B.R. Wells

Arkansas Rice Research Studies 2017

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

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Cover Photo: Karen Moldenhauer, professor of rice breeding and holder of the Arkansas Rice Industry Chair for Variety Development, University of Arkansas System Division of Agriculture rice breeding program, shows cross pollinated plants in the Rice Research and Extension Center breeding greenhouse, August, 2015, Stuttgart, Ark. Photo credit: Fred Miller, University of Arkansas System Division of Agriculture Communications.

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University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72704

DEDICATED IN MEMORY OF

Bobby R. Wells

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

Wells was a world-renowned expert on rice production with special emphasis in rice nutrition and soil fertility. He had a keen interest in designing studies to determine how the rice plant reacted to different cultural practices and nutrient supplementation: including timing and rates of nitrogen, phosphorus, and potassium fertilization; zinc fertilization of high pH soils; irrigation methods; dates and rates of seeding and the reasons for differing responses.

Wells was a major participant in the pioneering effort by University of Arkansas Division-based scientists in the development of the Degree-Day 50 (DD50) computer rice production program which assists growers with 26 management decisions during the season based on temperature, rice cultivar, and growth stage; including herbicide application, critical times to scout and spray for insects and diseases, and nitrogen fertilizer application. The DD50 program developed in the 1970s remains a vital program to this day in assisting growers, consultants and extension agents in making important management decisions concerning inputs to optimize rice yield and quality. Other rice-growing states have followed suit in this important development and have copied the Arkansas DD50 program.

He was the principle developer of the nitrogen fertilizer application method known famously at the time as the Arkansas 3-way split application strategy; who his successor discovered, using the isotopic tracer N-15, to be the most efficient method (i.e., as concerns nitrogen uptake) of fertilizing rice with nitrogen in the world. The application method has since been modified to a 2-way split, because of the release of new short stature and semi-dwarf cultivars, but its foundation was built on Wells' 3-way split method.

Wells was a major participant in the development of cultivar-specific recommendations for getting optimum performance from new cultivars upon their release and reporting research results at Cooperative Extension Service meetings as well as in the Extension Service publications, even though he had no extension appointment; he just did what he thought was best for the Arkansas rice farmer. He made numerous presentations at annual meetings of the Tri-Societies and Rice Technical Working Group, published many journal articles, and several book chapters. He loved being a professor and was an outstanding teacher who taught a course in soil fertility and developed a course in rice production. Both courses are still being taught today by his successors. The rice production course he developed is the only rice production course being taught in the USA to the best of our knowledge.

Wells 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/program chair (1982-1984) and chairman (1984-1986) of the RTWG. He was appointed head of the Department of Agronomy (later renamed the Department of Crop, Soil, and Environmental Sciences) in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, teaching, and service.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993), and posthumously, the Distinguished Service Award from the RTWG (1998) and induction into the Arkansas Agriculture Hall of Fame (2017). Wells edited this series when it was titled Arkansas Rice Research Studies from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the B.R. Wells Rice Research Studies in his memory starting with the 1996 publication. The name of this publication was modified in 2014 to the B.R. Wells Arkansas Rice Research Studies.

FOREWORD

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

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

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

ACKNOWLEDGMENTS

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

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Trends in Arkansas Rice Production, 2017

J.T. Hardke[1]

Abstract

Arkansas is the leading rice-producer in the United States. The state represents 46.4% of total U.S. rice production and 47.1% of the total acres planted to rice in 2017. Rice cultural practices vary across the state and across the U.S. However, these practices are also dynamic and continue to evolve in response to changing political, environmental, and economic times. This survey was initiated in 2002 to monitor and record changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas System Division of Agriculture Rice DD50 Program was included to summarize variety acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

Introduction

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

[1] Rice Extension Agronomist, Department of Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, Stuttgart.

Procedures

A survey has been conducted annually since 2002 by polling county agriculture extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information were obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture's Rice Degree-Day 50 (DD50) program enrollment.

Results and Discussion

Rice acreage by county is presented in Table 1 with distribution of the most widely-produced cultivars. RiceTec CLXL745 was the most widely planted cultivar in 2017 at 18.6% of the acreage, followed by RT XP753 (16.5%), Jupiter (8.9%), CL153 (8.9%), Diamond (8.6%), CL151 (6.8%), Roy J (5.8%), CL172 (3.6%), Titan (3.0%), and RT CLXL729 (2.8%). Additional cultivars of importance in 2017, though not shown in the table, were RT CLXP756, Wells, CL111, RT XP760, Taggart, Cheniere, and RT 7311 CL.

Arkansas planted 1,161,000 acres of rice in 2017 which accounted for 47.1% of the total U.S. rice crop (Table 2). The state-average yield of 7490 lbs/acre (166 bu/acre) represented a 570 lb/acre increase compared to 2016. This represented the third highest state average yield for Arkansas on record. Mild temperatures combined with frequent rainfall throughout the spring and summer seemed primarily responsible for the yield increase. Final harvested acreage in 2017 totaled 1,104,000. The total rice produced in Arkansas during 2017 was 82.6 million hundredweight (cwt). This represents 46.4% of the 178.2 million cwt produced in the U.S. during 2017. Over the past 3 years, Arkansas has been responsible for 47.5% of all rice produced in the U.S. The six largest rice-producing counties by acreage in Arkansas during 2017 included Poinsett, Lawrence, Lonoke, Jackson, Greene, and Arkansas, representing 43.6% of the state's total rice acreage (Table 1).

Planting in 2017 began to considerably outpace the 5-year state average due to dry, moderate conditions during April (Fig. 1). Planting progress had reached 67% by 16 April compared to 38% planting progress averaged across the previous 5 years. This early progress was especially fortunate as regular rainfall events began at the end of April and would last all the way to harvest for much of the state. In particular, extreme flooding occurred around May 1 which caused a loss of over 100,000 acres of rice and impacted another 300,000 acres in the form of levees lost and stands reduced. By 30 April, 89% of acres had been planted compared to the 5-year average of 65%.

As harvest began, rainfall events began to lessen in frequency and amount, allowing for a faster than average harvest. By 17 September, harvest progress had reached 59% compared to 52% in the 5-year average (Fig. 2). About 78% of the crop had been harvested by 24 September compared with 66% harvest progress on the same date in previous years. Harvest progress was complete (100%) by 29 October.

Over 51% of the rice produced in Arkansas was planted using conventional tillage methods in 2017 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres were planted using stale seedbed (43.7%) or no-till (4.9%) systems. True no-till rice production is not common but is done in a few select regions of the state.

More rice was produced on silt loams soils (47.5%) than any other soil texture in 2017 (Table 3). Rice production on clay or clay loam soils (24.0% and 22.9%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil type present unique challenges in rice production such as tillage practices, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation, accounting for 70.2% of the rice acreage in 2017 (Table 3). Approximately 23% of the acreage in 2017 was planted following rice, with the remainder made up of rotation with other crops including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas was produced in a dry-seeded, delayed-flood system with only 6.1% using a water-seeded system. Annually, approximately 85% of all the Arkansas rice acreage is drill-seeded with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the "waste" by collecting all available water and re-using. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater was used to irrigate 73.3% of the rice acreage in Arkansas in 2017 with the remaining 26.8% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990's, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet irrigation which uses poly-tubing as a means of irrigating rice to conserve water and labor. As of 2017, rice farmers utilize this practice on 33.4% of the rice acreage. Most remaining acreage is still irrigated with conventional levee and gate systems. Intermittent flooding is another means of irrigation increasing in interest recently as a means to reduce pumping costs and water use; but the practice accounted for only 3.3% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 3.5% of acreage.

Stubble management is important for preparing fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including tillage, burning, rolling, and winter flooding. In 2017, 44.6% of the acreage was burned, 47.3% was tilled, 24.0% was rolled, and 20.5% was winter flooded. Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather, but in 2017 as in 2015 and 2016 burned acreage saw a noticeable rise as dry fall conditions permitted more of this stubble management practice to take place.

Contour levee fields accounted for 47.9% of rice acres in 2017. Precision-leveled, or straight levee, fields represented 38.0% and zero-graded fields 14.2%. Each year growers attempt to make land improvements where possible to improve overall rice crop management, particularly related to water management. Modifying the slope, and subsequently the levee structure and arrangement in fields, can have a profound impact on the efficiency of rice production. Straight levee and zero-grade fields have shown to significantly reduce water use in rice production in Arkansas.

The use of yield monitors at harvest (70.6%) and grid soil sampling (35.8%) have increased slightly in recent years. However, only 25.4% of rice acres were fertilized using variable rate equipment in 2017. Urea stabilizers (products containing NBPT) are currently used on 77.7% of rice acres in Arkansas to limit nitrogen losses due to ammonia volatilization. The use of the Nitrogen Soil Test for Rice (N-STaR) remains low at 4.7% of acres, but additional tools are being developed to improve confidence and adoption of this practice.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 62.0% of rice acres in 2017. Conditions favorable for the development of disease did not occur until late in the growing season despite mild, rainy conditions. Approximately 45% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were moderate overall. Insecticide seed treatments were used on 73.5% of rice acreage in 2017 as producers continue to utilize this technology each year due to its benefits for both insect control and improved plant growth and vigor.

Clearfield rice continues to play a significant role in rice production in Arkansas. This technology (all cultivars combined) accounted for 45% of the total rice acreage in 2017 (Fig. 3). Proper stewardship of this technology will be the key to its continued success on the majority of rice acres. In areas where stewardship has been poor, imadazolinone-resistant barnyardgrass has been discovered. Evidence of these resistant populations may have served to reduce the number of Clearfield acres by emphasizing the negative effects of improper technology management. In addition, multiple years of this technology and crop rotation have likely cleaned up many red rice fields to the point where they can be safely returned to conventional rice production.

Significance of Findings

State average yields over the past 20 years in Arkansas have increased from an average of 120 bu/acre in 1993-1995 to an average of 161 bu/acre in 2015-2017, an increase of 41 bu/acre. This increase can be attributed to the development and adoption of more productive cultivars and improved management practices, including better herbicides, fungicides, and insecticides, improved water management through precision-leveling and multiple-inlet irrigation, improved fertilizer efficiency via timing and the use of urease inhibitors, and increased understanding of other practices such as seeding dates and tillage. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

Acknowledgments

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Literature Cited

USDA-NASS. 2018. United States Department of Agriculture National Agricultural Statistics Service. Crop Production Summary 2017. Access date: 10 Feb. 2018. Available at: http://usda.mannlib.cornell.edu/usda/current/CropProdSu/CropProdSu-01-12-2018.pdf

Table 1. 2017 Arkansas

	Harvested Acreage[a]		Medium-grain			Long-grain
County	**2016**	**2017**	**Jupiter**	**Titan**	**Others[b]**	**CL151**
Arkansas	90,193	66,009	1324	2276	1523	1384
Ashley	8923	4092	0	0	0	0
Chicot	35,524	20,441	0	0	717	1639
Clay	2102	2181	0	0	0	0
Craighead	82,535	63,950	8121	445	756	11,447
Crittenden	70,876	56,568	6687	0	1933	3624
Cross	63,483	41,202	6040	610	0	0
Desha	99,540	61,578	7588	4880	406	5357
Drew	21,509	9162	0	0	171	0
Faulkner	13,590	8138	0	0	0	0
Greene	80,237	67,214	2310	0	0	6071
Independence	10,805	7274	1245	0	0	641
Jackson	113,446	77,306	11,534	6090	1380	8237
Jefferson	75,313	55,105	452	0	0	0
Lafayette	4751	4798	0	0	0	0
Lawrence	104,971	88,320	10,196	1945	1650	11,553
Lee	25,228	7314	0	820	0	0
Lincoln	22,872	15,068	0	0	0	0
Lonoke	90,233	80,333	2991	0	0	562
Mississippi	64,018	49,073	0	0	1574	5687
Monroe	52,591	37,228	1751	1883	275	0
Phillips	32,151	13,473	641	0	0	855
Poinsett	121,335	91,810	24,674	1708	2437	8274
Pope	2798	2525	0	0	0	0
Prairie	64,137	54,410	5528	2368	210	701
Pulaski	3920	4899	0	0	0	0
Randolph	33,646	28,066	0	7922	0	5630
St. Francis	42,451	25,981	1634	2278	0	0
White	9569	6013	1211	0	0	0
Woodruff	61,186	46,473	4407	389	0	2924
Others[c]	9638	5981	0	0	0	697
Unaccounted[d]	7433	2018				
2017 Total		1,104,000	98,333	33,615	13,032	75,283
2017 Percent		100.00	8.91	3.04	1.18	6.82
2016 Total	1,521,000		96,309		29,288	24,706
2016 Percent	96		6.33		1.93	1.62

[a] Harvested acreage. Source: USDA-NASS, 2018.
[b] Other varieties: LaKast, RT CLXP756, Wells, CL111, RT XP760, Taggart, Cheniere, RT 7311 CL, Francis, RT XL723, RT Gemini 214 CL, CL272, RT XP754, CL163, Mermentau, Jazzman-2, Rex, AB647, Caffey, Della-2, Bengal, Antonio, Catahoula, Thad, Spring, Presidio, and Jazzman.
[c] Other counties: Conway, Faulkner, Franklin, Hot Springs, Little River, Miller, Perry, and Yell.
[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and preliminary estimates obtained from each county from the USDA Farm Service Agency.

harvested rice acreage summary.

Long-grain							
CL153	CL172	Diamond	RTCL XL729	RTCL XL745	RT XP753	Roy J	Others[b]
3296	892	7453	1266	20,296	15,345	225	10,729
0	0	0	0	4092	0	0	0
3421	0	0	0	6190	3721	0	4752
0	0	0	0	0	0	0	2181
15,380	553	3377	1107	9826	5820	6	7111
9,421	10,392	0	0	12,537	10,777	0	1196
273	0	2102	1990	5174	13,900	9290	1823
3977	3947	6151	407	5231	9202	4416	10,017
29	392	20	0	695	2160	2198	3496
0	2594	0	0	3039	357	0	2149
14,914	0	7237	108	17,601	5939	0	13,035
321	0	641	0	2245	577	641	962
4330	0	12,203	0	7996	12,025	5456	8055
2494	0	0	613	14,511	16,463	12,100	8472
720	720	0	0	0	960	0	2399
15,161	11,807	11,463	0	668	2021	0	21,854
0	0	2803	0	0	1693	1997	0
0	0	0	0	5910	9157	0	0
1773	0	5144	4682	19,534	21,819	4070	19,758
3808	0	24	0	13,840	22,236	0	1904
784	1075	7158	1232	4641	4735	3084	10,608
0	0	998	0	0	3564	5133	2281
10,319	333	15,013	0	12,503	2884	7709	5957
0	0	0	0	746	0	0	1779
3090	1640	2891	5354	16,398	6199	751	9281
0	0	2399	0	0	0	0	2499
0	0	657	1783	5629	3978	0	2467
7	0	836	0	8867	4509	2676	5173
0	0	656	273	1087	362	333	2090
4954	5563	5135	11,704	3827	958	2254	4357
0	155	119	0	1931	517	1111	1450
							2018
98,473	40,062	94,480	30,520	205,015	181,879	63,453	169,855
8.92	3.63	8.56	2.76	18.57	16.47	5.75	15.39
201,097	120,476	24,323	337,893	23,570	230,332	276,622	98,587
13.22	7.92	1.60	22.22	1.55	15.14	18.19	6.48

Table 2. Acreage, grain yield, and production of rice in the United States from 2015 to 2017[a].

State	Area planted			Area harvested			Yield			Production		
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017
	(1000 ac)						(lbs/ac)			(1000 cwt[b])		
Arkansas	1311	1546	1161	1291	1521	1104	7340	6920	7490	94,710	105,314	82,644
California	429	541	445	426	536	443	8890	8840	8410	37,877	47,394	37,277
Louisiana	420	437	400	415	428	395	6940	6630	6710	28,791	28,390	26,503
Mississippi	150	195	115	149	194	114	7110	7180	7400	10,594	13,929	8,436
Missouri	182	236	169	174	231	160	7020	6650	7440	12,212	15,352	11,900
Texas	133	195	173	130	187	158	6900	7360	7260	8,964	13,766	11,468
United States	2625	3150	2463	2585	3097	2374	7472	7237	7507	193,148	224,145	178,228

[a] Source: USDA-NASS, 2018.
[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2015 to 2017[a].

	2015		2016		2017	
Cultural Practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Arkansas rice acreage	1,286,000	100.00	1,521,000	100.00	1,104,000	100.00
Soil texture						
Clay	264,441	20.6	363,146	23.9	264,556	24.0
Clay Loam	268,398	20.9	313,327	20.6	253,048	22.9
Silt Loam	689,012	53.6	734,481	48.3	524,393	47.5
Sandy Loam	53,116	4.1	96,343	6.3	46,521	4.2
Sand	11,033	0.9	13,703	0.9	15,482	1.4
Tillage practices						
Conventional	818,368	63.6	928,017	61.0	567,141	51.4
Stale Seedbed	386,620	30.1	536,682	35.3	482,989	43.7
No-Till	81,011	6.3	56,301	3.7	53,870	4.9
Crop rotations						
Soybean	930,396	72.3	1,040,054	68.4	775,246	70.2
Rice	273,627	21.3	309,667	20.4	255,716	23.2
Cotton	3718	0.3	1908	0.1	810	0.1
Corn	42,343	3.3	60,890	4.0	41,419	3.8
Grain Sorghum	15,450	1.2	22,621	1.5	3151	0.3
Wheat	852	0.1	16,864	1.1	810	0.1
Fallow	19,613	1.5	65,471	4.3	26,849	2.4
Other	0	0.0	3525	0.2	0	0.0
Seeding methods						
Drill Seeded	1,074,460	83.6	1,288,211	84.7	922,503	83.6
Broadcast Seeded	211,540	16.4	232,789	15.3	181,497	16.4
Water Seeded	70,302	5.5	82,791	5.4	67,271	6.1
Irrigation water sources						
Groundwater	982,419	76.4	1,126,578	74.1	808,910	73.3
Stream, Rivers, etc.	146,202	11.4	211,537	13.9	147,487	13.4
Reservoirs	157,379	12.2	182,885	12.0	147,603	13.4
Irrigation methods						
Flood, Levees	731,614	56.9	942,868	62.0	659,547	59.7
Flood, Multiple Inlet	521,689	40.6	503,719	33.1	368,401	33.4
Intermittent (AWD)	21,241	1.7	33,616	2.2	36,907	3.3
Furrow	11,456	0.9	40,797	2.7	39,018	3.5
Sprinkler	0	0.0	0	0.0	127	0.0
Other	0	0.0	0	0.0	0	0.0
Stubble management						
Burned	559,736	43.5	668,592	44.0	491,927	44.6
Tilled	501,329	39.0	666,375	43.8	522,690	47.3
Rolled	343,383	26.7	383,633	25.2	264,858	24.0
Winter Flooded	262,846	20.4	330,233	21.7	226,776	20.5

continued

Table 3. Continued.

	2015		2016		2017	
Cultural Practice	**Acreage**	**% of total**	**Acreage**	**% of total**	**Acreage**	**% of total**
Land management						
Contour levees	625,600	48.6	703,436	46.2	528,556	47.9
Precision-level	519,907	40.4	607,274	39.9	418,990	38.0
Zero-grade	141,897	11.0	210,290	13.8	156,454	14.2
Precision agriculture						
Yield Monitors	847,603	65.9	1,002,492	65.9	779,179	70.6
Grid Sampling	386,143	30.0	456,706	30.0	395,431	35.8
Variable-rate fertilizer	336,228	26.1	397,670	26.1	280,321	25.4
Use urea stabilizer (NBPT)	--	--	--	--	857,937	77.7
N-STaR	--	--	165,013	10.8	52,073	4.7
Pest management						
Insecticide seed treatment	867,242	67.4	1,154,060	75.9	811,813	73.5
Fungicide (foliar application)	674,727	52.5	833,312	54.8	684,889	62.0
Insecticide (foliar application)	462,302	35.9	623,344	41.0	492,395	44.6

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

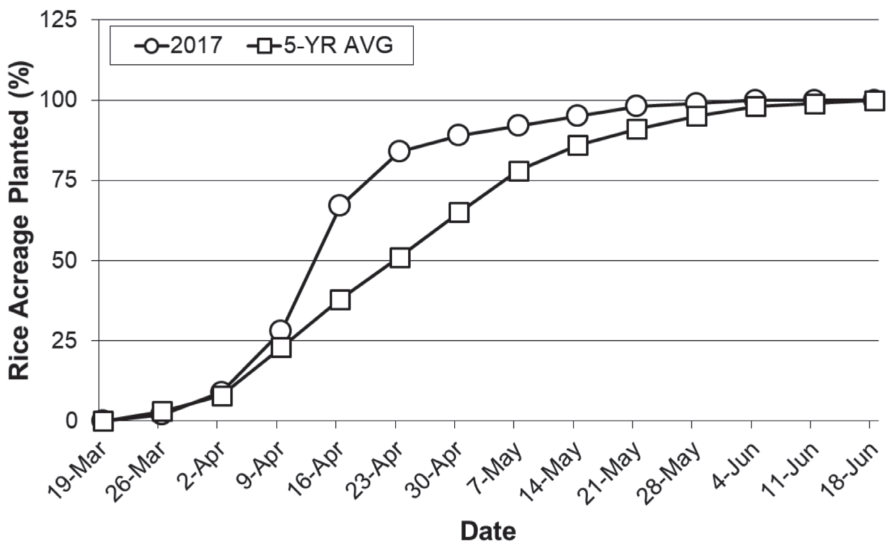

Fig. 1. Arkansas rice planting progress during 2017 compared to the 5-year state average (USDA-NASS, 2018).

