% MC), placed in the indicated relative humidity (RH) environments.

ECONOMICS

The Value of Rice Harvesting Efficiency

J.A. Hignight and K.B. Watkins

ABSTRACT

The ability to efficiently harvest rice on eastern Arkansas farms is very important to reducing the risk of yield and quality loss to inclement weather. Many factors can decrease harvest efficiency and increase per-acre harvesting costs and time that could have been allocated somewhere else. Time spent harvesting is also influenced by the header size used to harvest rice. With a 30-foot header and combine, the acres harvested per hour increase while reducing the total per-acre harvesting costs. A smaller horse-power combine with a 22-foot header proved to have slightly higher direct costs than a larger combine with a 25-foot header, but when fixed costs were included, the 22-foot header had lower total costs.

INTRODUCTION

Rice harvesting efficiency can be defined as a percent of time actually harvesting compared to the theoretical efficiency rate of 100%. A harvesting efficiency rate of 100% would be the acres per hour if a combine were harvesting continuously at full capacity. Loss of efficiency could come from inadequate transportation availability, distance and time at unloading facility, grain unloading from combine, field size and topography, and waiting on grain trucks to arrive. Under perfect circumstances, these factors could slow down or even delay the rice harvest on a farm, resulting in an increase in harvesting costs and the potential for yield and quality loss from an incoming weather event.

Increased energy costs over the past few years have increasingly added pressure on farms to manage and use resources more efficiently. Harvesting inefficiency studies have mainly focused on crops like sugarcane, which have very high harvesting costs (Baker, 2007). Other studies have focused on speeds and the loss of grain through the back of the combine (Wilson et al., 2001). This analysis will focus on the per-acre costs of rice harvesting under alternative efficiencies and will calculate the direct and fixed costs under these scenarios. Although transportation issues and weather were mentioned and have costs associated with them, this analysis will focus on rice harvesting costs.

PROCEDURES

Estimated 2008 direct and fixed costs for rice production on silt loam soils in eastern Arkansas are presented in (Table 1), according to the main production operations. These costs come from the University of Arkansas Cooperative Extension Service using the Mississippi State Budget Generator and can be found on the Web site: www.aragriculture.org. This table also includes the percent that each operation represents as its portion of the total costs. Harvesting costs contribute up to 8.8% of total production costs. Harvesting direct costs include labor, diesel fuel, repair and maintenance on equipment, and interest on operating capital for a combined cost of $20.62/acre. Fixed costs associated with harvesting are $29.39/acre.

Breakdown of harvesting costs for the budget by dollar value for each item in the harvest operation as well as its percentage of the total rice harvesting costs are presented in (Table 2). Diesel fuel is the largest direct cost at $9.82/acre or 19.6% of total harvesting costs. This is based upon the 2008 Arkansas rice budget's diesel price of $2.33/gal. As this cost increases, its share of the budget would too. Fixed costs represent the largest costs at $29.39/acre or 58.8% of total harvesting costs. These expenses are for a combine with a 25-foot header, a 180 to 199 horsepower tractor, and a 700-bushel grain cart. As diesel fuel increases, per-acre specified harvesting costs will rise and as efficiency decreases, fixed expenses per acre will increase due to increased machinery operating time per acre harvested.

To calculate the impact of alternative rice harvesting efficiencies, an analysis was conducted using the Mississippi State Budget Generator and changing the combine efficiency rate. The program uses data on specified equipment, purchase price, salvage value, repair and maintenance, labor costs, and fuel needed to perform operations at the set efficiency rate. Fixed expenses are calculated using the capital recovery method to capture the costs of machinery and equipment ownership.

Three combine headers were analyzed. The first was a 22-foot header with a combine size of 200- to 250-hp. Twenty-five and 30-foot headers were assumed to use a 250- to 300-hp combine. Both the 22- and 25-foot combines were assumed to operate at 2 miles per hour while the combine with the 30-foot header was assumed to harvest at 1.75 miles per hour. The tractor and grain cart efficiencies were also changed relative to the change in harvesting efficiency. The range of rice-harvesting efficiency was from 55% to 75% with 65% being the average used in the Arkansas Cooperative Extension Service Rice Budgets. The rates below and above average will simulate harvest as idle time decreases or increases. Table 3 presents the costs associated with decreases and increases in harvesting efficiency with three different headers and combines.

RESULTS AND DISCUSSION

An example of fuel and labor usage over 1,000 acres is presented in (Table 3). Due to the use of a smaller horsepower combine, the 22-foot header would use 30 gallons less than the 25-foot header but would use 141 gallons more than the 30-foot header at average efficiency. The difference is in the amount of area being harvested per hour and the efficient use of the combine's horsepower. By increasing the efficiency from 65% to 75%, a farm could decrease harvesting-fuel use by 536 gallons with the 25-foot header. Labor has an inverse relationship with the size of the header. Savings of 47 labor hours could occur from the increase of a header size of 22 ft to 30 ft. Increased efficiency from 65% to 75% on a 1,000-acre rice farm could save 39 labor hours with a 25-foot header.