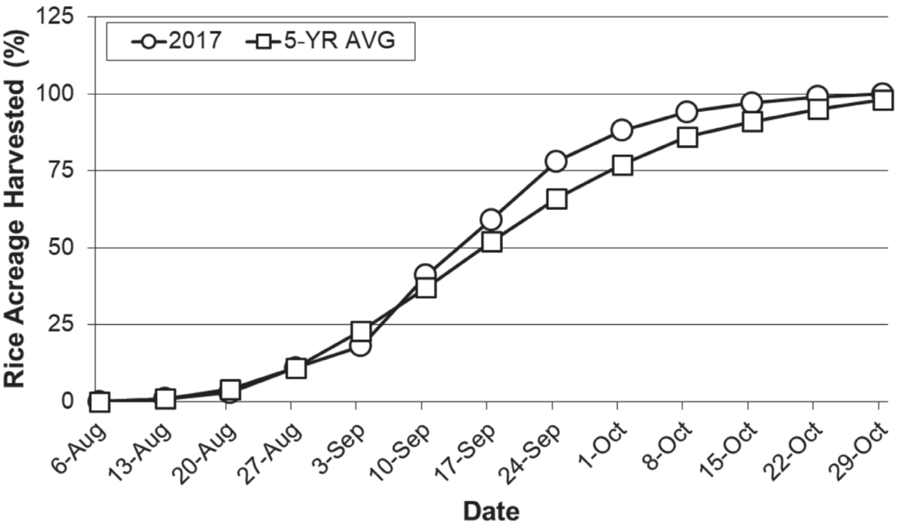

Fig. 2. Arkansas rice harvest progress during 2017 compared to the 5-year state average (NASS, 2018).

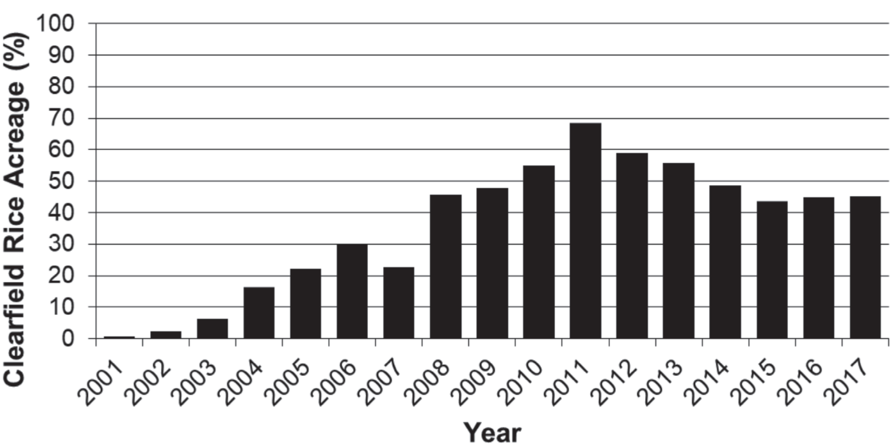

Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2017.

2017 Rice Research Verification Program

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Abstract

The 2017 Rice Research Verification Program (RRVP) was conducted on 15 commercial rice fields across Arkansas. Counties participating in the program included Arkansas, Clay, Conway, Desha, Jackson, Jefferson, Lafayette, Lincoln, Lonoke, Poinsett, Prairie, Pulaski, Randolph, White and Woodruff counties for a total of 709 acres. Grain yield in the 2017 RRVP averaged 187 bu/acre ranging from 152 to 248 bu/acre. The 2017 RRVP average yield was 21 bu/acre greater than the estimated Arkansas state average of 166 bu/acre. The highest yielding field was in Prairie County with a grain yield of 248 bu/acre. The lowest yielding field was in Desha County and produced 152 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 51/69 (% head rice/% total milled rice).

Introduction

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

The goals of the RRVP are to: 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, 5) incorporate data from RRVP into CES educational programs at the county and state level. Since 1983, the RRVP has been conducted on 461 commercial rice fields in 33 rice-producing counties in Arkansas.

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Since the program's inception 35 years ago, RRVP yields have averaged 18 bu/acre better than the state average. This greater 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 CES 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 are made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

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

Counties participating in the program during 2017 included Arkansas, Clay, Conway, Desha, Jackson, Jefferson, Lafayette, Lincoln, Lonoke, Poinsett, Prairie, Pulaski, Randolph, White and Woodruff. In addition, county agents with rice responsibilities in eight other counties participated in the program training on a weekly basis. The Conway County field facilitated training for the majority of this group.

The fifteen rice fields totaled 709 acres enrolled in the program. Nine different cultivars were seeded: (CL151, CL153, RiceTec [RT] CLXL745, RT CLXP756, Diamond, Mermentau, Roy J, RT 7311 CL, and RT XP753). Cooperative Extension Service recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, rice cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 187 bu/acre with a range of 152 to 248 bu/acre (Table 1). All grain yields of RRVP fields are reported in dry bushels (12% moisture). The RRVP average was 21 bu/acre greater than the Arkansas state average yield of 166 bu/acre. Similar yield differences have been observed many times since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The Prairie County field, seeded with RT 7311 CL, was the highest-yielding RRVP field at 248 bu/acre. Ten of the fifteen fields enrolled in the program exceeded 170 bu/acre. Desha County had the lowest yielding field with Roy J producing 152 bu/acre.

Milling data was recorded on all of the RRVP fields. The average milling yield for the fifteen fields was 51/69 (% head rice / % total milled rice) (Table 1). The highest milling yield was 63/73 with RT XP753 in White County. The lowest milling yield was 39/58 with RT CLXP756 in Arkansas County. A milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Prairie County on 30 March and ended with Randolph County on 19 May (Table 1). Two of the verification fields were planted in March, twelve in April, and one in May. An average of 69 lbs of seed/acre was planted for pureline cultivars and 24 lb seed/acre for hybrids. Seeding rates were determined with the CES RICESEED program for all fields. An average of 13 days was required for emergence. Stand density averaged 17 plants/ft^2 for pureline cultivars and 6 plants/ft^2 for hybrids. The seeding rates in some fields were higher than average due to planting method, soil texture, and planting date. Broadcast seeding and clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized for all fifteen RRVP fields and reduced the total nitrogen (N) fertilizer recommendation by an average of 13 lbs N/acre when compared with the standard N recommendation. However, various issues unrelated to N-STaR triggered the decision to apply additional N in 3 fields at some point in the season. The issues prompting these N additions are described in the field reviews and the amounts are included in Table 2.

As with standard N fertilizer recommendations for rice, N-STaR N recommendations take into account a combination of factors including soil texture, previous crop, and cultivar requirements (Tables 1 & 2). The GreenSeeker hand-held crop sensor was used at least weekly in all fields after panicle initiation through boot stage in order to verify that the N levels in the rice plants were adequate for the targeted yield potential.

Phosphorus (P), potassium (K), and zinc (Zn) fertilizer were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied pre-plant to Arkansas, Clay, Conway, Desha, Jackson, Lonoke, Poinsett, Prairie, Randolph and Woodruff County fields. Potassium was applied to Arkansas, Clay, Conway, Jackson, Lonoke, Poinsett, Prairie, Randolph, White and Woodruff Counties. Zinc was applied as a pre-plant fertilizer to fields in Arkansas, Clay and Lonoke Counties, while Zn seed treatment was used with all hybrid rice cultivars at a rate of 0.5 lb Zn/100 lb seed. The average cost of fertilizer across all fields was $87.63.

Weed Control

Clomazone (Command) was utilized in 10 of the 15 program fields for early-season grass control (Table 3). Quinclorac (Facet) was utilized in 8 of 15 fields as either a stand-alone, premix or tank mix application for both pre-emergence and early post-emergence treatments. Overlapping residuals proved to be an effective strategy utilized in 11 of 15 fields. Nine fields utilized a combination of both grass and broadleaf residuals.

Five fields (Clay, Jackson, Lincoln, Prairie and Randolph Counties) were seeded in Clearfield cultivars (Table 1). All of these utilized Clearfield technology herbicides. Due to weather conditions, two fields (Randolph and White Counties) did not receive a pre-emergence herbicide application for grass weed control (Table 3).

Disease Control

A foliar fungicide was applied in 4 of the 15 fields (Desha, Jackson, Poinsett and Randolph Counties) (Table 4). The treatments were primarily for the prevention of kernel smut and rice blast diseases. Generally, fungicide rates are determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history. However, preventative treatments for kernel smut and rice blast require specific rates depending on the product used. All 15 fields had a seed treatment containing a fungicide.

Insect Control

Eight fields (Arkansas, Conway, Desha, Lafayette, Lincoln, Prairie, Pulaski and White Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). Seven fields received an insecticide seed treatment with CruiserMaxx Rice and seven with NipsIt INSIDE.

Irrigation

Well water was used for irrigation in eight of the 15 fields in the 2017 RRVP while seven fields (Arkansas, Conway, Lincoln, Poinsett, Prairie, Randolph and White Counties) were irrigated exclusively with surface water. Three fields (Arkansas, Conway and Lincoln Counties) were zero-grade. One field (Jefferson County) was furrow irrigated (row rice). Multiple Inlet Rice Irrigation (MIRI) was utilized in 11 fields and multiple risers were utilized in 3 fields. Typically, a 25% reduction in water use is observed when using MIRI which employs polytube irrigation and a computer program to determine the size of tubing required plus the correct number and size of holes punched into it to achieve uniform flood-up across the field. Flow meters were used in 11 fields to record water usage throughout the growing season (Table 5). In fields where flow meters for various reasons could not be utilized, the average across all irrigation methods (30 inches) was used. The difference in irrigation water used was due in part to rainfall amounts which ranged from a low of 15 inches to a high of 32 inches.

Economic Analysis

This section provides information on production costs and returns for the 2017 Rice Research Verification Program (RRVP). Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 15 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all operating inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2017 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs, and actual cash outlays could differ as producers provide unpaid labor for equipment maintenance.

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

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs ranged from $414.27/acre for Woodruff County to $636.45 for Prairie County, while operating costs per bushel ranged from $2.27/bu for Jefferson County to $3.24/bu for Desha County. Total costs per acre (operating plus fixed) ranged from $523.58/acre for Woodruff County to $748.64/acre for Prairie County, and total costs per bushel ranged from $2.59/bu for Jefferson County to $3.84/bu for Desha County. Returns to or above operating costs ranged from $216.02/acre for Desha County to $568.91/acre for Jefferson County, and returns to or above total costs ranged from $121.64/acre for Pulaski County to $494.43/acre for Jefferson County.

A summary of yield, rice price, revenues, and expenses by expense type for each RRVP field is presented in Table 7. The average rice yield for the 2017 RRVP was 187 bu/acre but ranged from 152 bu/acre for Desha County to 248 bu/acre for Prairie County. An Arkansas average long-grain cash price of $4.95/bu was estimated using USDA, National Agricultural Statistics Service (NASS) US long price data for the months of August through October. The RRVP had all fields planted to long grain rice. A premium or discount was given to each field based on the milling yield measured for each field and a standard milling yield of 55/70 for long-grain rice. Broken rice was assumed to have 65% of whole grain price value. If milling yield was higher than the standard, a premium was made while a discount was given for milling less than the standard. Estimated long-grain prices adjusted for milling yield varied from $4.41/bu in Prairie County to $5.31/bu in White County.

The average operating expense for the 15 RRVP fields was $521.88/acre (Table 7). Post-harvest expenses accounted for the largest share of operating expenses on average (21.6%) followed by seed (17.4%), fertilizers & nutrients (16.8%), and chemicals (16.2%). Although seed's share of operating expenses was 17.4% across the 15 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($149.85/acre; 26.0% of operating expenses), a non-Clearfield hybrid was used ($134.39/acre; 24.2% of operating expenses), a Clearfield non-hybrid (pureline) cultivar was used ($71.31/acre; 15.7% of operating expenses) or a non-Clearfield non-hybrid (pureline) cultivar was used ($36.91/acre; 7.6% of operating expenses).

The average return to or above operating expenses for the 15 fields was $387.02/acre and ranged from $216.02/acre for Desha County to $568.91/acre for Jefferson County (Table 7). The average return above total specified expenses for the 15 fields was $277.05/acre and ranged from $121.64/acre for Pulaski County to $494.43/acre for Jefferson County. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. Table 8 also lists the specific rice cultivars grown on each RRVP field.

Field Summaries

Arkansas County

The zero-grade Arkansas County field was located just north of Dewitt on a Dewitt silt loam soil. The field consisted of 37 acres, the previous crop grown on the field was soybean, and conventional tillage practices were used for field preparation in the spring. The cultivar chosen was Diamond treated with Cruiser Maxx Rice insecticide seed treatment and was drill seeded at a seeding rate of 65 lbs/acre on 19 April. Emergence was observed on 2 May with a stand count of 18 plants/ft^2. According to the soil test, 0-30-90-10 (lbs/acre N-P_2O_5-K_2O-Zn) was applied. Command and League herbicides were applied at planting on 19 April. Propanil and Facet were applied as pre and post-emergence herbicides on 26 May. Using the N-STaR recommendation, N fertilizer in the form of urea plus an approved NBPT product was applied at 240 lbs/acre on 27 May. Midseason N was applied according to the Greenseeker response index on 22 June at a rate of 100 lbs/acre. An adequate flood was maintained throughout the growing season. Stink bugs reached threshold levels and Mustang Max insecticide was applied on 10 August. No fungicide treatment was necessary for disease control. The field was harvested on 19 August yielding 190 bu/acre with an average harvest moisture of 17% and a milling yield of 55/71. Total irrigation was 30 acre-inches with a season rainfall total of 24 inches.

Clay County

The precision-graded Clay County field was located west of McDougal on a Foley silt loam soil. This was the first rice crop following precision-grading work. The field was 52 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the fall and a pre-plant fertilizer based on soil test analysis was applied in the spring at a rate of 0-45-90-25-13 (lbs/acre N-P_2O_5-K_2O-S-Zn). CL153 with Apron XL seed treatment was drill-seeded at a rate of 65 lbs/acre on 6 April. Rice emergence was observed on 18 April with a stand count of 10 plants/ft^2. Clearpath was applied pre-emergence on 7 April providing good weed control and was followed by a post-emergence herbicide tank mix of Newpath, Sharpen and crop oil concentrate applied on 22 April. Urea was applied preflood on 22 May at a rate of 288 lbs/acre. Multiple Inlet Rice Irrigation was utilized to achieve a more efficient permanent flood. Based on N-STaR recommendations and verified by Greenseeker, no midseason N was applied. No insecticide or fungicide treatments were required for pest control. The rice was harvested on 11 July yielding 167 dry bu/acre. Although lower than the yield potential for this cultivar under more favorable conditions, it is a good yield for the first crop on a precision-graded field. The milling yield was 62/70 And the average harvest moisture was 15.8%. Total irrigation for the season was 8.1 acre-inches and rainfall was 17.25 inches.

Conway County

The zero-grade Conway County field was southeast of Blackwell. The original soil classification was a Dardanelle silt loam, but since zero grading a silty clay loam to clay loam is a more accurate soil texture for most of the field. The field was 48 acres and the previous crop grown on the field was rice. Conventional tillage practices were used for field preparation in the spring and based on soil test analysis, a pre-plant fertilizer at the rate of 18-46-0 (N-P_2O_5-K_2O) was applied. A burndown/pre-emergence herbicide tank mix of glyphosate plus Prowl H_2O and Bolero was applied at planting. Rice Tec hybrid XP753 with the company's standard seed treatment plus NipsIt INSIDE insecticide was drill-seeded at a rate of 24 lbs/acre on 15 April. Rice emergence was observed on 26 April with stand count of 5.8 plants/ft^2. A post-emergence application of Propanil was made on 25 May providing good control of weeds except for patches of weedy rice. Because of the weedy rice in this field Clearfield rice should have been planted but the allotment of Clearfield hybrid seed was insufficient. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood on 26 May at a rate of 155 lbs/acre. A permanent flood was established within 2 days and sufficient flood levels were maintained throughout the season. Greenseeker technology was utilized weekly during midseason growth stages to monitor N needs. Based on the Greenseeker response index, urea was applied on 22 June at a rate of 100 lbs/acre. A normal late boot application of urea for hybrid cultivars at a rate of 65 lbs/acre was made on 14 July. Rice stink bugs moved into the field at extremely high numbers and were controlled with a single lambda-cyhalothrin application on 19 July. Fortunately, no fungicide treatments were required during the season. The rice was harvested on 11 September with an average harvest moisture of 15%. The field yielded a respectable179 dry bu/acre but the milling yield was only 46/71. The low milling yield was probably due to the impact of the red rice and the wetting, drying, and rewetting of mature grain before the field could be harvested. Total irrigation for the season was 29 acre-inches and rainfall was 17 inches.

Desha County

The 85-acre contour levee field was located just south of Dumas on Herbert silt loam and Perry clay soil. Traditional tillage practices were performed and the previous crop was soybean. According to the soil test the pre-plant fertilizer 0-40-0-0 (lbs/acre N-P_2O_5-K_2O-Zn) was applied in the spring with a terra gator. Roy J treated with Cruiser-Maxx Rice seed treatment was drill-seeded at 67 lbs/acre on 10 April. Command and League were applied on 11 April as pre-emergence herbicides. Emergence was observed on 20 April with 14 plants ft^2. Duet was applied as a post-emergence herbicide on 12 May. Nitrogen fertilizer in the form of urea plus an approved NBPT product was applied at 170 lbs/acre on 26 May in accordance with the N-STaR recommendation. Midseason urea was applied at 100 lbs/acre on 26 June according to Greenseeker response index. The field had a history of kernel smut and propiconazole fungicide was applied on 13 July and a preventative azoxystrobin fungicide for rice blast was applied on 22 July. Stink bugs reached threshold levels and lambda-cyhalothrin insecticide was applied on 22 July. The field was harvested on 7 September at an average harvest moisture of 17%, a yield of 152 bu/acre, and a milling yield of 46/69. The irrigation amount was 28 acre-inches and the total rainfall amount was 28 inches.

Jackson County

The precision-graded Jackson County field was southeast of Newport on a Crowley silt loam and Jackport silty clay loam. The field was 113 acres and the previous crop grown on the field was soybean. Conventional tillage practices were used for field preparation in the spring and based on soil test analysis, a pre-plant fertilizer at the rate of 0-46-60 (N-P_2O_5-K_2O) was applied. A pre-emergence application of Command herbicide was applied at planting. RiceTec hybrid CLXL745 with the company's standard seed treatment plus NipsIt INSIDE insecticide was drill-seeded at a rate of 26 lbs/acre on 11 April. Rice emergence was observed on 26 April with a stand count of 6 plants/ft^2. Excellent weed control was achieved with a post-emergence application of Newpath herbicide plus a nonionic surfactant on 22 May followed by Clearpath plus crop oil on 3 June. Ammonium sulfate was applied on 31 May at the rate of 100 lbs/acre to speed recovery from weather related stresses and shorten the period to flood-up. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood on 9 June at a rate of 185 lbs/acre. A permanent flood was subsequently established within 4 days and flood levels were maintained well throughout the season. Greenseeker technology was utilized weekly during midseason growth stages verifying that N levels in the rice were adequate. The late boot application of urea for hybrid cultivars was made at a rate of 70 lbs/acre on 11 July. A smut disease preventative treatment was applied on 21 July with a fungicide tank mix of Quilt Xcel and Tilt 3.6EC. Rice stinkbugs did not reach treatment thresholds and no insecticides were required. The rice was harvested on 12 September yielding 206 dry bu/acre. The milling yield was 59/70 and the average harvest moisture was 17%. Total irrigation for the season was 13.6 acre-inches and rainfall was 17.5 inches.

Jefferson County

The 38-acre furrow-irrigated field was located 10 miles south of Pine Bluff on the Arkansas River. The soil class consisted of Portland Clay and Herbert silt loam soil and the previous crop grown was soybean. The hybrid XP753 treated with Cruiser-Maxx Rice and the company's standard seed treatment was drill seeded at 24 lbs/acre on 7 April. No pre-plant fertilizer was necessary according to soil testing. Emergence was observed on 20 April at 8 plants/ft^2. Roundup, Command and League herbicides were applied 7 April and residual herbicides were extended for 38 days with the help of continual rains. Facet L herbicide and crop oil concentrate were applied on 15 May. Nitrogen in the form of urea was applied with an approved NBPT product according to furrow irrigated rice recommendations. The first N fertilizer application was applied at 150 lbs/acre on 22 May, followed by 150 lbs/acre on 30 May, and finally 75 lbs/acre on 6 June. Intermittent flushing was utilized every 2-3 days as irrigation. No fungicides or insecticides were warranted during the growing season. The field was harvested with an average harvest moisture of 17% on 23 August. The field yielded a remarkable 238 bu/acre with a milling yield of 46/69. The The irrigation amount was 30 acre-inches and the rainfall amount totaled 24 inches.

Lafayette County

The 39-acre contour field was located south of Lewisville on Billyhaw and Bossier clay soil. Spring conventional tillage practices were used and no pre-plant fertilizer was required according to the soil test. Mermentau treated with CruiserMaxx Rice was drill-seeded at 95 lbs/acre on 1 April. Command and glyphosate herbicides were applied at planting. Emergence was observed on 16 April with 20 plants/ft^2. Regiment, Facet L and Permit were applied as post-emergence herbicides on 5 May. Using the N-STaR recommendation, N fertilizer in the form of urea was applied at 340 lbs/acre on 11 May. Field flooding took only 2 days so the use of an NBPT product with urea was not recommended. Midseason N as urea was applied at 100 lbs/acre on 12 June according to the Greenseeker response index. Stink bugs reached threshold levels and Karate Z was applied on 13 July. The field was harvested 4 September yielding 195 bu/acre. The milling yield was 55/67 and the average harvest moisture was 12%.

Lincoln County

The 39-acre zero-grade field was located just east of Star City on a Perry clay soil. The previous crop was continuous rice and no spring tillage practices were performed on the field. Rice Tec CL XP756 treated with Cruiser Maxx Rice in addition to the company's standard seed treatment was drill-seeded on April 31st at a seeding rate of 25 lbs/acre. Newpath and Command herbicides were applied at planting. The rice emerged on 13 April at 9 plants/ft^2. Weedy rice also emerged between the drill rows from the continuous rice cropping system. Super Wham, Prowl, and Command herbicides were applied as post and pre-emergence herbicides on 17 April and Clearpath and Permit Plus were applied 11 May. Using the N-STaR recommendation, N in the form of urea with an approved NBPT product was applied at 200 lbs/acre on 13 May. The late boot urea application was applied on 10 July at 70 lbs urea/acre. Stink bugs reached threshold levels twice and were treated with Mustang Max on 13 July and again on 8 August. The field was harvested on 26 August yielding 196 bu/acre. The milling yield was 39/68 and the average harvest moisture was 18%. The irrigation water use was 3.6 acre-inches and the rainfall totaled 32 inches. The continuous weekly rains during the growing season accounted for cost savings on irrigation. The weedy rice (along with rain and high humidity at harvest) likely contributed to the low milling yield.

Lonoke County

The 40-acre contour field was located north of Lonoke on a Callaway silt loam soil. Spring conventional tillage practices were used and pre-plant fertilizer was applied at 0-60-90-10 (N-P_2O_5-K_2O-Zn) according to the soil test. RiceTec XP753 treated with CruiserMaxx Rice in addition to the company's standard seed treatment was drill-seeded at 19 lbs/acre on 14 April which is below the recommended seeding rate for this hybrid. Roundup, Command, and League were applied 18 April as burndown and pre-emergence herbicides. Stand emergence was observed on 26 April with 6 plants/ft^2. Facet L, Permit Plus, and Sharpen were applied as post-emergence herbicides on 16 May. Excessive rains throughout May, June, and July damaged levees requiring continual repair yet on the positive side gave extended herbicide residual control. Nitrogen in the form of urea with an approved NBPT product was applied 24 May according to the N-STaR recommendation. The late-boot urea application was applied on 13 July at 75 lbs/acre. No fungicides or insecticides were necessary due to disease or stink bugs not reaching threshold levels. The field was harvested on 4 August with a yield of 176 bu/acre and a milling yield of 54/71. The rainfall for the growing season totaled 22.6 inches and the irrigation water use totaled 30 acre-inches.

Poinsett County

The precision-graded Poinsett County field was located northwest of Harrisburg on a Henry silt loam soil. The field was 46.4 acres and the previous crop grown was soybean. Conventional tillage practices were used for field preparation in the fall and a pre-plant fertilizer was applied in the spring at a rate of 0-90-112 (lbs/acre N-P_2O_5-K_2O). The cultivar Roy J with CruiserMaxx Rice seed treatment was drill-seeded at a rate of 66 lbs/acre on 14 April. Rice emergence was observed on 25 April with a stand count of 14 plants/ft^2. Command pre-emergence herbicide was applied on 15 April. At the 2-3 leaf stage, the rice was covered by floodwaters from heavy rains and remained under water for more than a week. The rice survived with a stand count of 11.8 plants/ft^2 and appeared to recover over a period of 2 weeks. Ammonium sulfate at a rate of 100 lbs/acre was applied on 15 May to help stimulate this recovery. On 30 May recovery was sufficient to apply a post-emergence herbicide tank mix of Facet L plus Prowl H_2O and crop oil concentrate and excellent weed control was achieved. Based on N-STaR recommendations, urea plus an approved NBPT product was applied in a single pre-flood application at a rate of 260 lbs/acre on 3 June. Flood-up using multiple risers was achieved within 72 hours. Greenseeker technology was utilized weekly to monitor N fertilizer needs during midseason growth stages until late boot. No midseason N was required based on the Greenseeker response index. A generic propiconazole fungicide was applied on 18 July as a preventive treatment for smut disease. Rice stinkbugs did not reach treatment thresholds and no insecticides were required. The field was harvested on 26 September with a average harvest moisture of 15%. The field yielded only 155 dry bu/acre, which was a low yield for this cultivar yet an improvement over recent field history despite weather related challenges during the season. The milling yield was very low at 42/70 and likely reflects the impact of intermittent wetting,drying, and rewetting of mature grain before the field could be harvested. Total irrigation for the season was 12.8 acre-inches and rainfall was 22.2 inches.

Prarie County

The 39-acre contour field was located south of Hazen on a Stuttgart silt loam soil. Spring conventional tillage practices were used for field preparation and pre-plant fertilizer 0-30-60 (lbs/acre N-P_20_5-K_20) was applied based on soil testing. The hybrid RT 7311 CL was drill-seeded on 30 March at 24 lbs/acre. Command and League were applied as pre-emergence herbicides on 2 April. Stand emergence was observed on 12 April with 8 plants/ft^2. Newpath herbicide was flown on 4 acres of the north end of the field for grass escapes and Clearpath herbicide was applied on 9 May. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood at a rate of 260 lbs/acre on 10 May. Multiple Inlet Rice Irrigation was utilized to achieve a more efficient permanent flood. Late-boot urea was applied 23 May. Stink bugs reached threshold levels twice and Lambda-cyhalothrin was applied 7 July and again on 28 July. The field was harvested with a moisture of 18% and a near verification record yield of 248 bu/acre. Unfortunately, the milling yield was a disappointing 42/66. Rainfall total was 22 inches and irrigation water use was 32 acre-inches.

Pulaski County

The 60-acre contoured field was located just south of Bredlow Corner on a Desha clay soil. Then Diamond cultivar was treated with CruiserMaxx Rice and drill-seeded at 65 lbs/acre on 15 April. No pre-plant fertilizer was necessary according to the soil test. Command was applied as a pre-plant herbicide at planting and Facet L and Permit were applied as post-emergence herbicides on 28 April. Command, League, and Propanil were applied 16 June followed by Facet L and Regiment on 20 June. Several herbicide applications were warranted due to levees delayed by excessive rain and power unit issues. Nitrogen in the form of urea was applied with an approved NBPT product at 220 lbs/acre according to the N-STaR recommendation. Midseason urea was applied at 100 lbs/acre on 8 July according to the Greenseeker response index. Stink bugs reached threshold level and Karate Z was applied on 27 July. The field was harvested on 2 October yielding 175 bu/acre. The milling yield was 43/67 and the average harvest moisture was 17%. Rainfall total was 16 inches and irrigation amounts totaled 30 acre-inches.

Randolph County

The traditionally contoured Randolph County field was located east of Pocahontas on Amagon and Dundee silt loam soils. The field was 9 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied at a rate of 0-46-60 (lbs/acre N-P_20_5-K_20). On 19 May, CL151 with CruiserMaxx Rice seed treatment was drill-seeded at a rate of 65 lbs/acre. Rice emergence was observed on 27 May and consisted of 22 plants/ft^2. Weather conditions did not allow for a pre-emergence herbicide application. The herbicide tank mix of Clearpath, Sharpen, and crop oil concentrate was applied post-emergence on 7 June providing good control of weeds. Using the N-STaR recommendation, urea was applied in a single preflood application at a rate of 270 lbs/acre on 22 June. Flood-up with surface water was achieved within 24 hours. Once the permanent flood was established, flood levels were maintained well throughout the season. Greenseeker technology was utilized weekly to monitor N needs of the rice during midseason growth stages until late boot. No midseason N was recommended based on the Greenseeker response index. Based on weather conditions and field evaluations, a fungicide application was applied as a blast disease preventative on 27 July followed by a second blast preventative fungicide application the next week. Rice stinkbugs did not reach treatment thresholds and no insecticides were required. The field was harvested on 14 October with a harvest moisture of 16.9%, a yield of 164 dry bu/acre, and a milling yield of 59/69. Total irrigation was 33 acre-inches and total rainfall for the season was 15 inches.

White County

The traditionally contoured White County field was located southeast of Kensett on Calhoun and Immanuel silt loam soils. The field was 24 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied at a rate of 0-0-60 (lbs/acre N-P_20_5-K_20). On 20 April, RiceTec hybrid XP753 with the company's standard seed treatment plus NipsIt INSIDE insecticide was drill-seeded at a rate of 26 lbs/acre. Rice emergence was observed on 3 May and consisted of 8 plants/ft^2. Weather conditions precluded a pre-emergence herbicide application. A post-emergence herbicide tank mix of Facet L, Prowl H_2O, and crop oil concentrate was applied on 17 May providing excellent control of weeds. Using the N-STaR recommendation, urea plus an approved NBPT product was applied preflood at a rate of 261 lbs/acre on 28 May. Multiple Inlet Rice Irrigation was utilized to achieve a more efficient permanent flood. After the permanent flood was established, flood levels were maintained sufficiently until the irrigation pump's power unit failed. This resulted in flood loss and dry soil on the upper 12 acres before irrigation could resume. Nitrogen depletion in that area was confirmed by using the Greenseeker response index. A N correction using urea was applied to the affected acres at a rate of 100 lbs/acre on 23 June. The entire field received the normal hybrid late boot application of urea at the rate of 65 lbs/acre on 14 July. Greenseeker evaluations continued weekly until late boot. No further N deficiency was detected. Based on field evaluations, no fungicide application was required. Rice stink bugs exceeded the threshold for treatment and were controlled with a single lambda-cyhalothrin application on 21 July. The field was harvested on 7 September yielding 205 bu/acre. Moisture at harvest was 18% and the milling yield was 63/73. Total irrigation was 12.1 acre-inches and total rainfall for the season was 25.18 inches.

Woodruff County

The traditionally contoured Woodruff County field was located just north of Hunter on a Overcup silt loam soil. The field was 42 acres and the previous crop grown was soybean. Spring conventional tillage practices were used for field preparation and a pre-plant fertilizer based on soil test analysis was applied at a rate of 0-45-90 (lbs/acre N-P_20_5-K_20). On 25 March, a pre-plant herbicide tank mix of RoundUp and FirstShot was applied to control early spring weeds. The cultivar Diamond with CruiserMaxx Rice seed treatment was drill-seeded at a rate of 66 lbs/acre on 9 April. Rice emergence was observed on 16 April and consisted of 20 plants/ft^2. A pre-emergence herbicide tank mix of Command and League was applied on 13 April. This was eventually followed by a post-emergence herbicide application of Facet L and crop oil concentrate on 27 May. A delay in the post-emergence herbicide application was necessary due to the south end of the field sustaining significant injury 2 weeks earlier from off-target herbicide drift and recovery was prolonged. The remaining stand count appeared sufficient for high yield potential. However, subsequent observations revealed that tillering in the injured rice was significantly below the uninjured area of the field. Using the N-STaR recommendation, urea plus an approved NBPT product was applied in a single preflood application rate of 270 lbs/acre on 30 May. A timely flood-up was achieved but an irrigation problem was encountered leading to flood loss which ultimately resulted in symptoms of N deficiency. The deficiency was confirmed utilizing Greenseeker technology. Flood irrigation resumed and on 23 June a N correction of 100 lbs urea/acre was applied. Greenseeker utilization continued weekly until late boot and no further N deficiency was detected. Based on field evaluations, no fungicides were required and rice stinkbugs did not reach treatment thresholds. The field was harvested on 7 September averaging 157 dry bu/acre. This is a low yield for this cultivar reflecting losses from the injured area of the field plus other stresses on the crop at critical growth stages. Moisture at harvest was 15% and the milling yield was 60/70. Total irrigation was 18.7 acre-inches and total rainfall for the season was 18.64 inches.

Significance of Findings

Data collected from the 2017 RRVP reflects the general trend of improved rice yields and returns compared to the previous two growing seasons. Analysis of this data showed that the average yield was significantly higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

Acknowledgments

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Literature Cited

USDA-NASS. 2018. United States Department of Agriculture. National Agricultural Statistics Service. Quick Stats (Searchable Database). Access date: 14 February 2018. Available at: https://quickstats.nass.usda.gov/

Table 1. Agronomic information for fields enrolled in the 2017 Rice Research Verification Program.

Field location by county	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield[a]	Harvest moisture
		(acres)		(lbs/ac)	(plants/ft^2)				(bu/ac)		(%)
Arkansas	Diamond	37	Soybean	65	18	19-Apr	02-May	19-Sep	190	55/71	17
Clay	CL153	52	Soybean	65	10	04-Apr	18-Apr	11-Sep	167	62/70	16
Conway	XP753	48	Rice	24	5.8	15-Apr	26-Apr	11-Sep	179	46/71	15
Desha	Roy J	85	Soybean	67	14	10-Apr	20-Apr	07-Sep	152	46/69	17
Jackson	CLXL745	113	Soybean	26	6	11-Apr	26-Apr	12-Sep	206	59/70	17
Jefferson	XP753	38	Corn	22	8	07-Apr	20-Apr	23-Aug	238	46/69	17
Lafayette	Mermentau	39	Soybean	95	20	01-Apr	16-Apr	04-Sep	195	55/67	12
Lincoln	CLXP756	38	Rice	25	9	31-Mar	13-Apr	26-Aug	196	39/58	18
Lonoke	XP753	40	Soybean	19	6	14-Apr	26-Apr	04-Sep	176	54/71	16
Poinsett	Roy J	46	Soybean	66	11.8	14-Apr	25-Apr	26-Sep	155	42/70	15
Prairie	RT 7311 CL	39	Soybean	24	8	30-Mar	12-Apr	26-Aug	248	42/66	18
Pulaski	Diamond	60	Soybean	65	22	15-Apr	28-Apr	02-Oct	175	43/67	17
Randolph	CL151	9	Soybean	66	22	19-May	27-May	14-Oct	164	59/69	17
White	XP753	24	Soybean	26	8	20-Apr	03-May	07-Sep	205	63/73	18
Woodruff	Diamond	42	Soybean	66	20	10-Apr	16-Apr	07-Sep	157	60/70	15
Average		47		[b]	[c]	12-Apr	25-Apr	11-Sep	187	51/69	16.33

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

[b] Seeding rates averaged 69 lbs/acre for conventional cultivars and 24 lbs/acre for hybrid cultivars.

[c] Stand density averaged 17 plants/ft^2 for conventional cultivars and 6 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization program, and soil classification for fields enrolled in the 2017 Rice Research Verification Program.

		Soil Test			Applied fertilizer			
Field location by county	pH	P[a]	K[a]	Zn[a]	Mixed Fertilizer[b] N-P-K-Zn	N-Star urea (46%N) rates and timing[c,d]	Total N rate[e]	Soil Classification
		--------(lb/ac)---------			--------------(lb/ac)-----------------		(lb N/ac)	
Arkansas	6.4	34	166	10.8	0-30-90-10	240-100-0	156	Dewitt Silt Loam
Clay	6.7	27	151	6.5	0-45-90-13	315-0-0	133	Foley silt loam
Conway	6.1	49	344	9.2	18-46-0-0	155-0-65	147†	Dardanelle silt loam
Desha	7.4	70	682	6.6	0-40-0-0	170-100-0	124	Hebert silt loam/Perry clay
Jackson	5.9	24	355	4.2	0-46-60	207-0-65	138[N]	Crowley silt loamm/Jackport silty clay loam
Jefferson	6.5	86	292	18.6	0-0-0-0	150-150-75*	172	Portland clay/Hebert silt loam
Lafayette	7.2	38	686	4.2	0-0-0-0	340-100-0	202	Billyhaw clay/Bossier clay
Lincoln	6.5	68	742	10.4	0-0-0-0	200-0-70	124	Perry clay
Lonoke	6.0	36	92	4.0	0-60-90-10	225-0-75	138	Calloway silt loam
Poinsett	7.0	28	154	12.9	0-90-112-0	260-0-0	121	Henry silt loam
Prairie	6.3	64	318	18.0	0-30-60-0	260-0-70	152	Stuttgart silt loam
Pulaski	6.0	99	333	4.0	0-0-0-0	220-100-0	147	Desha clay
Randolph	6.0	32	357	9.4	0-46-60-0	270-0-0	270	Amagon/Dundee silt loams
White	7.1	96	224	13.1	0-0-60-0	260-0-65	173†	Calhoun/Immanuel silt loams
Woodruff	6.9	46	208	8.2	0-45-90-0	207-0-0	140†	Overcup silt loam

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

[b] Column includes seed treatments and regular pre-plant applications.

[c] Timing: preflood – midseason – boot. Each field was fertilized according to its N-STaR recommendation. The mark (*) denotes an adjusted N-STaR rate and timing for furrow irrigated rice. The N-STaR base without the furrow irrigated adjustments was 135-0-30 (294-0-65 lbs of urea).

[d] The N-Star preflood N recommendation in all fields was treated with an approved NBPT product to minimize nitrogen loss due to ammonia volatilization.

[e] Some fields required additional seasonal N exceeding the N-Star recommendation in order to counteract nitrogen depletion (details in field reviews). This additional N is included in the totals marked (†). Extra N applied 2 weeks or more before flood-up to address other issues is recorded in the Mixed Fertilizer column. The total marked ([N]) includes 21 lbs of N from Ammonium Sulfate applied 10 days before the pre-flood urea (details in field review).

Table 3. Herbicide rates and timings for fields enrolled in the 2017 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	(trade name and product rate/acre)[a]	
Arkansas	Command (12.8 oz) + League (6.4 oz)	Propanil (4 qt) + Facet L (32 oz) + COC (1 pt)
Clay	Clearpath (0.5 lb)	Newpath (4 oz) + Sharpen (1 oz) + COC (6.4 oz)
Conway	Prowl H_2O (2 pt) + Bolero (3 pt) + Glyphosate (1 qt)	Propanil (3 qt)
Desha	Command (20 oz) + League (6.4 oz)	Duet (3 qt) + COC (1 qt)
Jackson	Command (12.8 oz)	Newpath (4 oz) + Nonionic Surfactant (2.6 oz) FB Clearpath (.5 lb) + COC (8 oz)
Jefferson	Command (16 0z) + League (6.4 oz) + Glyphosate (27 oz)	Facet L (22 oz)
Lafayette	Command (24 oz) + Glyphosate (1 qt)	Regiment (0.5 oz) + Facet L (32 oz) + COC (1 pt)
Lincoln	Newpath (5 oz) + Command (19 oz)	Super Wham (3 qt) + Prowl H_2O (2.1 pt) + Command (16 oz) FB Clearpath (0.5 lb) + Permit Plus (0.75 oz) + COC (1 pt)
Lonoke	Command (12.8 oz) + RoundUp (1 qt) + League (6.4 oz)	Facet L (32 oz) + Permit Plus (0.75 oz) + Sharpen (1 oz)
Poinsett	Command (12.8 oz)	Facet L (32 oz) + Prowl H_2O (2.1 pt) + COC (1 qt)
Prairie	Command (12.8 oz) + League (6.4 oz)	Newpath (4 oz) on 4 acres only FB Clearpath (0.5 lb) + COC (1 pt) on entire field
Pulaski	Facet L (22 oz) + Permit (1 oz) + COC (1 pt)	Command (16 0z) + League (6.4 oz) + Propanil (1 qt) + COC (1 pt) FB Facet L (21 oz) + Regiment (0.5 oz) + DynaPac (1 pt)
Randolph	None	Clearpath (0.5 lb) + Sharpen (1 oz) + COC (8 oz)
White	None	Facet L (22 oz) + Prowl H_2O (2.1 pt) + COC (1 qt)
Woodruff	Command (12.8 oz) + League (6.4 oz)	Facet L (22 oz) + COC (1 qt)

[a] FB = followed by and is used to separate herbicide application events; COC = crop oil concentrate.

Table 4. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2017 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field location by county	Fungicide and/or insecticide seed treatment for control of diseases and insects of seedling rice[a]	Fungicide applications for control of sheath blight/kernel smut/false smut	Fungicide applications for control of rice blast	Insecticide applications for control of rice water weevil	Insecticide applications for control of rice stink bug/chinch bug
	(trade name and product rate/cwt seed)	(trade name and product rate/acre)			
Arkansas	CruiserMaxx Rice (7 fl oz)	------	------	------	Mustang Max (4 oz)
Clay	Apron XL	------	------	------	------
Conway	RTST + NipsIt INSIDE	------	------	------	Lambda-Cyhalothrin (3.6 oz)
Desha	CruiserMaxx Rice (7 fl oz)	Propiconazole (6 oz)	Azoxystrobin (12.5 oz)	------	Lambda-Cyhalothrin (1.8 oz)
Jackson	RTST + NipsIt INSIDE	Quilt Xcel (16 oz) + Tilt (1.5 oz)	------	------	
Jefferson	RTST + NipsIt INSIDE	------	------	------	------
Lafayette	CruiserMaxx Rice (7 fl oz)	------	------	------	Karate (1.8 oz)
Lincoln	RTST + NipsIt INSIDE	------	------	------	Mustang Max (4 oz)
Lonoke	RTST + NipsIt INSIDE	------	------	------	------
Poinsett	CruiserMaxx Rice (7 fl oz)	Propiconazole (6 oz)	------	------	------
Prairie	RTST + NipsIt INSIDE	------	------	------	Lambda-Cyhalothrin (1.8 oz) FB Lambda-Cyhalothrin (1.8 oz)
Pulaski	CruiserMaxx Rice (7 fl oz)	------	------	------	Karate (1.8 oz)
Randolph	CruiserMaxx Rice (7 fl oz)	------	Quadris (12.8 oz) FB Quadris (12.8 oz)	------	------
White	RTST + NipsIt INSIDE	------	------	------	Lambda-Cyhalothrin (1.8 oz)
Woodruff	CruiserMaxx Rice (7 fl oz)	------	------	------	------

[a] RTST refers to RiceTec Seed Treatment. This abbreviation defines those fields whose seed was treated by RiceTec, Inc. prior to seed purchase. RTST seed is treated with compounds intended to enhance germination and early-season plant growth while RTST + NipsIt INSIDE includes all the components of RTST plus an insecticide to further protect seedlings.