As shown earlier, total harvesting costs for the 2008 rice budget example using a 25-foot header would be $50.01/acre. Under the least-efficient scenario and the same combine setup, total harvesting costs would be $59.10/acre as shown in (Table 4). At 75% efficiency, total harvesting costs would be $43.33/acre. With a range of $15.77/acre, the costs associated with harvesting inefficiency can add up over the entire rice harvest.

A farm setup with a 22-foot header would actually have a small savings per acre compared to the 25-foot header. Direct expenses are the highest per acre due the additional fuel and labor needed for each acre of rice harvest. Fixed expenses have savings compared to the 25-foot header due to the price difference between the 200- to 250-hp combine and the 250- to 300-hp combine. During average efficiency, the 22-foot header would have a total cost of $49.15/acre while the range between the least efficient and most efficient would be $15.51/acre.

Harvesting costs would be the least using a 30-foot header with a combine size of 250 to 300 hp. Both direct and fixed expenses are lower than the previously discussed setups. With the additional header length, fuel and labor costs are reduced and would average $48.08/acre during average efficiency. The range between the least efficient and most efficient is $56.81 and $41.64/acre, respectively. Savings are very apparent between using a 25-foot or 30-foot header. Both use the same horsepower combine, but at average efficiency the difference is $1.93/acre. This difference could pay for the price difference between header sizes during one harvest season.

SIGNIFICANCE OF FINDINGS

This analysis shows the costs of inefficient rice harvest for three combine/header setups. Fuel is the largest percentage of direct costs for harvesting. The amount of fuel can be decreased as efficiency increases. This aspect of harvesting gains a greater importance as fuel cost rises. Labor is also an important factor at harvest and also decreases as harvesting efficiency increases. Direct costs could range from 13.4% below to 18.2% above total costs per acre compared to the average harvesting efficiency.

Analysis of the three headers sizes presents a conclusion that as the header size increases, direct costs can decrease per acre. Fixed expenses are the largest portion of harvesting total costs. Based upon the capital recovery method, fixed expenses were the least for a 30-foot header and greatest for a 25-foot header. Since both use the same combine, it is reasonable that if an upgrade from a 22-foot and 200- to 250-hp combine is made, an operator should purchase the 30-foot header instead of the 25-foot header due to savings on fuel, labor, and fixed expenses under the different rice-harvesting efficiencies per acre. Results from the alternative efficiencies show the total costs of harvesting, but an inefficient harvest could result in significant losses of grain and milling yields.

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Table 1. Estimated costs of production for rice in eastern Arkansas, 2008[z].

	Direct costs	Fixed costs	Total costs	Percent of total costs
	---------------($/acre)---------------			(%)
Field preparation	20.25	20.86	41.11	7.3
Seed and planting	30.64	7.79	38.43	6.8
Irrigation and preparation	90.04	28.64	118.68	21.0
Fertilizer and applications	142.76		142.76	25.3
Other inputs and applications	77.45		77.45	13.7
Harvesting	20.62	29.39	50.01	8.8
Transportation	24.00		24.00	4.2
Drying and checkoff	50.16		50.16	8.9
Operating interest on capital	22.77		22.77	4.0
Total	**478.69**	**86.68**	**565.37**	**100.0**

[z] Source: Arkansas Cooperative Extension Service Rice Budgets.

Table 2. Rice harvesting costs breakdown per acre, 2008.

Item	Unit	Price	Quantity	Amount	Percent of total costs
		($/unit)		($/acre)	(%)
Direct expenses					
Labor	hour	9.45	0.3173	3	6.0
Diesel fuel	gallon	2.33	4.2125	9.82	19.6
Repair and maintenance	acre	7.25	1	7.25	14.5
Interest				0.55	1.1
Total direct expenses				20.62	41.2
Total fixed expenses				29.39	58.8
Total harvesting costs				50.01	100.0

Table 3. Rice harvesting fuel and labor use on 1,000 acres at alternative efficiency levels and combine header sizes.

	55%	60%	65%	70%	75%
Gallons of diesel					
22 ft	4900	4513	4183	3899	3652
25 ft	4935	4545	4213	3926	3677
30 ft	4732	4359	4042	3768	3529
Labor hours					
22 ft	411	379	352	328	308
25 ft	371	342	317	296	278
30 ft	356	329	305	285	267

Table 4. Estimated impact of efficiency rates on per-acre rice harvest costs, 2008.

Efficiency rate	Rice header size	Direct costs	Fixed costs	Total costs
	(ft.)	($/acre)	($/acre)	($/acre)
55%	22	24.44	33.65	58.09
	25	24.37	34.73	59.10
	30	23.45	33.36	56.81
60%	22	22.39	30.86	53.25
	25	22.35	31.84	54.19
	30	21.48	30.58	52.06
65%	22	20.67	28.48	49.15
	25	20.62	29.39	50.01
	30	19.84	28.24	48.08
70%	22	19.20	26.45	45.65
	25	19.15	27.30	46.45
	30	18.40	26.22	44.62
75%	22	17.91	24.67	42.58
	25	17.86	25.47	43.33
	30	17.19	24.45	41.64