Table 5. Rainfall and irrigation information for fields enrolled in the 2017 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + irrigation
	(inches)	(acre-inches)	(inches)
Arkansas	24.0	30.0*	54.0*
Clay	17.3	8.1	25.4
Conway	17.0	29.0	46.0
Desha	28.0	28.0	56.0
Jackson	17.5	13.6	31.1
Jefferson	23.9	30.0*	53.9*
Lafayette	18.0	28.3	46.3
Lincoln	32.0	3.6	35.6
Lonoke	22.6	30.0*	52.6*
Poinsett	22.2	12.8	35.0
Prairie	21.5	32.0	53.5
Pulaski	16.4	30.0*	46.4*
Randolph	15.0	30.0*	45.0*
White	25.6	12.1	37.7
Woodruff	18.6	18.7	37.3
Average[b]	21.3	18.6†	40.4

[a] An average established from flow meter data over a period of years was used for several fields not equipped with flow meters to monitor irrigation water use. Irrigation amounts using this calculated average are followed by an asterisk (*).

[b] Average values for Irrigation and Rainfall + Irrigation are only for those fields with measured irrigation amounts and does not include fields where the state average irrigation value of 30.0 acre-inches was used.

Table 6. Operating costs, total costs, and returns for fields enrolled in the 2017 Rice Research Verification Program.

County	Operating costs		Returns above operating costs	Fixed costs	Total costs	Returns above total costs	Total costs
	Per acre	Per bushel					
	($/acre)	($/bu)	------------------------($/acre)------------------------				($/bu)
Arkansas	595.02	3.13	354.99	75.18	670.19	279.81	3.53
Clay	453.01	2.71	404.44	99.64	552.65	304.80	3.31
Conway	573.46	3.20	279.09	76.45	649.91	202.64	3.63
Desha	492.73	3.24	216.02	90.38	583.10	125.64	3.84
Jackson	584.39	2.84	457.03	100.30	684.68	356.73	3.32
Jefferson	540.84	2.27	568.91	74.48	615.32	494.43	2.59
Lafayette	481.97	2.47	454.02	105.72	587.69	348.31	3.01
Lincoln	509.17	2.60	358.79	61.98	571.15	296.81	2.91
Lonoke	552.78	3.14	322.59	108.08	660.85	214.51	3.75
Poinsett	449.79	2.90	264.36	97.71	547.49	166.66	3.53
Prairie	636.45	2.57	456.59	112.20	748.64	344.39	3.02
Pulaski	538.13	3.08	246.53	124.89	663.02	121.64	3.79
Randolph	455.40	2.78	365.49	151.97	607.37	213.52	3.70
White	550.76	2.69	537.96	126.35	677.11	411.61	3.30
Woodruff	414.27	2.64	383.57	109.31	523.58	274.25	3.33
Average	521.88	2.82	378.02	100.97	622.85	277.05	3.37

Table 7. Summary of revenue and expenses per acre for fields enrolled in the 2017 Rice Research Verification Program.

Receipts	**Arkansas**	**Clay**	**Conway**	**Desha**	**Jackson**	**Jefferson**	**Lafayette**	**Lincoln**
Yield (bu.)	190	167	179	152	206	238	195	196
Price received	5.00	5.13	4.76	4.66	5.06	4.66	4.80	4.43
Total crop revenue	**950.00**	**857.46**	**852.55**	**708.75**	**1041.41**	**1109.75**	**935.99**	**867.96**
Operating expenses								
Seed	36.93	64.16	138.72	41.88	149.25	138.72	54.82	121.75
Fertilizers and nutrients	113.81	119.14	76.27	59.81	95.44	73.69	70.40	50.50
Chemicals	101.01	42.39	65.56	149.33	65.30	61.40	94.17	136.71
Custom applications	37.80	41.16	52.85	51.10	54.95	35.00	37.80	35.00
Diesel fuel	15.04	18.48	16.04	15.52	18.11	9.18	18.85	10.86
Repairs and maintenance	18.27	21.94	18.70	20.58	21.43	18.77	23.77	15.89
Irrigation energy costs	0.00	21.05	0.00	42.78	35.34	45.84	43.24	5.50
Labor, field activities	9.88	10.31	9.58	10.86	9.87	6.25	12.88	6.45
Other Inputs and fees, pre-harvest	147.61	13.61	87.71	9.14	10.38	8.36	8.37	8.23
Post-harvest expenses	114.67	100.78	108.03	91.73	124.32	143.63	117.68	118.29
Total operating expenses	**595.02**	**453.01**	**573.46**	**492.73**	**584.39**	**540.84**	**481.97**	**509.17**
Returns to operating expenses	**354.99**	**404.44**	**279.09**	**216.02**	**457.03**	**568.91**	**454.02**	**358.79**
Capital recovery and fixed costs	75.18	99.64	76.45	90.38	100.30	74.48	105.72	61.98
Total specified expenses[a]	**670.19**	**552.65**	**649.91**	**583.10**	**684.68**	**615.32**	**587.69**	**571.15**
Returns to specified expenses	**279.81**	**304.80**	**202.64**	**125.64**	**356.73**	**494.43**	**348.31**	**296.81**
Operating expenses/yield unit	3.13	2.71	3.20	3.24	2.84	2.27	2.47	2.60
Total expenses/yield unit	3.53	3.31	3.63	3.84	3.32	2.59	3.01	2.91

continued

Table 7. Continued.

Receipts	**Lonoke**	**Poinsett**	**Prairie**	**Pulaski**	**Randolph**	**White**	**Woodruff**	**Average**
Yield (bu.)	176	155	248	175	164	205	157	187
Price received	4.97	4.61	4.41	4.48	5.01	5.31	5.08	4.83
Total crop revenue	**875.36**	**714.15**	**1093.03**	**784.66**	**820.89**	**1088.72**	**797.84**	**899.90**
Operating expenses								
Seed	109.82	38.08	178.56	18.85	78.46	150.28	38.08	90.56
Fertilizers and nutrients	119.09	133.13	91.07	59.23	77.70	83.98	91.14	87.63
Chemicals	84.66	54.84	82.24	157.46	59.73	45.91	65.56	84.42
Custom applications	21.00	60.20	60.20	50.40	46.90	60.27	49.49	46.27
Diesel fuel	18.69	20.01	17.73	19.50	22.18	21.29	20.05	17.44
Repairs and maintenance	24.55	22.27	24.55	26.22	32.94	27.46	24.00	22.76
Irrigation energy costs	45.84	6.57	9.66	77.95	16.94	9.29	5.64	24.38
Labor, field activities	12.80	7.45	11.83	13.09	13.37	13.38	12.62	10.71
Other inputs and fees, pre-harvest	10.10	13.70	10.95	9.80	8.20	15.19	12.93	24.95
Post-harvest expenses	106.22	93.54	149.67	105.61	98.97	123.72	94.75	112.77
Total operating expenses	**552.78**	**449.79**	**636.45**	**538.13**	**455.40**	**550.76**	**414.27**	**521.88**
Returns to operating expenses	**322.59**	**264.36**	**456.59**	**246.53**	**365.49**	**537.96**	**383.57**	**378.02**
Capital recovery and fixed costs	108.08	97.71	112.20	124.89	151.97	126.35	109.31	100.97
Total specified expenses[a]	**660.85**	**547.49**	**748.64**	**663.02**	**607.37**	**677.11**	**523.58**	**622.85**
Returns to specified expenses	**214.51**	**166.66**	**344.39**	**121.64**	**213.52**	**411.61**	**274.25**	**277.05**
Operating expenses/yield unit	3.14	2.90	2.57	3.08	2.78	2.69	2.64	2.82
Total expenses/yield unit	3.75	3.53	3.02	3.79	3.70	3.30	3.33	3.37

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

Table 8. Selected variable input costs per acre for fields enrolled in the 2017 Rice Research Verification Program (RRVP).

County	Rice Type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Arkansas	Diamond	36.93	113.81	95.25	5.76	---	15.04	---[a]
Clay	CL153	64.16	119.14	42.39	---	---	18.48	21.05
Conway	XP753	138.72	76.27	57.43	8.13	---	16.04	---[a]
Desha	Roy J	41.88	59.81	116.63	4.07	28.63	15.52	42.78
Jackson	CLXL745	149.25	95.44	48.24	---	17.06	18.11	35.34
Jefferson	XP753	138.72	73.69	61.40	---	---	9.18	45.84
Lafayette	Mermentau	54.82	70.40	90.11	4.07	---	18.85	43.24
Lincoln	CLXP756	121.75	50.50	125.19	11.52	---	10.86	5.50
Lonoke	XP753	109.82	119.09	84.66	---	---	18.69	45.84
Poinsett	Roy J	38.08	133.13	50.13	---	4.71	20.01	6.57
Prairie	RT 7311 CL	178.56	91.07	64.17	18.07	---	17.73	9.66
Pulaski	Diamond	18.85	59.23	153.40	4.07	---	19.50	77.95
Randolph	CL151	78.46	77.70	12.67	---	47.06	22.18	16.94
White	XP753	150.28	83.98	41.85	4.07	---	21.29	9.29
Woodruff	Diamond	38.08	91.14	65.56	---	---	20.05	5.64
Average	**---**	**94.30**	**87.38**	**74.54**	**7.47**	**24.37**	**17.25**	**30.00**

[a] Water was applied by gravity flow to RRVP fields in Arkansas County. Thus, irrigation energy costs were equal to zero for this county.

Advances in Molecular Analysis in a Hybrid Rice Breeding Program

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Abstract

Researchers in molecular genetics at the University Of Arkansas System Division Of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. have been performing DNA marker-assisted selection (MAS) for over 17 years. Currently four rice breeding programs and cooperative extension activities utilize the laboratory. Much of the effort over the last 17 years has been devoted to the genotypic characterization of parental lines and progeny in the areas of new long-grain and medium-grain cultivar development, hybrid rice breeding, aromatic rice breeding, backcross populations, genomic mapping of specific traits, and seed purification. In 2017, genetic analysis was performed on 10 major projects for breeding involving DNA marker-assisted selection for the important traits of cooking quality, rice blast disease resistance, and Clearfield resistance. Eight other smaller projects were conducted for the breeding programs and two small projects for Rice Extension Agronomy. The Molecular Genetics lab focused considerable effort towards the hybrid rice breeding program, screening 4123 samples with up to 28 markers. The hybrid rice projects included parental materials, male-sterile and restorer lines, and selected F_1 hybrid lines in development currently. In total, the lab processed 5656 mostly bulked genomic DNA samples, generating 54,571 data points for the year. The work was accomplished using 65 DNA template plates, 621 PCR plates, 172 runs on the ABI 3500xL, and 77 KASP runs.

Introduction

One of the major goals of the University of Arkansas Hybrid Rice Breeding program is to develop hybrid rice cultivars that possess the same superior long grain cooking quality that producers have come to expect from conventionally bred Arkansas rice varieties. Toward that goal, much effort has been devoted to the genotypic characterization of superior male-sterile and restorer lines and tracking alleles in the developed hybrid lines. Using DNA markers can confirm hybridity, seed purity, and

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genotype-phenotype correlations in an evaluation conducted on a level not affected by time or environmental influences. All of this work can enable the breeder to devote time, funds, and resources on only those materials that have potential for further development in the breeding program, and not waste efforts and money on undesirable materials that will be eliminated.

Materials submitted for molecular analysis were screened with DNA markers that were determined to be informative from the parental genotyping data. The simple sequence repeat (SSR) and insertion-deletion (InDel) markers included random fingerprint markers and markers that are linked to the rice blast resistance genes, aroma, and cooking quality. They were analyzed by capillary electrophoresis while single nucleotide polymorphism (SNP) markers were analyzed using the Kompetitive Allele-Specific PCR (KASP™) platform. More emphasis is being placed on developing KASP markers for the rice breeding programs. At 48 cents per sample, KASP chemistry costs only 27% of the price of ABI 3500xL analysis at $1.75 per sample. Three new KASP markers developed by the molecular breeding program at LSU were added to the molecular toolbox in 2017. They include markers for aroma and two of the rice blast resistance genes.

The objective of this ongoing study is to apply DNA marker technology to assist with the mission of the UARREC Rice Breeding Programs. The goals include (i) characterizing parental materials on a molecular level for important agronomic traits and purity, (ii) performing DNA marker-assisted selection of progeny to confirm identity and track gene introgression, and (iii) ensuring seed quality and uniformity by eliminating off types.

Procedures

Leaf tissue from individually tagged field plants or greenhouse-grown seedlings was collected in manila coin envelopes and kept in plastic bags on ice until placed in storage at the molecular genetics lab. In some instances, seeds were germinated in Petri dishes to obtain leaf tissue. The leaf tissue was stored at -80 °C until sampled. Total genomic DNA was extracted from the embryo using a Sodium hydroxide/Tween 20 buffer and neutralized with 100mM TRIS-HCl, 2 mM EDTA (Xin et al., 2003).

Each set of DNA samples was arrayed in a 96-well format, processed through a OneStep-96 PCR Inhibitor Removal system (Zymo Research Corporation, Irvine, Calif.), and used directly as the starting template for SSR and InDel analysis. For KASP reactions, the DNA plate was diluted 1:5 in water to prepare the KASP reaction template.

Polymerase Chain Reaction (PCR) of SSR and InDel markers was conducted using primers pre-labeled with attached fluorophores of either HEX, FAM, or NED by adding 2 µl of starting DNA template in 25 µl reactions and cycling in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) for 35 cycles of a traditional 3-step PCR protocol. To save on processing and analysis costs, PCR plates were grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.). PCR products were resolved using capillary electrophoresis on an ABI 3500xL

Genetic Analyzer. Data was analyzed using GeneMapper Software V5.0 (Applied Biosystems, Foster City, Calif.).

The KASP reactions were prepared by adding 5 µl of each DNA sample and 5 µl of the 2X Master Mix + 0.14 µl Assay Mix to the wells of a 96-well opaque qPCR plate (LGC Genomics, Beverly, Mass.). The plate was then sealed with qPCR film (LGC Genomics, Beverly, Mass.), and the KASP reactions were cycled in a Mastercycler Pro S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.) using a 61-55 °C Touchdown protocol. The plates were then allowed to cool to room temperature prior to reading on a BMG Labtech FLUOstar Omega SNP plate reader (LGC Genomics, Beverly, Mass.). Detected fluorescence was analyzed using KlusterCaller software (LGC Genomics, Beverly, Mass.). The KASP marker for *Waxy* Exon 6 was determined to be not as reliable as the KASP marker for *Waxy* Exon 1 and the SSR marker RM190 for predicting amylose content. In the instances in which RM190 and *Waxy* Exon 1 agreed, but *Waxy* Exon 6 data contradicted the other two, the *Waxy* Exon 6 marker was ignored for allele scoring purposes.

Results and Discussion

Male-Sterile Lines. This project screened 241 samples with six markers linked to amylose and the rice blast resistance genes *Pi-b*, *Pi-k*, *Pi-ta*, and *Pi-z*., generating 1446 data points. Ninety-eight samples had high amylose, 45 samples had low amylose, 24 were segregating for intermediate to high amylose, 53 were segregating for low to high amylose, and 10 were segregating for low to intermediate amylose.

Two samples had disease resistance at the *Pi-b* locus, 13 samples were segregating for *Pi-b* resistance, and the remaining samples were susceptible. At the *Pi-k* locus, 40 samples were segregating for *Pi-Leah*, one sample was segregating for *Pi-k*^{h}, and the remaining samples were susceptible. At the *Pi-ta* locus, 225 samples had *Pi-ta* resistance, 7 samples were segregating, and the rest were susceptible. All samples were susceptible for rice blast disease at the *Pi-z* locus. All segregating plants were eliminated from this population so that resources could be devoted to the development of the homozygotes. All data is listed in Table 1.

Restorer F_2 Populations. Since there have not been any reliable markers identified for any restorer genes, these 62 populations were screened with seven markers linked to plant height, amylose, and the rice blast resistance genes *Pi-b*, *Pi-k*, *Pi-ta*, and *Pi-z* for selection of the 2149 samples. Over 16,400 data points were generated for this project. At the *sd1* locus, 464 samples were semi-dwarfs, 1424 were tall, and 241 were segregating for the trait. For cooking quality assessment, 189 samples had high amylose; 1365 samples had intermediate amylose, 188 samples had low amylose, 59 samples were segregating low to high amylose, 138 samples were segregating intermediate to high, and 180 were segregating low to intermediate.

All plants were susceptible to disease at the *Pi-b* locus. At the *Pi-k* locus, 84 samples had *Pi-k*^{s}, 177 samples had *Pi-Leah*, and 76 had *Pi-k*^{h}. There were 163 samples were segregating for *Pi-k*^{s} and *Pi-Leah*, one sample was segregating for *Pi-k*^{s} and *Pi-k*^{h}, 85 samples were segregating for *Pi-k*^{s}, 143 were segregating for *Pi-Leah*, and 324 were segregating for *Pi-k*^{h}. The remaining 1079 samples were susceptible. At the *Pi-ta* locus, 258 samples had *Pi-ta* resistance, 213 were segregating, and 1547 were susceptible. At the *Pi-z* locus, 17 samples had *Pi-z* resistance, 25 were segregating, and 2028 were susceptible. All data is listed in Table 1.

Significance of Findings

Marker screening of hybrid breeding materials revealed that progress is being made in reducing trait segregation and identifying promising lines to advance. It allowed characterization of male-sterile and restorer lines, enabling the breeder to eliminate those lines that either had alleles linked to undesirable phenotypes, or were segregating to such an extent that they were not usable without a tremendous prior investment of resources and effort. Marker analysis in hybrid breeding, long grain breeding, medium grain breeding, and aromatic breeding enabled the breeders to track progress of lines in development and assess the status of the populations, and eliminate those materials that are not desirable for inclusion in future rice breeding efforts. This saves time, resources, and funds that would otherwise be utilized on breeding materials destined for elimination from the development pipelines.

Acknowledgments

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Literature Cited

Xin, Z., J.P. Velten, M.J. Oliver, and J.J. Burke. 2003. High-Throughput DNA Extraction Method Suitable for PCR. BioTech. 34:4:820-825.

Table 1. Hybrid Rice Breeding Program populations screened with markers linked to cooking quality, rice blast disease resistance, and plant height.

Test Population	Amylose RM190	*Pi-b* RM208	*Pi-k* RM224	*Pi-ta* Pi-indica	*Pi-z* AP5659	*sd1* RM1339
Male						
Steriles	98-Hi	2 Res	40 Seg Pi-Leah	225 Res	All Sus	
	45-Lo	13 Seg	1 Seg *Pi-k*^{h}	7 Seg		
	24 Seg Int-Hi	226 Sus	200 Sus	9 Sus		
	53 Seg Lo-Hi					
	10 Seg Lo-Int					
Restorer						
Lines	189-Hi	All Sus	84 *Pi-k*^{s}	258 Res	17 Res	464 SmDwf
	1365 Int		177 Pi-Leah	213 Seg	25 Seg	1424 Tall
	188-Lo		76 *Pi-k*^{h}	1547 Sus	2028 Sus	241 Seg
			163 Seg			
	138 Seg Int-Hi		*Pi-k*^{s}/Pi-Leah			
	59 Seg Lo-Hi		1 Seg *Pi-k*^{s}/*Pi-k*^{h}			
	180 Seg Lo-Int		85 Seg *Pi-k*^{s}			
			143 Seg Pi-Leah			
			324 Seg *Pi-k*^{h}			
			1079 Sus			

Seg = segregating, Int = intermediate, Sus = susceptible, Hi = high, Lo = low, Int-Hi = intermediate to high, Lo-Hi = low to high, Lo-Int = low to intermediate, Res = resistant, SmDwf = semi-dwarf.

Screening of Diverse *Japonica* Rice Genotypes for Grain Yield and Quality under High Nighttime Temperature

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Abstract

We report here a pilot screen of a set of 6 diverse *Oryza sativa* L. ssp. *japonica* rice cultivars/genotypes for their response to high nighttime temperature (HNT), with the objective of identifying genotypes that show tolerance for grain yield and quality under HNT. The genotypes were screened in temperature controlled greenhouses for HNT initiated at the R2 and R5 reproductive stages, and continued until maturity. The genotypes include two US cultivars (Bengal and Kaybonnet) and four other diverse rice genotypes (310111, 310799, 310814, and 310747). The cultivars Kaybonnet, Bengal, and 310111 displayed good grain yield and grain quality at the R2 and R5 growth stages under HNT. The long-grain Kaybonnet and medium grain Bengal exhibited the lowest level of chalky grain under HNT, and are thus of value for genetic studies on grain quality.

Introduction

High nighttime temperature (HNT) at the flowering stage is one of the major causes of poor grain filling leading to low grain yield and quality in rice under field conditions, and can be simulated under controlled conditions in the greenhouse (Cooper et al., 2006; Counce et al., 2005). Increased temperature effects rice plants in the three growth stages: a) vegetative—at panicle initiation; b) reproductive—from panicle initiation to flowering; and c) ripening—from flowering to grain maturation (Kumar et al., 2017). The effects can be caused by two mechanisms: i) high maximum temperatures with high humidity can cause spikelet sterility and reduce grain quality, and (ii) increased nighttime temperatures that reduce assimilate accumulation.

Genetic variation for the HNT tolerance trait occurs in many rice genotypes, where deficient alleles can display a reduction in filled grains and/or chalky grains—the easi-

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est quantifiable phenotype. To identify 'all the major loci' involved in these traits, it is necessary to make a genome wide scan such as genome wide association study (GWAS) for different favorable loci needed for the trait, and use this information for breeding. To do this we initiated a HNT screen on the USDA-ARS rice 'mini-core' collection (URMC) of 203 *Oryza sativa* germplasm from all over the world (Agrama et al., 2009). The objective of the present study was to compare different quantifiable phenotypes and make correlations between responses, determine the genetic versus environmental variation, and identify a number of donor lines for HNT tolerance.

Exposure of developing rice panicles during the milky grain-filling stage to temperatures above 26°C, can result in a decline in grain size (Tashiro and Wardlaw, 1991), and in chalky endosperm with immature starch granules, suggesting that starch accumulation is impaired at high temperature. To initiate a systems level analysis of HNT response across a broad germplasm collection, including the multiple genes involved, we screened a sample of 6 *japonica* rice cultivars including 2 which are adapted to U.S. growth conditions, for grain yield and quality under HNT in controlled environments. The molecular genetic analysis of heat tolerance and HNT quality traits will aid in an understanding of the HNT response in rice and the development of improved cultivars.

Procedures

Plant Growth Conditions and Temperature Treatments

A set of 6 *japonica* rice genotypes including two US varieties (Kaybonnet, Bengal) and four other diverse rice genotypes from the Genetic Stocks *Oryza* Collection (GSOR), USDA-ARS Dale Bumpers National Rice Research Center, Stuttgart, Ark. (Table 1), were screened during summer 2017 under temperature stress treatments in the greenhouses in the Rosen Center at the University of Arkansas System Division of Agriculture in Fayetteville. To evaluate heat tolerance, we measured the number of filled grains (NFG) per panicle from plants with HNT initiated at two reproductive stages (R2 and R5) compared to control. Screening for tolerance and grain quality under HNT was conducted in greenhouse conditions. Plants at the R2 (booting stage) and R5 (after anthesis to grain filling) were transferred to HNT of 28 °C (82.4 °F) till harvest, while controls were maintained at 22 °C (71.6 °F) with the day temperature of 30 °C (86 °F). The data logger (HOBO MX2303) was installed in the greenhouses to record the temperature throughout the growth period, showing continuous HNT during most of the flowering and grain maturity period. At physiological maturity, panicles were harvested, air-dried and used for grain phenotyping and chalk measurements.

Grain Yield Components

Plant samples were harvested at physiological maturity and five panicles were taken from each treatment (control and HNT treatments) and two growth stages (R2 and R5) for counting the NFG per panicle and 100- grain weight. The NFG per panicle were counted manually from each panicle from each treatment after air-drying in the dryer at 70 °C. The 100-grain weight was measured on 100 grains of each genotype from each treatment using an analytical balance (model: BSA124S-CW, Sartorius AG, Germany). Data shown are the means of five replicates with each replicate being an average of three 100 grain samples for 100-grain weight. A significant difference between treatments within the cultivar was determined by analysis of variance (ANOVA) using JMP pro 9.0.

Chalk Measurement

Rough rice was de-hulled using a manually-operated de-huller (Rice Husker TR120). Chalkiness was measured using an image analysis system WinSEEDLE™ Pro 2005a (Regent Instruments Inc., Sainte-Foy, Quebec, Canada) and expressed as percent of affected grains in the projected area. Data shown are the average of two biological replicates with each replicate measured being an average of two 100 grain samples. A significant difference between treatments within the cultivar was determined by pairwise comparisons of means using Student's *t*-test.

Results and Discussion

Six *japonica* varieties/genotypes (Table 1) including two U.S. varieties (Kaybonnet and Bengal), and other four diverse genotypes (310111, 310799, 310814, and 310747) were evaluated for grain yield components (NFG per panicle and 100- grain weight) and quality parameters (percent chalkiness in brown grain), under heat stress treatment and control conditions in the greenhouse. The response to HNT of the six rice genotypes is shown for NFG calculated for the treatments at R2 and R5 growth stages (Fig. 1A and B). The results of the screening at R2 stage with Kaybonnet, Bengal and 310111 show <50% reduction in NFG per panicle; while 310799, 310814, and 310474 exhibit > 75% reduction in the number of filled grains (NFG) per panicle (Fig. 1A). The R5 stage HNT screens of Kaybonnet, Bengal, and 310111 show < 22% reduction in NFG per panicle while 310799, 310814, and 310474 exhibit > 47% reduction in NFG per panicle (Fig. 1B).

The air-dried, de-hulled seed were measured for chalkiness using an image analysis system WinSEEDLE™ Pro 2005a, expressed as the percent projected area of grain showing chalkiness. Kaybonnet, Bengal and 310111 showed the lowest level of chalky grain with 3%, 2.5%, and 3.2%, while 310799, 310814, and 310747 exhibited 30.15%, 40.46%, and 51.14% chalky grain, respectively, for R5 stage HNT treatment under greenhouse conditions (Fig. 2A). The 100-grain weight was also measured at R5 stage under HNT for three replications of 100 grain per plant using an analytical balance. Kaybonnet showed the lowest reduction in 100-grain weight (0.75%) and 310747 exhibited the highest reduction in 100- grain weight (18.14%) at R5 stage under HNT stress in the greenhouse conditions (Fig. 2B). The results suggest that Kaybonnet, Bengal, and 310111 were found heat tolerant showing the lowest reduction in NFG at R2 and R5 stages, 100-grain weight and % chalkiness at R5 stage; while 310799, 310814, and 310747 genotypes were found heat sensitive under HNT under these screens.

Significance of Findings

In this report, we show the results of screening 6 *japonica* rice genotypes for grain yield and grain quality at different developmental growth stages under controlled greenhouse conditions. The screen identifies heat tolerant genotypes shown by low reduction in seed set under continuous HNT stress during the fertilization and maturation phase. Subsequently, the heat tolerant genotypes maintain high grain quality represented by low chalky grain and higher 100-grain weight. The controlled screen in the greenhouse at specific growth stages is therefore effective as a fast screen for identification of varieties that can be useful for plant breeding and crop improvement.

The varieties/genotypes used in the analysis can now be studied for molecular genetic analysis of the genes involved in heat tolerance and grain quality under HNT, as segregating populations have been developed or are in the process of development, using comparable sensitive genotypes as parents, to map loci of importance for heat tolerance and grain quality in US cultivars.

Acknowledgments

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Literature Cited

Agrama, H.A., W. Yan, F. Lee, R. Fjellstrom, M.-H. Chen, M. Jia, A. McClung. 2009. Genetic assessment of a mini-core developed from the USDA rice genebank. Crop Sci. 49: 1336–1346.

Cooper, N.T.W., T.J. Siebenmorgen, P.A. Counce, and J.-F. Meullenet. 2006. Explaining rice milling quality variation using historical weather data analysis. Cereal Chem. 83:447-450.

Counce P.A., R.J. Bryant, C.J. Bergman, R.C. Bautista, Y.J. Wang, T.J. Siebenmorgen, K.A.K. Moldenhauer, and J.F. Meullenet. 2005. Rice milling quality, grain dimensions, and starch branching as affected by high night temperatures. Cereal Chem. 82:645-648.

Kumar A., J. Thomas, S. Yingling, Y. Dwiningsih, V, Ramegowda V, J. Gaspar, C, Henry, P. Counce, T.J. Siebenmorgen, K.A.K. Moldenhauer, A. Pereira. 2017. Screening diverse rice cultivars for heat tolerance and grain quality under high nighttime temperature. Arkansas Rice Research Studies, AAES Research Series 635: pp 61-67.

Tashiro T. and I.F. Wardlaw. 1991. The effect of high temperature on kernel dimensions and the type and occurrence of kernel damage in rice. Crop and Pasture Science 42(3), 485-496.

Table 1. The diverse *japonica* rice genotypes obtained from USDA rice mini core collection (URMC) were used for screening under high nighttime temperature (HNT) in greenhouses during the summer 2017 season.

Sample Number	GSOR Number[a]	Cultivar Name	Country of Origin
1	301408	Kaybonnet	USA
2	301418	Bengal	USA
3	310111	Bombilla	Spain
4	310799	Ragasu	Taiwan
5	310814	Grassy	Haiti
6	310747	Bhim Dhan	Nepal

[a] GSOR stands for the Genetic Stocks *Oryza* Collection identification number.

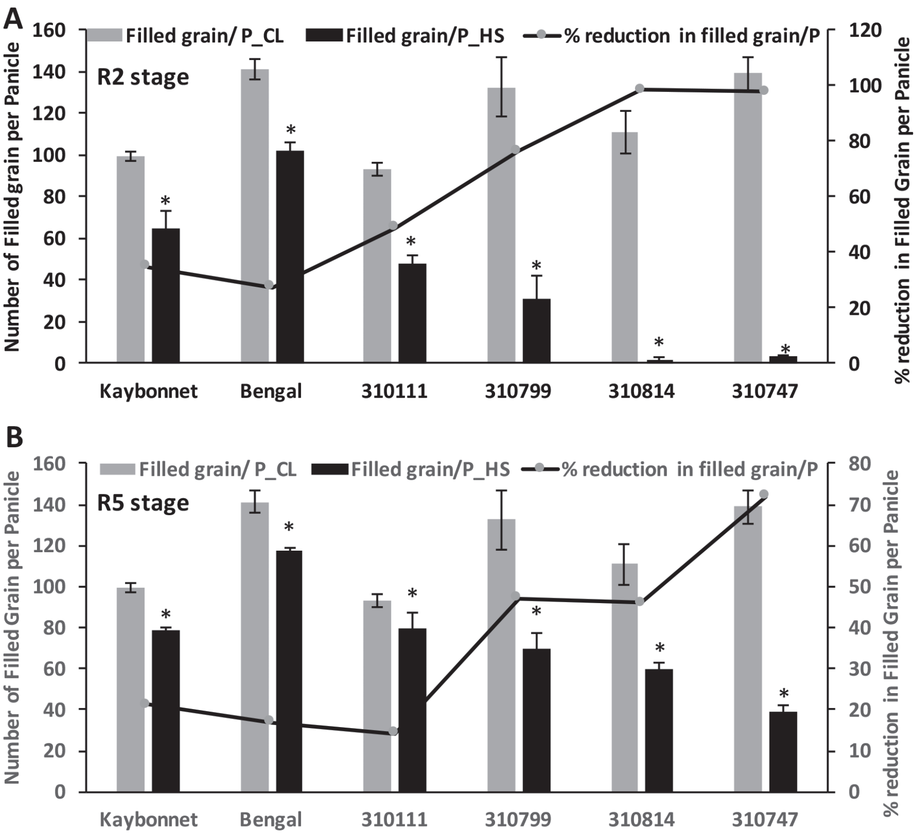

Fig. 1. Effect of high nighttime temperature (HNT) on the grain yield component, number of filled grain (NFG) per panicle, in 6 japonica rice genotypes. The genotypes were treated to HNT of 28°C at R2 and R5 stages until maturity with controls maintained at 22°C, and daytime temperature constant for all genotypes at 30°C. At physiological maturity, seeds were harvested, air-dried, and de-hulled using a manually operated de-huller (Rice Husker TR120). NFG per panicle and % reduction in NFG per panicle was measured for the grain harvested from control and heat stressed treatment at the R2 (A) and R5 (B) stages. Under HNT, the R2 stage shows lower NFG per panicle and higher reduction in the number of grains per panicle as compared to R5 stage. Data are the means of five replicates. Asterisks indicate significance at *P* ≤ 0.05 using ANOVA.

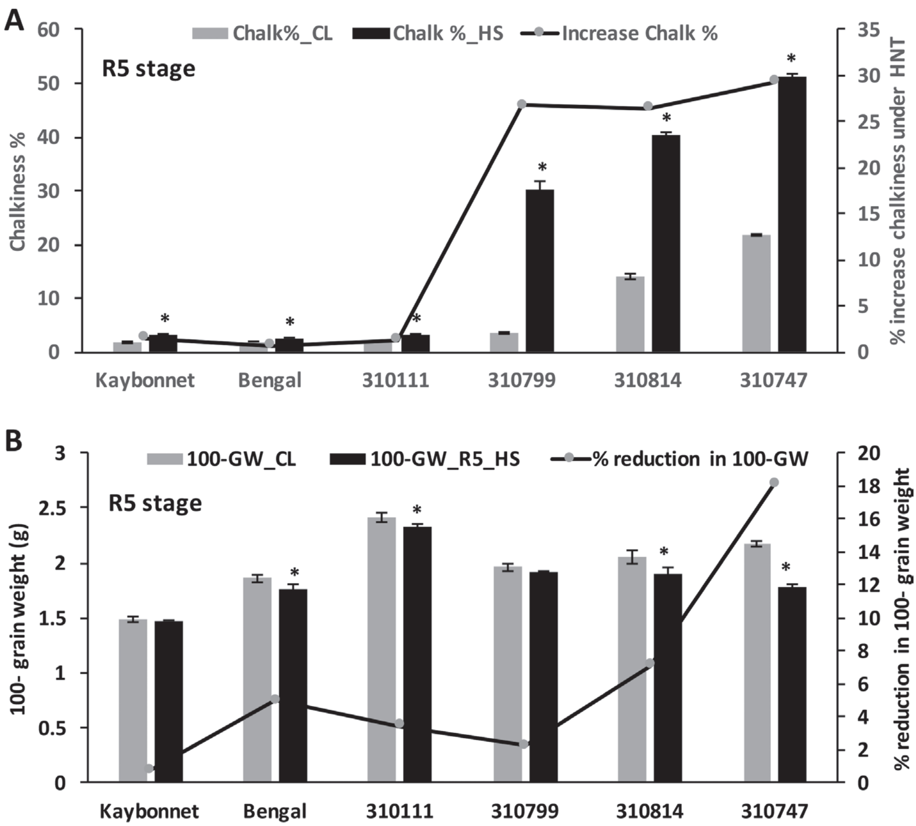

Fig. 2. Response of high nighttime temperature (HNT) on grain quality (% chalkiness) and grain yield (100- grain weight) component traits in 6 japonica rice genotypes. The genotypes were treated to HNT of 28°C at R5 stage until maturity with controls maintained at 22°C, while daytime temperature was kept constant at 30°C. At physiological maturity, seeds were harvested, air-dried, and de-hulled using a manually operated de-huller (Rice Husker TR120). (A) Chalkiness of brown grains was measured using an image analysis system (WinSEEDLE™ Pro 2005a) and expressed as percent of grain projected area for the grain harvested from control and heat stressed treatments at R5 stage in greenhouses. The heat tolerant genotypes showed low percent of chalkiness in the grains and an increase in chalkiness as compared to the control. (B) 100-grain weight was measured thrice using 100 grains harvested from R5 stage using an analytical balance. Data shown are the means of two biological replicates with each replicate measured twice using 100 grains for chalkiness and the means of three replicates of 100 grains for 100-grain weight. Asterisks indicate significance at *P* ≤ 0.05.

Breeding and Evaluation for Improved Rice Varieties—The Arkansas Rice Breeding and Development Program

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Abstract

The Arkansas rice breeding program has the ongoing goal to develop new long- and medium-grain cultivars as well as specialty cultivars including aromatics and Japanese quality short-grains. Cultivars are evaluated and selected for desirable characteristics. Those with desirable qualities which require further improvement are utilized as parents in future crosses. Important components of this program include: high-yield potential, excellent milling yields, pest and disease resistance, improved plant type (i.e. short stature, semidwarf, shorter maturity, erect leaves), and superior grain quality (i.e. low chalk, cooking, processing and eating). New cultivars are continually being released to rice producers for the traditional Southern U.S. markets as well as for the emerging specialty markets, which are gaining in popularity with rice consumers. This report describes the progress of the long-grain and specialty rice pure line rice breeding effort at the University of Arkansas System Division of Agriculture.

Introduction

The rice breeding and genetics program at the University of Arkansas System Division of Agriculture's, Rice Research and Extension Center (RREC), Stuttgart, Ark. is by nature a continuing project with the goal of producing improved rice cultivars for rice producers in Arkansas and the Southern U.S. rice growing region. The Arkansas rice breeding program is a dynamic team effort involving breeders, geneticists, molecular

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geneticists, pathologists, soil scientists, physiologists, entomologists, economists, systems agronomists, weed scientists, cereal chemists, extension specialists, and statisticians. We also encourage input from producers, millers, merchants and consumers. As breeders, we integrate information from all of these disciplines to make selections that are relevant to the needs of the entire rice industry. We are always looking for ways to enable the producer to become more economically viable, adding value to their product. Breeding objectives shift over time to accommodate the demands of these players.

Breeding objectives for improved long-grain and specialty rice cultivars include: standard cooking quality, excellent grain and milling yields, low chalk in the kernel, improved plant type, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal, more recently bacterial panicle blight has been added to this list. Blast resistance has been addressed by the pathology team, as well as through research by visiting scholars, and graduate students and by the development and release of the cultivars ‘Katy’, ‘Kaybonnet’, ‘Drew’, ‘Ahrent’, ‘Templeton’ and ‘CL172’. ‘Banks’ was also released from this program with blast resistance, but because blast resistance was derived from backcrossing, it did not contain the minor genes needed to protect it from *IE-1k* in the field. These cultivars are among the first to have resistance to all of the common Southern U.S. rice blast races. These first blast resistant cultivars released were susceptible to *IE-1k*, but they had field resistance, which kept the disease at bay. Templeton, one of the more recently released blast resistant cultivars has resistance to the race *IE-1k*. Furthermore, many of the experimental lines in the Arkansas rice breeding program have the gene *Pi-ta* which provides resistance to most southern blast ecotypes and some of these also have resistance to *IE-1K*. Sheath blight tolerance has been an ongoing concern and the cultivars from this program have also had the best sheath blight tolerance of any in the US. Rough rice grain yield has become one of the most important characteristic in the last few years and significant yield increases have been realized with the release of the long-grain cultivars ‘LaGrue’, ‘Wells’, ‘Francis’, Banks, ‘Taggart,’ ‘Roy J’, ‘LaKast’ and ‘Diamond’.

Procedures

The rice breeding program continues to utilize the best available parental material from the US breeding programs, the USDA World Collection, and the International Centers, CIAT, IRRI and WARDA. Crosses are made yearly to improve grain yield and to incorporate genes for broad-based disease resistance, improved plant type (i.e. short-stature, shorter maturity, erect leaves), superior quality (i.e. low chalk, and good 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, chalk, 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, marker assisted selection, mutation breeding, and biotechnology (gene editing in the future) 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 conducted each year by the Rice Extension Agronomist. These trials contribute to the selection of 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, which are inoculated with sheath blight, blast and bacterial panicle blight, general observation tests which are planted in fields with historically high incidences of disease, and general observations which are made during the agronomic testing of entries.

Results and Discussion

Diamond, released to seed growers in 2016, was grown on 8.62 % of the Arkansas acreage in 2017 and will be on a high acreage in 2018 because of its excellent yields. It is a very-high yielding, short-season, long-grain line. The yield of Diamond for the 2015-2017 Arkansas Rice Performance Trials (ARPT) was 194 bushels/acre compared to Roy J, Lakast, Wells, and 'Titan' at 177, 177, 171, and 186 (Table 1). Diamond not only has a yield advantage over Roy J but it reaches maturity approximately five days earlier. Diamond has the desired kernel length of greater than 7 mm at 7.21 mm according to the Riceland Foods Inc. Laboratory. Head rice yield and cooking quality are also comparable to Wells and Roy J, and it has a clear translucent kernel with low chalk (Table 1). Diamond, LaKast, and Wells have moderate lodging resistance ratings. Dried rice was used to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. The milling yield of Diamond in the ARPT, 2015-2017 (Table 1) was 57/69, compared to LaKast and Wells at 56/69 and 55/70, respectively. Diamond does not carry any major resistance genes for rice blast and is rated susceptible to rice blast, similar to LaKast or Wells. It is moderately susceptible to bacterial panicle blight and very susceptible to false smut.

The program released an aromatic line Aroma17 in January of 2018, which has good yield, plant type, aroma and taste (Wisdom et al. 2018). There are several other aromatic lines which are being considered for the future.

In 2016, the high nighttime temperatures and rain showers during heading took a toll on rice yields in Arkansas. Selecting germplasm that could better tolerate these conditions was difficult. The Stuttgart Initial Test (SIT), which is grown at two locations, the RREC and the University of Arkansas, System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, supplied an opportunity to select lines grown under different conditions. At the RREC, the growing conditions included: hot nighttime temperatures and rain during heading, while at PTRS the conditions were good during heading. These lines were in the ARPT in 2017 (Table 2) for further evaluation. EXP17084 yielded over 200 bushels/acre at all five of the ARPT locations with an average rough rice yield of 210 bushels/acre and it had good milling at 57/69 compared to Diamond at 206 bushels/acre milling a 56/59. Another line EXP17087 was also interesting because it contains *Pi-ta* and *Ks* two blast resistance genes. This line yielded 192 bushels/acre and milled a 59/71.

Crosses were made for high yield, good quality, improved milling, and disease resistance in various combinations. Crosses were made for long-grain conventional lines as well as aromatic lines in 2017. The F2 populations from these crosses will be evaluated in 2017 and selections will be grown in the winter nursery during the winter of 2018–2019. During the winter of 2017–2018, we had 4000 F3 lines growing in Puerto Rico. Panicles harvested from each row produced the F4 lines, grown at the RREC as P panicle rows in 2018.

Marker-assisted selection continues to be utilized by this program to help select improved lines with specific genes. In this program, molecular markers allow selection of lines which carry genes associated with high yield in the wild species *Orzya rufipogon*, the *Pi-ta* gene for blast resistance and the CT classes to predict cooking quality (see Boyett et al., 2005 and 2008). In 2018, a line will be grown in the ARPT, from the *Oryza rufipogon* crosses that had the highest yield in the ARPT seed increase in 2017. Additionally, this program is conducting research to identify molecular markers linked to quality traits. These markers will enable breeders to select for high milling quality in early breeding generations. The data derived from this project improves our accuracy and efficiency in choosing parents and advancing lines.

Significance of Findings

The goal of the rice breeding program is to develop maximum yielding cultivars with excellent quality and good levels of disease resistance for release to Arkansas rice producers. The release of Taggart, Templeton, Roy J, LaKast and most recently Diamond demonstrate that continued improvement in rice cultivars for the producers of Arkansas are achieved through this program. Diamond could potentially be the modern replacement for Wells. Improved lines will continue to be released from this program in the future. The new cultivar Aroma17 will provide the producers with an Arkansas aromatic line. New cultivars will have the characteristics of improved: yield, disease resistance, plant type, rough rice grain and milling yields, low chalk, the desired larger kernel size, and overall grain quality. 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 that have emerged in recent years.

Acknowledgments

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Literature Cited

Boyett, V.A., J.W. Gibbons, J. Jiang, and K.A.K. Moldenhauer. 2005. Advancements in marker-assisted selection methods and applications. *In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2004. University of Arkansas Agricultural Experiment Station Research Series 529:25-29. Fayetteville.

Boyett, V.A., J. You, and K.A.K. Moldenhauer. 2009. Challenges of marker-assisted selection of quantitative trait loci introgression form *O. rufipogon. In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.), B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:56-61. Fayetteville.

Wisdom, D.K.A., K.A.K. Moldenhauer, X. Sha, J.T. Hardke, Y.A. Wamishe, M.M. Blocker, D.L. McCarty, C.H. Northcutt, V.A. Boyett, V.I. Thompson, D.L. Frizzell, J.M. Bulloch, B.A. Beaty, C.D. Kelsey and S.B. Belmar. 2018. Aroma17, an aromatic jasmine-type, long-grain rice variety. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2017. University of Arkansas Agricultural Experiment Station Research Series 651:94-98. Fayetteville.

Table 1. Three year average 2015-2017 Arkansas Rice Performance Trials for Diamond and other long-grain cultivars.

	Yield[a]					50%	Chalky	
Cultivar	2015	2016	2017	Mean	Height	Heading	Kernels[b]	Milling
	--------------(bu/ac)-------------				(in.)	(days)	%	%HR/%TR[c]
Diamond	186	188	206	194	40	84	1.61	57/69
LaKast	162	182	188	177	41	81	1.53	56/69
Roy J	169	167	196	177	41	88	1.70	58/70
Taggart	167	179	183	176	43	87	1.54	55/70
Wells	161	171	182	171	40	85	1.75	55/70
RTXP753[d]	212	231	220	221	43	80	3.12	49/68
RTXL745CL[e]	187	192	202	194	43	79	3.27	52/69

[a] Yield trials in 2015 and 2017 consisted of five locations, Rice Research and Extension Center, (RREC), Stuttgart Ark., Pine Tree Research Station, (PTRS), Colt, Ark., Northeast Research and Extension Center, (NEREC), Keiser, Ark.;, Clay County Ark. Farmer Field, (CC); and Desha County Ark. Farmer Field (DC); and in 2016 the trials were conducted at the RREC, PTRS, NEREC, Newport Extension Center, (NEC) and CC.

[b] Data for chalk is from 2014-2016 Riceland Grain Quality Laboratory data.

[c] Milling figures are % head rice/% total rice 2014-2016, except Clearfield line 2015-2016.

[d] RT stands for RiceTec.

[e] CL stands for Clearfield lines.

Table 2. 2017 Arkansas Rice Performance Trials for long-grain cultivars and experimental lines.

Cultivar	Yield[a] RREC	PTRS	NEREC	CC	DC	Mean	Height	50% Heading	Milling
	------------------------(bu/ac)-----------------------						(in.)	(days)	%HR/%TR[b]
Diamond	214	177	204	227	208	206	38	91	56/69
LaKast	194	172	179	201	197	188	39	89	56/70
Roy J	197	184	205	209	186	196	40	94	60/70
Taggart	182	177	184	190	184	183	41	94	59/71
Wells	166	164	196	191	191	182	39	91	56/71
RTXP753[c]	231	201	214	230	222	220	38	87	49/70
EXP17084	201	201	217	229	205	210	37	93	57/69
EXP17087	203	169	190	205	192	192	38	91	59/71

[a] Yield trials in 2017 consisted of five locations, Rice Research and Extension Center, (RREC), Stuttgart Ark., Pine Tree Research Station, (PTRS), Colt, Ark., Northeast Research and Extension Center, (NEREC), Keiser, Ark.;, Clay County Ark. Farmer Field, (CC); and Chicot-Desha County Ark. Farmer Field (DC).

[b] Milling figures are %head rice/% total rice 2014-2016, except Clearfield line 2015-2016.

[c] RT stands for RiceTec.

Identification of Genetic Sources of Arkansas Male-Sterile Rice Lines

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Abstract

Hybrid rice production using the two-line system requires developing environment genetic male-sterile (EGMS) lines which become male-sterile in certain environmental conditions. An EGMS line contains genes that can be induced to express by temperature (TGMS), daylight (PGMS), or both (PTGMS). This study will determine (1) the genetic sources (TGMS, PGMS, PTGMS) of several Arkansas EGMS lines, (2) the environmental thresholds of each line, and (3) the optimum/absolute planting dates to induce full sterility of these lines in Arkansas. A total of eight EGMS lines are being tested including 4 lines designated as 236s, 801s, 805s, and 811s developed by the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; and 4 mutant male-sterile lines designated as GSOR 1, GSOR 2, GSOR 3, and GSOR 4 developed by the Dale Bumpers National Rice Research Center (DBNRRC-USDA-ARS) near Stuttgart, Ark. First, the lines were screened in growth chambers using different temperatures to identify the genetic source and environmental threshold for each line. Plants were tested at the heading stage for pollen sterility via the pollen stain method. Next, each line was planted in a randomized block design with 3 replications and 3 planting dates to determine the optimum planting dates at field conditions at RREC in summer 2017. The percentage of sterility from selected single plants of each line as well as the overall percentage of sterility from each plot were recorded. The results from the growth chamber study revealed that 801s and 811s expressed sterility at a daytime temperature >29.4 °C and nighttime temperature >26.7 °C, while 236s expressed sterility when daytime temperature >32.2 °C and nighttime temperature >29.4 °C. The results also suggested that the different day lengths did not affect sterility in these lines. The field study showed that 811s expressed sterility in all three planting dates indicating that the optimum planting was May 10th. The 236s plants tested from the 1st planting date expressed sterility indicating that the absolute planting date was April 25. All GSOR lines in the growth chamber conditions remained fertile, however, in the field test a few plants of GSOR 2, GSOR 3, and GSOR 4 showed sterility. All GSOR 1 plants were fertile in the field condition.

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Introduction

In 2010, the University of Arkansas established a hybrid rice breeding program to produce new, improved hybrid cultivars in response to the success and popularity of commercial hybrids under the direction of Zongbu B. Yan and Chris W. Deren. Since environment genetic male-sterile (EGMS) lines were not available for this program, efforts were made to develop EGMS lines through spontaneous mutation by making wide crosses between genetically dissimilar parents. The ending resulted in establishing four EGMS lines designated as 236s, 801s, 805s, and 811s (Yan et al., 2010).

Prior to the University of Arkansas research initiative, scientists at Dale Bumper National Rice Research Center, USDA-ARS at Stuttgart, Ark. conducted a study to develop new sources of male sterility conferred by a dominant sterility gene by using gamma-irradiation in 1993 and 1994. They believed such mutant genes could produce a stable male-sterile line preferable for variety development. Four male-sterile, mutant lines were developed from the following cultivars: "Kaybonnet" (GSOR 1), "Orion" (GSOR 2), "Cypress" (GSOR 3), and "LaGrue" (GSOR 4). The results from the study determined that GSOR 1, 2 and 4 possess dominant male sterility genes and GSOR 3 possesses recessive male sterility genes (Zhu and Rutger, 1999).

Procedures

There are several important challenges surrounding the development of male-sterile lines and the production of hybrids in Arkansas. One is that the identity of the genetic source of sterility in male-sterile lines developed at the University of Arkansas and USDA-ARS are unknown. A second is the variability in Arkansas' weather at the different latitudes in Arkansas and during each growing season in rice production regions. Depending on the sterility gene in the male-sterile line it could cause the line to become fertile. Also it was observed under field conditions that the late tillers subjected to low temperatures at the R2 growth stage shift from sterile to partially fertile. Our objectives in this study are to: 1) identify the genetic sources of sterility [temperature (TGMS), daylight (PGMS), or both (PTGMS)] in Arkansas and GSOR male-sterile lines; 2) determine the environmental threshold of the sterile lines according to which sterility gene(s) the lines possess; 3) determine the optimum/absolute planting dates to ensure an environment conveying sterility; and 4) find an optimum planting density to reduce late tiller panicles that may become fertile if the environment changes by planting with different seeding rates. We hypothesize that 1) the genetic source of sterility in the EGMS lines developed at the University of Arkansas are TGMS and the lines developed at USDA-ARS are not EGMS, but possibly CMS; 2) the environmental threshold of the TGMS lines for male sterility should be when daytime temperatures are above 30 °C and when nighttime temperatures are above 24 °C; 3) the Arkansas climate during rice growing season should be ideal for a sterile environment; and 4) that increasing planting density (canopy) may prevent producing late fertile tillers. The ultimate goal of this study is to determine the environmental threshold for inducing sterility of these newly, developed EGMS lines so that they may be properly and successfully used in the production of Arkansas hybrid seed. The results of this study can be used by rice breeders and geneticists for further genetic analysis of sterile gene(s) and by agronomists and seed producers for producing hybrid seed in Arkansas rice lands at optimum conditions.

Seed Increase and Genotypic Evaluation

The seeds of the 811s, 236s, 801s, and 805s EGMS lines were received through the seed source of the RREC hybrid breeding program. To increase genetic uniformity of male-sterile lines of 236s and 811s about 200 plants from each line were grown under greenhouse conditions in December 2015, and tissue samples from each plant were collected and tested via molecular markers to select for homozygous plants, thus improving purity. Meanwhile, several phenotypic characteristics such as heading date (when 50% of panicles have partially exerted from the boot), plant height, and percentage of sterility were recorded. Then homozygous plants were identified, ratooned and placed in lower temperature (21.1 °C) for seed production (Moldenhauer and Slaton, 2001). In the summer of 2016 the same procedure was done for 801s and 805s except that the plants were planted in the field at RREC. The selections based on the same phenotypic characteristics described for 236s and 811s were made, ratooned, placed in the fall in a controlled environment, and allowed to set seed to establish a pure seed source of the Arkansas male-sterile lines. Meanwhile, seeds from GSOR 1, 2, 3 and 4 experimental lines were obtained from the germplasm collection at Dale Bumper's National Rice Research Center, USDA-ARS, Stuttgart, Ark.

Growth Chamber Study

This study follows a method described by Lee et al. (2005) in which different maximum and minimum temperatures, and day-lengths (hours) are used in determining spikelet sterility/fertility. Four treatments (T1, T2, T3, and T4 at 12.5 h) from Table 1 were applied to 236s, 811s, GSOR 1, GSOR 2, GSOR 3, and GSOR 4. For each environmental treatment, four male-sterile plants from each sterile line were grown in a 3.785-liter pot. There were two replications in each treatment, thus there are eight male-sterile plants from each sterile line. Each treatment was applied for 25 days. The pots were placed in a plastic tub with the dimension of 6 × 6 × 6 inches in the greenhouse where the plants were monitored daily to determine developmental growth stages, and to maintain water levels and apply fertilizer according to the standard rice growing recommendations in Arkansas. The plants were transferred later to the assigned GC to apply the treatment at the plants' reproductive growth stage 1 (R1) which is approximately 20–30 days prior to the R2 growth stage (Moldenhauer et al., 2013). Five panicles from each plant were tested for sterile/fertile pollen grains using a pollen stain test (Guzman et al., 2011). After panicle heading occurred, three panicles from each plant were randomly selected and tested for sterility/fertility. Results from 24 panicles are perfectly adequate to represent each line in each treatment. From each selected panicle, at least six anthers were harvested from three spikelets for pollen stain testing. The average number of sterile panicles revealed which treatment was the optimum threshold environment to induce sterility of the line. These lines were evaluated based on pollen appearance (Fig 1) and each plant was classified based on the percentage of pollen grains that were categorized as sterile (Table 2).

Field Study

We conducted a field study during the summer of 2017 to determine the optimum planting date for sterile lines in field conditions. The Arkansas male-sterile lines, except 805s (due to low amount of available seed), and GSOR lines were tested in a randomized block design in three replications and using 3 planting dates of 25 April, 2 May, and 11 May at the RREC. Line 801s was planted only on the third date (11 May) due to the limited amount of available seeds. The plots of all the planting dates were composed of seven rows 7 ft long spaced 8 inches apart. Approximately 200 seeds of each male-sterile line were sowed. Ten plants from each plot were randomly selected, three panicles from each plant including one from the main stem, 1st tiller, and 2nd tiller were collected and tested via pollen staining. At the end of the season, 1890 panicles were evaluated for sterility/fertility. Each plot was evaluated on the average number of sterile panicles observed

Results and Discussion

Growth Chamber Study

The 811s plants were completely sterile at treatments 3 and 4, whereas partial fertile at treatments 1 and 2. The evaluation suggests that the 811s line's genetic source is TGMS and the threshold environment is when daytime is >29.4 °C and nighttime temperature is >26.7 °C. 236s plants were completely sterile at treatment 4, whereas fertility was partial at treatments 3 and 2, then completely fertile at treatment 1. The evaluation suggests that 236s line's genetic sources is TGMS and the threshold environment is when daytime temperature is <32.2 °C and nighttime temperature is >29.4 °C. The GSOR lines showed partial to fully fertile in all the treatments. There is a possibility that the gene associated with sterility was deleted from genome over the years, however, further treatments must be applied to determine if the genetic sources are PGMS.

Field Study

The 236s plants expressed partial sterility and partial fertility among the 3 planting dates. For the 1st planting date 87% of the 30 plants evaluated were sterile. For the 2nd planting date only 53% of the 30 plants evaluated were sterile. For the 3rd planting date 60% of the 30 plants evaluated were sterile. As shown in Fig. 2 nearly all of the critical sterility inducing days (R1 to heading date) for planting dates 2 and 3 were below the threshold for sterility, thus causing partial fertility among the plants. The evaluation supports a critical growth stage for inducing pollen sterility. The timing of R1 is approximately 25 days prior to heading. According to Virmani et al. (1997) the critical timing for inducing sterility varies from 15 to 25 days prior to heading or 5 to 15 days after panicle initiation (R1) . This agrees with material from Moldenhauer et al. (2013) which explains how at the R1 stage the number of potential grains per panicle is greatly affected by the environment, this data supports that the most critical timing for inducing sterility is from the R1 stage to 10 days after. The conclusion is that 236s must be planted earlier than any of three planting dates due to late heading (95 days) in order to be sterile.

The 801s plants expressed nearly complete sterility with 93% of the 30 plants testing as completely sterile. Looking at Fig. 3 all of the critical sterility inducing days (R1-10 days) were above the threshold, while ten days before heading the temperatures were below the threshold, thus indicating that there is little to no effect on inducing sterility ten days before heading. The conclusion is that the planting date used (10 May) is the absolute date to avoid a fertile environment with consideration of 86 days until heading.

The 811s plants expressed complete sterility in which all plants tested were sterile. As shown in Fig. 4 all of the critical sterility inducing days were above the threshold. The evaluation suggests that all of the daytime temperatures were above the daytime temperature threshold; nighttime temperature threshold is may be lower than 26.7 °C or it has no effect on sterility; and all three planting dates are optimum for a sterile environment when considering 75 days of heading.

The nighttime temperatures during the R1 stage – heading were below the thresholds (determined by the growth chamber study) of 236s, 801s, and 811s, but it seemed to not affect sterility. There are two possibilities from these results: (1) the nighttime temperature thresholds are lower than the growth chamber study results suggested, or (2) nighttime temperature does not have a great enough effect on sterility as long as daytime temperatures are above the daytime threshold.

The GSOR lines were mostly fertile, however, of all the GSOR 2 plants tested 4 were sterile, of all the GSOR 3 plants tested 12 were sterile, and of all the GSOR 4 plants tested 3 were sterile. These sterile plants were transferred into a growth chamber with a setting of photoperiod <13 h. If these plants become fertile and set seed then the genetic source must be PGMS.

Significance of Findings

This study has concluded that: 1) 236s, 801s, and 811s are TGMS; 2) 236s has an environmental threshold of daytime temperatures of 32.2 °C while 801s and 811s have an environmental threshold of 29.4 °C; 3) the critical stage for inducing sterility is R1-10 days; 4) planting dates for a sterile environment vary due to heading dates, however, 25 April was best for providing a sterile environment during the R1 stage; and 5) hybrid seed production in Arkansas can be more successful using TGMS lines with a daytime temperature threshold of 29.4 °C.

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Literature Cited

Guzman, C. D. and J. Oard. 2011. Rapid pollen staining method for the field identification of rice sterile lines, Louisiana State University, Agcenter.

Lee, D. S., Chen, L. J., and Suh, H. S. 2005. Genetic characterization and fine mapping of a novel thermo-sensitive genic male-sterile gene tms6 in rice (oryza sativa l.). Theoretical and Applied Genetics 111.

Moldenhauer, K.A.K., C.E. Wilson, Jr., P. Counce, and J. Hardke. 2013. Rice growth and development. In: J. Hardke (ed.). Arkansas rice production handbook. University of Arkansas Division of Agriculture Cooperative Extension Service, Little Rock, Arkansas.

Virmani, S.S., B.C. Viraktamath, C.L. Casal, R.S. Toledo, M.T. Lopez, and J.O. Manolo. 1997. Male sterility systems in rice. In: Hybrid rice breeding manual. International Rice Research Institute, Los Baños, Laguna, Philippines. pp. 11-26.

Table 1. Treatments of the male sterile lines.

Treatment	12.5 h	13 h	13.5 h	14 h
T1	23.9 °C, 21 °C[a]	23.9 °C, 21 °C[a]	23.9 °C, 21 °C[a]	23.9 °C, 21 °C[a]
T2	26.7 °C, 23.9 °C	26.7 °C, 23.9 °C	26.7 °C, 23.9 °C	26.7 °C, 23.9 °C
T3	29.4 °C, 26.7 °C	29.4 °C, 26.7 °C	29.4 °C, 26.7 °C	29.4 °C, 26.7 °C
T4	32.2 °C, 29.4 °C	32.2 °C, 29.4 °C	32.2 °C, 29.4 °C	32.2 °C, 29.4 °C

[a] Maximum (daytime) temperature, minimum (nighttime) temperature – at a day length of 12.5 h.

Table 2. Category of percentage of pollen grains that are sterile.

Pollen sterility (%)	Category
100	Completely Sterile (CS)
91–99	Sterile (S)
<90	Fertile (F)

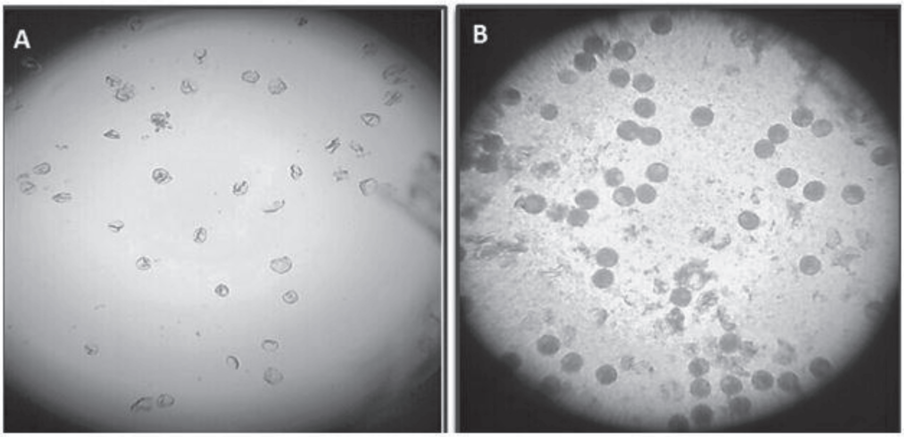
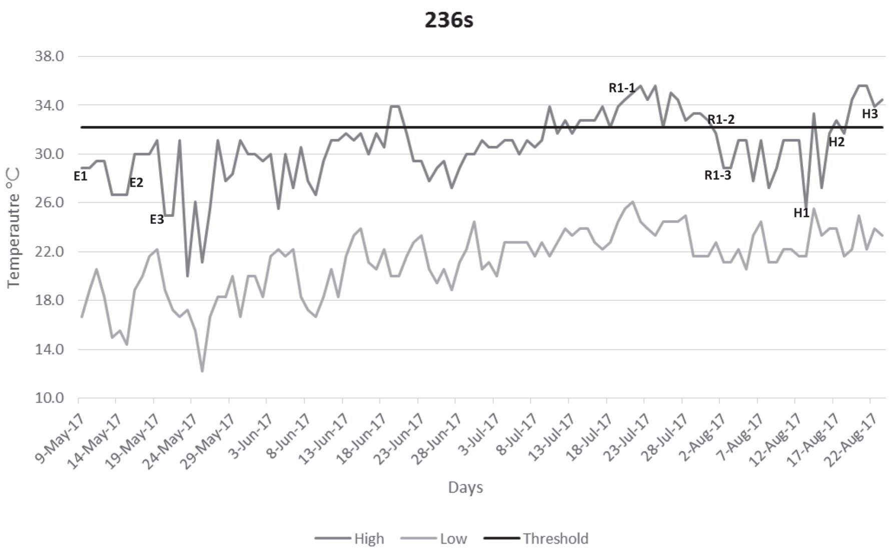
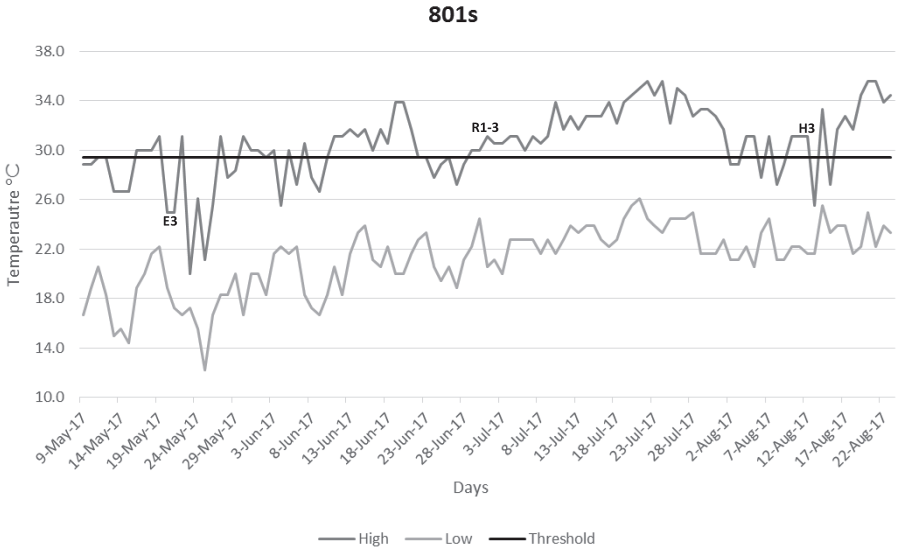


Fig. 1. Pollen grain appearance under a microscope (10x) after staining (A) sterile pollen, (B) fertile pollen.



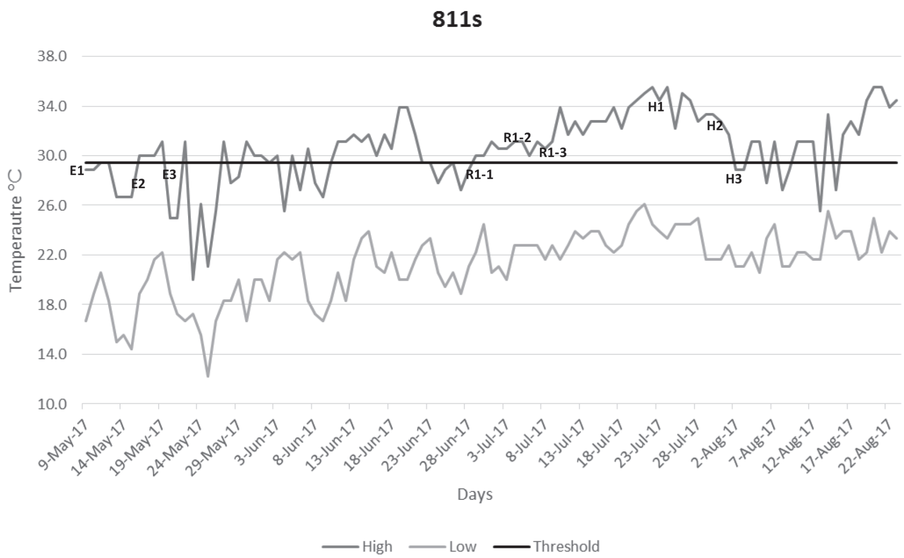
1st Planting Date: E1 – Emergence Date; R1-1 – R1 (Growth Stage) Date; H1 – Heading Date
2nd Planting Date: E2 – Emergence Date; R1-2 – R1 (Growth Stage) Date; H2 – Heading Date
3rd Planting Date: E3 – Emergence Date; R1-3 – R1 (Growth Stage) Date; H3 – Heading Date

Fig. 2. High and low temperatures during 236s growth.



3rd Planting Date: E3 – Emergence Date; R1-3 – R1 (Growth Stage) Date; H3 – Heading Date

Fig. 3. High and low temperatures during 801s growth.



1st Planting Date: E1 – Emergence Date; R1-1 – R1 (Growth Stage) Date; H1 – Heading Date
2nd Planting Date: E2 – Emergence Date; R1-2 – R1 (Growth Stage) Date; H2 – Heading Date
3rd Planting Date: E3 – Emergence Date; R1-3 – R1 (Growth Stage) Date; H3 – Heading Date

Fig. 4. High and low temperatures during 811s growth.

Evaluation of Advanced Semi-Dwarf Medium-Grain and Long-Grain Breeding Lines at Three Arkansas Locations

X. Sha[1], B.A. Beaty[1], J.M. Bulloch[1], T.L. Scott Jr., S.D. Clark[2] and M.W. Duren[3]

Abstract

A controlled yield trial under the most representative soil and environmental conditions is critical for rice breeders to identify the ideal genotypes for potential varietal releases. To bridge the gap between the single location, 2 replication preliminary yield trials and the multi-state Cooperative Uniform Regional Rice Nursery (URRN) and/or the multi-location statewide Arkansas Rice Performance Trial (ARPT) which only accommodate a very limited number of entries, an advanced elite line yield trial (AYT) was initiated in 2015.The trial is conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, (RREC), near Stuttgart, Ark.; the University of Arkansas System Division of Agriculture's Pine Tree Research Station, (PTRS), near Colt, Ark.; and the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, (NEREC), in Keiser, Ark.. This new trial will help us to select the best and the most uniform breeding lines for advancement into the URRN and/or ARPT trials, and ultimately will improve the quality of those yield trials.

Introduction

Complicated rice traits, such as yield and quality can only be evaluated effectively in replicated yield trials. Once reaching a reasonable uniformity, rice breeding lines are bulk-harvested and tested in single location, 2-replication preliminary yield trials, which include the Clearfield Stuttgart Initial Trial (CSIT) or Conventional Stuttgart Initial Trial (SIT). Each year, about 1000 new breeding lines are tested in CSIT or SIT trials. About 10% of the tested breeding lines, which yield numerically higher than commercial checks and possess desirable agronomical characteristics, need to be tested in replicated and multi-location advanced yield trials. However, the current advanced yield

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trials include the multi-state Uniform Regional Rice Nursery (URRN) and statewide Arkansas Rice Performance Trial (ARPT) that only accommodate about 20 entries from each breeder each year. Obviously, a new replicated and multi-location trial is needed to accommodate those additional breeding lines. In addition to the verification of the findings in the previous preliminary trials, the new trial will result in purer and more uniform seed stock for URRN and ARPT trials.

Procedures

A total of 80 entries were tested in 2017 AYT trial, which included 72 experimental lines (25 Clearfield long-grain, 7 Clearfield medium-grain, 21 semidwarf long-grain, and 19 medium-grain), and 8 commercial check varieties. Fifteen of the experimental lines were also concurrently tested in 2017 URRN and/or ARPT trials. The experimental design for all three locations is a randomized complete block with three replications. Plots measuring 5 feet wide (8 rows with an 7.5 inch row spacing) and 14 feet long were drill-seeded at 75 pounds per acre rate. The soil types at the Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) are Sharkey clay, Calloway silt loam, and DeWitt silt loam, respectively. Planting dates at NEREC, PTRS, and RREC were 14 April, 13 April, and 5 April, respectively. A single preflood application of 152 pound nitrogen in the form of urea was applied to a dry soil surface at 4- to 5-leaf stage, and a permanent flood was established 1-2 days later. At maturity, the six rows (including a border row) of each plot were harvested by using a Wintersteiger plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture content and plot weight were determined by the automated weighing system Harvest Master that is integrated into the combine. A small sample of seed was collected from the combine for each plot for later milling yield determination. Milling evaluations were conducted by Riceland Foods, Inc., Stuttgart, Ark. Grain yields were calculated as bushel per acre at 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, version 9.4 (SAS Institute, Cary, N.C.). Analysis of variance for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor were performed for each location, and a combined analysis was conducted across the three locations. The means were separated by Fisher's protected least square difference (LSD) test at the 0.05 probability level.

Results and Discussion

The average grain yield of all genotypes across 3 locations is 164 bushel per acre (bu/acre) (Table 1), which is slightly lower than the 166 bu/acre average in 2016 but 21 bu/acre (11%) lower than that of 2015. Among 3 locations, RREC has the highest yield of 189, followed by 160 bu/acre of PTRS, while NEREC has the lowest yield of 156 bu/acre. The low yield of PTRS may attribute to the combination of Grape Colaspis injury and Zinc deficiency; however, the uncharacteristically low yield of NEREC is without doubt due to the poor stand. Clearfield (CL) check variety CL151 has the highest yield of 206 bu/acre among all entries, while Titan has the highest yield of 198 bu/acre among all medium-grain entries. Check varieties, especially CL checks whose seeds were treated with insecticides, yielded higher than most experimental lines, whose seeds were not treated with insecticides and had the poor seed quality due to the bacterial panicle blight epidemics in 2016. Overall, medium-grain rice performed better than long-grain rice. The top 5 highest yielding experimental lines are CL medium-grain lines 17AYT029, 17AYT018 (RU1701167), and 17AYT016 (RU1701136), conventional medium-grain line 17AYT066, and CL long-grain line 17AYT007 (RU1601133) with the average grain yield of 194, 192, 177, 188, and 184 bu/acre, respectively (Table 1). Milling yields are similar to that of 2015 but much improved from that of 2016. The average head rice and total rice of three locations are 68 and 70%, respectively (Table 2), which are 5% and 3% higher than that of 2016, respectively. The average seedling vigor is 4.8, which is much lower than the 3.6 of 2016, the average days to 50% heading is 90 days, and the average plant height is 40 inches (Table 2).

Among CL medium-grain lines, 17AYT029 and 17AYT018 (RU1701167) had a numerically higher grain yield than check CL272, while CL long-grain line 17AYT007 (RU1601133) continued to be the top yielding CL long-grain line, followed by 17AYT034 and 17AYT013 (RU1601099). 17AYT066 is the highest yielding conventional medium-grain line, followed by 17AYT065 and 17AYT069, while 17AYT048 is the highest yielding conventional long-grain line, followed by 17AYT075 and 17AYT080. Some of these lines were selected for purification and increase in 2018.

Significance of Findings

The new AYT trial successfully bridged the gap, between the single location preliminary yield trials with numerous entries and the multi-state or statewide advanced yield trial that can only accommodate a very limited number of entries, by offering the space for the trial of additional elite breeding lines. Our results enable us to verify the findings from other yield trials, and to identify the outstanding breeding lines, which otherwise were excluded from URRN or ARPT trials due to the insufficient space.

Acknowledgments

We would like to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. Technical supports from Emily Carr and Richard Weaver are greatly appreciated.

Table 1. Grain yield of 80 semi-dwarf long- and medium-grain breeding lines and commercial checks in the advanced elite line yield trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark., Pine Tree Research Station (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark. , 2017.

			Grain Yield			
Entry	Pedigree	GT[b]	NEREC	PTRS	RREC	Mean
			(bu/ac)			
17AYT001	CL153	CL	176	199	195	190
17AYT002	CL172	CL	178	193	187	186
17AYT003	CL272	CM	164	223	185	191
17AYT004	Mermentau	L	162	158	168	163
17AYT005	Titan	M	178	197	218	198
17AYT006	MRMT/DMND	L	147	160	191	166
17AYT007	RU1102192/4/WLLS/CFX-18/3/CFX-18//…	CL	164	192	195	184
17AYT008	RU1302048/RU1302045	CL	148	149	191	163
17AYT009	CTHL/RU1002192	L	134	144	192	157
17AYT010	RU1202168/JPTR	CM	136	169	178	161
17AYT011	MRMT/RU0502068	L	153	127	181	154
17AYT012	RU1302045/CL111	CL	160	164	196	173
17AYT013	RU0502068/RU1202088	CL	164	171	194	176
17AYT014	RU1002128/RU1202097	CL	154	168	202	175
17AYT015	RU1102034/RU1202155	CL	145	157	185	162
17AYT016	EARL/9902028//RU1202068	CM	165	160	207	177
17AYT017	RU1202094/RU0902088	CL	170	136	177	161
17AYT018	RU1202168/JPTR	CM	186	195	195	192
17AYT019	RU1102192/4/9502008-A//AR1188/CCDR/3/…	CL	171	153	190	171
17AYT020	MRMT/RU1401044	CL	162	170	184	172
17AYT021	EARL/4/ORIN//MERC/RICO/3/9602134	M	147	122	198	156
17AYT022	JPTR/RU0401136/3/RU9901127/97Y228//…	M	178	113	185	159
17AYT023	CCDR/04CLPY003	CL	174	124	187	162
17AYT024	RU1102034/3/CFX-18//CCDR/9770532 DH2	CL	162	136	185	161
17AYT025	CL172/RU1102034	CL	171	139	209	173
17AYT026	RU1202131/CL172	CL	173	137	192	167
17AYT027	RU1102192/RU1202088	CL	179	157	190	175
17AYT028	RU1202168/JPTR	CM	170	92	190	151
17AYT029	TITN/RU1202168	CM	179	205	198	194
17AYT030	TITN/RU1202168	CM	116	91	187	132
17AYT031	RU1202088/3/CFX-18//CCDR/9770532 DH2	CL	149	132	175	152
17AYT032	RU1202094/RU1102192	CL	155	138	188	160
17AYT033	RU1202097/RU1202088	CL	178	144	205	176
17AYT034	RU1102192/RU1202094	CL	173	157	199	177
17AYT035	RU1102192/RU1202097	CL	155	158	190	168
17AYT036	WLLS/CFX-18//DREW/CFX-18/4/ …	CL	171	168	187	176
17AYT037	WLLS/CFX-18//DREW/CFX-18/3/RU1102034	CL	152	163	165	160
17AYT038	RU1102034/RU1202051	CL	187	114	176	159
17AYT039	RU1302045/CL111	CL	163	162	192	172
17AYT040	MRMT/RU1202088	CL	173	121	174	156
17AYT041	CL151	CL	198	220	200	206
17AYT042	Diamond	L	171	177	212	187
17AYT043	Jupiter	M	166	166	191	174
17AYT044	CL271/JPTR	CM	176	171	181	176
17AYT045	RU1002128/RU1401133	CL	166	163	186	172
17AYT046	12PY833/NPTN	M	150	138	182	157

continued

Table 1. Continued.

Entry	Pedigree	GT[b]	Grain Yield NE	PT	RREC	Mean
			-----------------(bu/ac)-----------------			
17AYT047	ROYJ/RU1302146	L	145	155	172	157
17AYT048	CCDR/JEFF/3/9502008//AR1142/MBLE/4/…	L	151	169	207	176
17AYT049	9502008-A//AR1188/CCDR/3/CPRS/KBNT//…	L	115	128	185	143
17AYT050	RU0902028/RU0802031	L	107	135	185	142
17AYT051	RU1102028/MRMT	L	157	128	180	155
17AYT052	LFTE*2/Sasanishiki	M	109	114	171	131
17AYT053	LFTE*2/Sasanishiki	M	132	108	189	143
17AYT054	JPTR/J062	M	147	114	194	152
17AYT055	JPTR/J062	M	140	144	193	159
17AYT056	BNGL/SHORT RICO/4/9502065/3/BNGL//…	M	146	138	187	157
17AYT057	BNGL/SHORT RICO/4/9502065/3/BNGL//…	M	155	112	181	149
17AYT058	9502008-A//AR1188/CCDR/3/CPRS/KBNT//…	L	127	136	179	147
17AYT059	RU0801093/RU0802031	L	143	120	173	145
17AYT060	EARL/4/9502065/3/BNGL//MERC/RICO	M	161	103	180	148
17AYT061	RU0901121/5/9502008/CPRS/4/NWBT/…	L	146	117	180	147
17AYT062	RU1102034/RU1002128	L	174	133	187	164
17AYT063	RU1102134/5/CPRS/4/9502008/3/CPRS//…	L	141	107	202	150
17AYT064	RU1301133/JPTR	M	143	142	208	164
17AYT065	9902028/3/BNGL//MERC/RICO/4/JPTR	M	163	149	201	171
17AYT066	9865216DH2/EARL//JPTR	M	164	171	229	188
17AYT067	JPTR//EARL/9902028	M	152	150	190	164
17AYT068	JPTR/TITN	M	154	120	195	156
17AYT069	RICO/BNGL//PY678/MARS	M	158	134	217	170
17AYT070	RICO/BNGL//CFFY	M	129	149	197	159
17AYT071	JPTR/3/EARL//BNGL/SHORTRICO	M	143	136	206	162
17AYT072	JPTR/EARL	M	126	109	195	144
17AYT073	MRMT/LKST	L	145	146	203	165
17AYT074	MRMT/DMND	L	153	125	159	146
17AYT075	ROYJ/RU0902140	L	162	169	180	170
17AYT076	RU0802134/RU1202131	L	145	131	188	154
17AYT077	RU1002128/RU0803147	L	153	141	179	158
17AYT078	RU1202131/RU1401136	L	140	136	157	144
17AYT079	RU1301087/CTHL	L	143	124	183	150
17AYT080	RU1301087/RU1202131	L	157	166	186	170
c.v.(%)[a]			15.9	14.4	5.4	12.2
$LSD_{0.05}$			40	34	16	19

[a] c.v. = Coefficient of variance; LSD = least significant difference.

[b] GT = Grain type, CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain.

Table 2. Average seedling vigor (SV), days to 50% heading (HD), plant height (HGT), and milling yields (MY, % head rice/%/total rice) of 2017 advanced yield trial (AYT) conducted at University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark., Pine Tree Research Station (PTRS) near Colt, Ark., and Rice Research and Extension Center (RREC) near Stuttgart, Ark.

Entry	Pedigree	GT[a]	SV[b]	HD	HGT	Milling Yield
					(in.)	%HR/%TR
17AYT001	CL153	CL	3.3	89	40	68/70
17AYT002	CL172	CL	3.6	89	40	67/69
17AYT003	CL272	CM	3.4	88	42	69/71
17AYT004	Mermentau	L	5.3	89	39	66/68
17AYT005	Titan	M	4.1	84	41	70/72
17AYT006	MRMT/DMND	L	4.7	88	44	68/70
17AYT007	RU1102192/4/WLLS/CFX-18/3/CFX-18//…	CL	4.8	90	43	67/70
17AYT008	RU1302048/RU1302045	CL	4.9	89	40	68/71
17AYT009	CTHL/RU1002192	L	5.1	90	41	69/71
17AYT010	RU1202168/JPTR	CM	5.0	90	40	67/69
17AYT011	MRMT/RU0502068	L	5.1	93	40	68/70
17AYT012	RU1302045/CL111	CL	4.6	89	44	67/70
17AYT013	RU0502068/RU1202088	CL	4.4	91	42	68/70
17AYT014	RU1002128/RU1202097	CL	4.4	90	41	69/71
17AYT015	RU1102034/RU1202155	CL	4.7	90	41	68/71
17AYT016	EARL/9902028//RU1202068	CM	5.1	89	41	70/73
17AYT017	RU1202094/RU0902088	CL	4.8	89	43	69/71
17AYT018	RU1202168/JPTR	CM	4.6	87	41	69/71
17AYT019	RU1102192/4/9502008-A//AR1188/…	CL	4.8	87	40	68/70
17AYT020	MRMT/RU1401044	CL	4.8	88	40	68/70
17AYT021	EARL/4/ORIN//MERC/RICO/3/9602134	M	5.4	89	38	68/70
17AYT022	JPTR/RU0401136/3/RU9901127/97Y228//…	M	5.2	87	38	67/71
17AYT023	CCDR/04CLPY003	CL	5.0	89	40	68/70
17AYT024	RU1102034/3/CFX-18//CCDR/9770532 DH2	CL	4.7	93	43	69/71
17AYT025	CL172/RU1102034	CL	4.8	94	42	68/70
17AYT026	RU1202131/CL172	CL	4.8	89	42	67/69
17AYT027	RU1102192/RU1202088	CL	4.4	89	40	66/69
17AYT028	RU1202168/JPTR	CM	5.6	94	41	68/70
17AYT029	TITN/RU1202168	CM	4.7	91	42	66/68
17AYT030	TITN/RU1202168	CM	5.7	89	38	67/69
17AYT031	RU1202088/3/CFX-18//CCDR/9770532 DH2	CL	4.9	90	38	67/69
17AYT032	RU1202094/RU1102192	CL	4.7	88	42	67/70
17AYT033	RU1202097/RU1202088	CL	4.8	89	43	67/70
17AYT034	RU1102192/RU1202094	CL	4.7	86	41	68/70
17AYT035	RU1102192/RU1202097	CL	4.6	88	40	67/70
17AYT036	WLLS/CFX-18//DREW/CFX-18/4/CFX-26…	CL	4.8	89	43	68/71
17AYT037	WLLS/CFX-18//DREW/CFX-18/3/…	CL	5.0	90	42	68/70
17AYT038	RU1102034/RU1202051	CL	4.6	89	41	67/69
17AYT039	RU1302045/CL111	CL	4.8	89	43	65/68
17AYT040	MRMT/RU1202088	CL	4.8	91	40	68/70
17AYT041	CL151	CL	3.3	85	40	68/71
17AYT042	Diamond	L	4.6	90	41	66/69
17AYT043	Jupiter	M	4.6	90	38	68/70
17AYT044	CL271/JPTR	CM	4.7	88	40	69/70
17AYT045	RU1002128/RU1401133	CL	4.4	95	41	67/69
17AYT046	12PY833/NPTN	M	4.8	92	37	69/71

continued

Table 2. continued.

Entry	Pedigree	GT[a]	SV[b]	HD	HGT	Milling Yield
					(in.)	%HR/%TR
17AYT047	ROYJ/RU1302146	L	5.0	91	45	67/70
17AYT048	CCDR/JEFF/3/9502008//AR1142/…	L	4.6	89	43	68/71
17AYT049	9502008-A//AR1188/CCDR/3/CPRS/…	L	5.2	86	40	68/70
17AYT050	RU0902028/RU0802031	L	4.9	88	39	67/69
17AYT051	RU1102028/MRMT	L	4.7	89	40	68/70
17AYT052	LFTE*2/Sasanishiki	M	5.1	83	39	69/70
17AYT053	LFTE*2/Sasanishiki	M	5.2	86	41	69/71
17AYT054	JPTR/J062	M	5.2	92	38	69/70
17AYT055	JPTR/J062	M	5.0	91	38	68/70
17AYT056	BNGL/SHORT RICO/4/9502065/3/BNGL…	M	5.1	88	40	69/71
17AYT057	BNGL/SHORT RICO/4/9502065/3/BNGL…	M	4.9	89	40	70/71
17AYT058	9502008-A//AR1188/CCDR/3/CPRS/…	L	5.1	90	39	68/70
17AYT059	RU0801093/RU0802031	L	5.0	90	38	67/70
17AYT060	EARL/4/9502065/3/BNGL//MERC/RICO	M	5.4	95	36	69/70
17AYT061	RU0901121/5/9502008/CPRS/4/NWBT/…	L	4.9	90	39	67/69
17AYT062	RU1102034/RU1002128	L	4.6	91	41	69/71
17AYT063	RU1102134/5/CPRS/4/9502008/3/CPRS//…	L	5.0	91	40	67/70
17AYT064	RU1301133/JPTR	M	5.1	85	41	69/70
17AYT065	9902028/3/BNGL//MERC/RICO/4/JPTR	M	5.0	88	37	68/70
17AYT066	9865216DH2/EARL//JPTR	M	4.8	87	41	68/71
17AYT067	JPTR//EARL/9902028	M	5.0	91	37	68/70
17AYT068	JPTR/TITN	M	5.2	92	37	69/70
17AYT069	RICO/BNGL//PY678/MARS	M	5.2	89	37	69/70
17AYT070	RICO/BNGL//CFFY	M	5.4	90	37	69/71
17AYT071	JPTR/3/EARL//BNGL/SHORTRICO	M	5.0	90	38	68/70
17AYT072	JPTR/EARL	M	5.6	91	37	69/71
17AYT073	MRMT/LKST	L	4.7	90	46	66/69
17AYT074	MRMT/DMND	L	4.7	90	43	69/71
17AYT075	ROYJ/RU0902140	L	4.7	89	47	68/71
17AYT076	RU0802134/RU1202131	L	4.6	90	43	70/72
17AYT077	RU1002128/RU0803147	L	4.4	94	41	70/72
17AYT078	RU1202131/RU1401136	L	4.8	92	42	69/71
17AYT079	RU1301087/CTHL	L	5.2	97	37	66/69
17AYT080	RU1301087/RU1202131	L	4.8	90	45	67/69
c.v.(%)[c]			10.5	2.4	4.4	1.5/1.1
$LSD_{0.05}$			0.5	2	2	1/1

Abbreviations: GT = Grain type; SV = seedling vigor; HD = heading date; HGT = height.

[a] GT = Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, L = conventional long-grain, and M = conventional medium-grain;

[b] SV = seedling vigor; a subjective rating 1-7 taken at emergence, 1 = excellent stand and 7 = no stand.

[c] Coefficient of variance.

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South

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Abstract

To reflect the recent changes of the state rice industry and streamline the delivery of new and improved rice varieties to the Arkansas rice growers, the new medium-grain rice breeding project will expand its research areas and breeding populations to include both conventional and Clearfield medium- and semidwarf long-grain rice, as well as hybrid rice. Newest elite breeding lines/varieties from collaborating programs, as well as lines with diverse genetic origins will be actively collected, evaluated, and incorporated into the current crossing blocks for the programmed hybridization. To improve the efficiency and effectiveness, maximum mechanized-operation, multiple generations of winter nursery, and new technologies such as molecular marker-assisted selection (MAS) will also be rigorously pursued.

Introduction

Medium-grain rice is the important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2007-2016, an average of 0.17 million acres' medium-grain rice was grown annually, which makes up about 13% of total state rice acreage (USDA-ERS, 2017). Planted acres of medium-grain rice in Arkansas in the last decade have varied from a high of 243,000 acres in 2011 (21% of total rice planted in Ark.) to a low of 99,000 acres in 2008 (7% of total rice planted in Ark.).

A significant portion of Arkansas rice area was planted to semi-dwarf long-grain varieties, such as CL151, CL153, CL172, and Cheniere. However, locally developed

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semi-dwarf varieties offer advantages including better stress tolerance and more stable yields. Improved semi-dwarf long-grain lines can be also directly adopted by the newly established hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts should and have to continue.

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

Procedures

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection (MAS) will be carried out on backcross or top-cross progenies on simply inherited traits such as blast resistance and physicochemical characteristics. Segregating populations are planted, selected, and advanced at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. and the winter nursery in Lajas, Puerto Rico. Pedigree and modified single seed descent will be the primary selection technology employed. A great number of traits will be considered during this stage of selection including grain quality (shape and appearance), plant type, short stature, lodging resistance, disease (blast, sheath blight, and panicle blight) resistance, earliness, and seedling vigor. Promising lines having a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Small size sample milling, as well as the physicochemical analysis at the Riceland Foods Inc. Research and Technology Center, are conducted to eliminate lines with evident quality problems and/or to maintain standard U.S. rice quality of different grain types. Yield evaluations include the Stuttgart Initial Yield Trial (SIT) and Clearfield SIT (CSIT) at the RREC , the Advanced Elite Line Yield Trial (AYT) at the RREC, University of Arkansas System Division of Agriculture's Pine Tree Experiment Station (PTST) near Colt, Ark., and University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, the Arkansas Rice Performance Trials (ARPT) carried out by Jarrod Hardke, the rice extension specialist , at six locations in the rice growing regions across the state, and the Cooperative Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in California, Louisiana, Mississippi, Missouri, and Texas. Promising advanced lines will be provided to cooperating projects for the further evaluation of resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT or CSIT and beyond will be planted as head rows for purification and increase purposes.

Results and Discussion

A great number of breeding populations have been created and rapidly advanced since 2013 when the senior author was hired. The field research in 2017 included 789 transplanted F_1 populations, 933 space-planted F_2 populations, and 59,548 panicle rows ranging from F_3 to F_7. Visual selection on approximate 750,000 individual space-planted F_2 plants resulted in a total of 34,000 panicles, which will be individually processed and grown as F_3 panicle rows in 2018. From 59,548 panicle rows, 3550 were selected for advancement to next generation, while 1797 rows appeared to be uniform and superior to others, therefore were bulk-harvested as candidates of 2018 SIT or CSIT trials. In 2017 the Clearfield (CL) preliminary yield trial (CSIT), evaluated 638 new breeding lines which included 546 semi-dwarf CL long-grain and 92 CL medium-grain lines. Whereas, 462 new semi-dwarf breeding lines were tested in the SIT trial, which consist of 282 long-grain and 180 medium-grain lines. Marker-assisted selection (MAS) was conducted on all preliminary yield trial entries by using 11 SSR and SNP molecular markers for physicochemical characteristics and blast resistance genes. An 80-entry Advanced Elite Line Yield Trial (AYT) was conducted at the NEREC and PTRS in addition to the RREC. A number of breeding lines showed the yield potential similar to or better than the check varieties (Tables 1-4). Thirty advanced breeding lines were evaluated in the multi-state URRN and/or statewide ARPT trials. Results of those entries and selected check varieties were listed in Table 5. Three Puerto Rico winter nurseries consisting of a total of 12,000 rows were planted, selected, harvested and/or advanced throughout 2017. A total of 964 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes, which included 224 CL long-grain, 128 CL medium-grain, 166 semi-dwarf conventional long-grain, and 146 conventional medium-grain crosses. In addition, we also made 70 single crosses, 65 testcrosses, 161 backcrosses for hybrid rice breeding, and 4 single crosses for the development of mapping populations for heat tolerance traits.

The first conventional medium-grain variety 'Titan' developed by the RREC in more than a decade performed well in its first year of production. Titan matures about six days earlier than Jupiter and has excellent yield potential, good milling and grain quality, and improved blast resistance. Small-scale foundation seed increases of semi-dwarf CL long-grain lines 16AR1111 (RU1601111) and 16AR1133 (RU1601133), as well as CL medium-grain line 16AR1030 (RU1601030) will be conducted by Horizon Ag (Memphis, TN). Both breeder seed and breeder head rows of the conventional semidwarf long-grain line 16AR1124 (RU1601124) and conventional medium-grain line 17AR1124 (RU1701124) will be produced at the RREC in summer of 2018 for potential release. One hundred and eighty four breeding lines that outperformed commercial check varieties in the AYT, CSIT, and SIT trials were selected and were further evaluated in the laboratory before entering 2018 ARPT and/or URRN trials.

Significance of Findings

Successful development of the medium-grain variety Titan offers producers options in their choice of variety and management systems for Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

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Literature Cited

USDA-ERS. 2017. 2017 Rice Yearbook. Available at: http://www.ers.usda.gov/data-products/rice-yearbook/

Walton, M. 2003. Hybrid rice for mechanized agriculture. pp. 97-102. *In:* S.S. Virmani, C.X. Mao, and B. Hardy (eds.). Hybrid Rice for Food Security, Poverty Alleviation, and Environmental Protection. International Rice Research Institute, Los Baños, Philippines.

Table 1. Performance of selected Clearfield long-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2017.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/ac)	(%)	(%)
17CSIT056[b]	CL172/4/9502008-A//AR1188/CCDR/3/CFX-26/…	3.5	80	109	244	n/a	n/a
17CSIT368[b]	RU0902088/4/WLLS/CFX-18/3/CFX-18//CCDR/…	4.0	80	111	244	50.9	69.6
17CSIT580[c]	ROYJ/RU1501024	3.5	73	110	242	60.9	69.7
17CSIT407[b]	RU1302045/RU1102192	3.0	82	109	240	61.5	71.5
17CSIT615[c]	RU1102131/14CSIT203	4.0	74	100	239	55.4	70.2
17CSIT398[b]	RU1102034/RU1302045	4.0	82	111	235	60.2	67.4
17CSIT012[b]	CCDR/9502008-A/3/CFX-18//CCDR/9770532 DH2	3.0	83	106	234	63.9	70.3
17CSIT335[b]	RU1302045/RU1102028	4.0	82	111	230	n/a	n/a
17CSIT496[c]	CTHL/CL172	4.0	75	101	229	62.7	71.9
17CSIT010[b]	CCDR/JEFF/3/CFX-18//CCDR/9770532 DH2	4.0	85	109	229	63.6	70.7
17CSIT500[c]	RU1102031/CL172	4.0	73	107	229	52.0	70.5
17CSIT011[b]	CCDR/9502008-A//CFX-26/9702128	3.5	82	105	228	61.0	69.3
CL151[b]	CL151	3.0	83	106	230	62.7	69.5
CL153[b]	CL153	3.0	82	105	220	62.0	69.6
CL172[b]	CL172	3.0	83	98	213	56.7	63.8

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 19 April.
[c] Planted on 15 May.

Table 2. Performance of selected Clearfield medium-grain experimental lines and check varieties in the Clearfield Stuttgart Initial Trial (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2017.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/ac)	------------%------------	
17CSIT552[c]	14SIT818/RU1501096	4.5	74	105	251	46.8	65.8
17CSIT562[c]	RU1301124/CL261	4.0	73	107	248	57.2	68.3
17CSIT538[c]	TITN/RU1501096	4.0	71	103	246	49.5	65.1
17CSIT551[c]	14SIT818/RU1501096	4.0	73	108	243	52.1	67.1
17CSIT200[b]	JPTR/CL261	4.0	82	106	242	57.6	67.2
17CSIT537[c]	TITN/RU1501096	4.0	69	101	242	n/a	n/a
17CSIT539[c]	TITN/RU1501096	4.0	72	112	237	54.8	68.9
17CSIT543[c]	RU1401111/RU1501096	4.5	71	109	226	46.5	66.5
17CSIT352[b]	EARL/9902028//RU1202068	3.5	86	101	225	45.6	68.3
17CSIT535[c]	TITN/RU1501027	4.0	74	113	225	48.2	67.3
17CSIT563[c]	RU1301124/CL261	5.0	73	111	223	n/a	n/a
17CSIT310[b]	CL261/RU1301121	3.5	79	117	223	61.2	68.1
17CSIT531[c]	CFFY/RU1501027	4.0	75	107	222	n/a	n/a
CL153[b]	CL153	3.0	82	105	220	62.0	69.6
CL272[b]	CL272	3.5	88	112	208	55.1	66.0

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 19 April.
[c] Planted on 15 May.

Table 3. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2017.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields Head rice	Milling yields Total rice
				(cm)	(bu/ac)	---------------%---------------	
17SIT803[c]	RICO/BNGL//RU0602162/RU0502031	4.0	74	98	257	54.2	68.7
17SIT807[c]	9502065/3/BNGL//MERC/RICO/5/LFTE/4/…	4.0	75	101	254	63.4	69.3
17SIT802[c]	RICO/BNGL//RU0602162/RU0502031	4.0	75	103	250	65.8	68.9
17SIT823[c]	JPTR/3/EARL//BNGL/SHORTRICO	4.0	76	105	246	52.5	68.7
17SIT804[c]	RICO/BNGL//CFFY	4.0	77	99	246	60.9	69.3
17SIT832[c]	JPTR/EARL	4.5	76	94	244	40.8	67.5
17SIT925[c]	RU1001067/JPTR	4.0	74	94	240	48.1	64.9
17SIT826[c]	JPTR//9865216DH2/EARL	3.5	74	109	239	n/a	n/a
17SIT836[c]	RU1001067/RU0602171	4.0	77	101	238	62.8	68.7
17SIT926[c]	RU1001067/JPTR	4.0	77	97	238	44.7	66.3
17SIT775[b]	9865216DH2/EARL/5/9865216DH2/4/ORIN//…	4.0	87	111	213	41.2	65.7
17SIT568[b]	JPTR/RU1001099	5.0	93	105	212	60.6	67.6
Caffey[c]	Caffey	3.0	78	109	226	62.3	66.0
Jupiter[c]	Jupiter	3.0	76	103	223	64.3	67.8
Titan[b]	Titan	5.0	90	101	204	55.7	68.5

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] planted on 15 May.

Table 4. Performance of selected conventional long-grain experimental lines and check varieties in the Stuttgart Initial Trial (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2017.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/ac)	-----------%-----------	
17SIT897[c]	ROYJ/RU1102192	4.5	80	110	234	53.4	67.3
17SIT910[c]	RU1102034/RU1201108	4.0	77	102	232	50.2	66.7
17SIT905[c]	RU0802134/RU1301087	4.0	79	115	228	61.7	71.1
17SIT917[c]	RU1301087/CTHL	5.0	78	101	224	57.0	69.7
17SIT900[c]	RU0902125/RU1301084	5.0	79	117	224	56.4	70.5
17SIT889[c]	ROYJ/RU0902140	4.5	82	94	223	55.3	69.6
17SIT912[c]	RU1102131/RU1301087	4.0	81	99	222	62.4	70.6
17SIT934[c]	RU1202131/TGRT	4.5	80	117	214	52.7	68.5
17SIT879[c]	MRMT/RU1102192	4.0	73	120	213	n/a	n/a
17SIT626[b]	RU0502068/RU1002137	4.0	89	104	212	61.2	71.3
17SIT546[a]	RU1102034/RU1002128	4.5	93	105	208	61.5	71.4
Cheniere[c]	Cheniere	3.0	78	100	190	66.4	72.1
CL153[b]	CL153	3.0	92	94	194	62.0	69.6
Diamond[b]	Diamond	4.0	91	108	213	57.5	67.5
LaKast[c]	LaKast	4.5	90	122	213	56.4	69.1
Roy J[b]	Roy J	4.0	94	114	196	60.3	69.4

[a] A subjective 1-7 rating taken at emergence, 1 = perfect stand and 7 = no stand.
[b] Planted on 5 April.
[c] Planted on 15 May.

Table 5. Average yield, milling, and agronomic characteristics of selected experimental long-grain and medium-grain lines and check varieties tested in the Uniform Regional Rice Nursery (URRN) in Arkansas, Louisiana, Mississippi, Missouri, and Texas, 2017.

Entry	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling yields: Head rice	Milling yields: Total rice
				(cm)	(bu/ac)	(%)	
RU1601030	RU1202168/JPTR	CM	91	105	201	64.1	69.6
RU1701050	CL271/JPTR	CM	89	98	204	64.7	68.5
RU1701136	EARL/9902028//RU1202068	CM	89	104	209	59.1	72.5
RU1501024	CL111/3/CCDR//9502008/LGRU	CL	86	99	202	61.3	70.6
RU1601099	RU0502068/RU1202088	CL	90	110	198	62.7	72.7
RU1601111	RU1302048/RU1302045	CL	88	96	183	61.3	71.0
RU1601133	RU1102192/4/WLLS/CFX-18/3/CFX-18//CCDR/9770532 DH2	CL	90	102	208	64.5	71.1
RU1701096	CL172/RU1102192	CL	86	106	197	64.4	72.8
RU1701121	EARL/9902028//JPTR	M	89	100	208	63.5	69.6
RU1701124	JPTR/TITN	M	85	99	219	63.8	70.0
RU1701127	JPTR/J062	M	92	101	210	65.3	69.2
Jupiter	Jupiter	M	90	98	207	61.7	67.9
Titan	Titan	M	84	107	221	62.6	70.0
CL153	CL153	CL	88	96	193	61.7	71.3
CL172	CL172	CL	89	94	176	61.0	70.7
CL272	CL272	CM	90	108	201	62.0	70.3
Diamond	Diamond	L	87	105	222	57.6	70.3

[a] CL = Clearfield long-grain, CM = Clearfield medium-grain, L = long-grain, and M = medium-grain.

Developing Hybrid Parental Lines

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Abstract

In 2010, the University of Arkansas System Division of Agriculture, established the rice hybrid program to develop very high yield rice hybrids with good seed quality for the mid-Southern United States. In 2017 potential environment sensitive male-sterile lines (EGMS) possessing genes associated with good cooking quality for the "Two-line hybrid rice system" were developed. We continued developing several restorer lines (R line) for the "Three-line hybrid rice system". Hybrid (F_1) seeds were produced from crosses between the U of A male-sterile lines and Arkansas elite cultivars. Experimental hybrid lines developed during the summer of 2016 were evaluated for yield and quality characteristics. Combinating ability of experimental male-sterile lines was evaluated in a heterosis study. New sources of Environmental genic male-sterile lines were introduced from the International Rice Research Institute (IRRI) in the Philippines. Several advanced lines from the long and medium grain programs were selected to be used in hybrid rice development. Extensive phenotypic and molecular evaluations were completed to improve disease resistance and cooking quality, and to identify semi dwarf, non-aromatic plants.

Introduction

In the last decade, farmers in Arkansas grew more hybrid rice due to its performance and durable resistance/tolerance to biotic and abiotic stresses (Lyman and Nalley, 2013). Hybrid rice is a commercially grown crop of F_1 seed resulting from a cross between two genetically diverse pure-line parents (Virmani et al., 2003). There are two systems for hybrid rice production a two-line and three-line system (Virmani et al., 2003). The two types of male sterility are utilized for F_1 hybrid production in rice. In the first one, the two-line system, is known as an environment-sensitive genetic male-sterile (EGMS), the sources of sterility are several genes, in which the expression is regulated by specific environmental conditions. In the second type, known as cyto-

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plasmic male-sterile (CMS), the three –line system, the sterility results from specific nuclear and mitochondrial interactions. Large-scale production of hybrid seed is made possible via male-sterile lines, which are developed to serve as the female parents. The F_1 plants resulting from a cross of male-sterile × male parent demonstrate higher yield compared to the parents due to a phenomenon known as "Heterosis". Seed yield is the foremost goal in hybrid rice production. Several studies showed that heterosis effectively influences several yield components such as panicle number and spikelet number (Amandakumar and Sreehangasamy, 1984; Chang et a1., 1971, 1973; Devarathinam 1984).

Procedures

Field Study

The male-sterile plants and male parents were planted in two areas namely an isolated field and a crossing block, respectively on three dates. The isolated field was more than 200 feet from the closest rice field, and was surrounded by soybean fields. We planted corn around the isolated field to provide a natural wind barrier to help prevent possible outcrossing between the male-sterile and other rice. No outcrossing was observed during the summer of 2017. During crossing season, we transferred the male-sterile plants from the isolated field to the crossing block and planted them within the selected male parent's plot. Two provision were utilized for preventing any outcrossing first, the male-sterile plant had to be shorter than the male parent, and second we set up pollen tents that isolated the plots from the rest of the crossing block. To build a pollen tent suitable for rice, several factors were considered. The structure of pollen tent needed be resistant to wind and rain, light weight, and affordable. The mesh should block entry of unwanted pollen into the tent, allow air flow into the tent to help control temperature and diseases, and be inexpensive. In 2017, we set up 25 of these tents, each was placed on a plot for 7-10 days.

Heterosis Study

We planted F_1 seeds from each combination made in 2016 in a yield trial with three replications. Several phenotypic characteristics were recorded during planting season including plot uniformity, heading date, 50 percent heading date, plant height, shattering, lodging, plant type, 10 plant seed yield and plot yield. The results revealed that evaluation of a hybrid line based on 10-15 single plant was not consistent with the plot evaluation.

Evaluation F_2 generation

More than 4100 F_2 plants from 2016 crosses of 236s, 805s, and 811s with 17 high yielding, semi dwarf, and non-aroma cultivars or advanced lines, developed to produce new male-sterile lines, for new two line system, were grown in the greenhouse and evaluated for agronomic traits such as amylose content, disease resistance and plant height. They were also tested in the field for sterility. Two thousand five hundred F_2 plants from crosses between several University of Arkansas R lines (351R, 367R, 394R, and 396R) with high yielding, semi dwarf, and non-aroma cultivars or advanced lines, for the three line system, were also evaluated in the greenhouse for these traits.

Results and Discussion

In 2017 we focused on developing hybrid parental lines for both the two lines and three-lines system as well as evaluating the combination ability and productivity of hybrids from the 2016 crosses between BC_1F_3 male-steriles and several cultivars. The result of these activities follow.

Two-line System

A total 191 lines from two BC_1F_4 populations between 236s by RU1201102 and Francis were tested in field conditions during the summer of 2017 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Previously, these lines had been tested and selected based on good cooking quality and several agronomic traits via a molecular study. Each plot was evaluated based on phenotypic characteristics such as uniformity, heading date, plant height, plant type, number of panicle per plant, stiff straw, overall panicle exertion, seed size, and % sterility of the first panicle.

Uniformity of plant height, plant type, or seed size in some BC_1F_4 plots improved. The results showed that 71% of BC_1F_4 plots were uniform and 28% were segregating for one or more of traits mentioned above. However, the rate of segregation within a plot was relatively small (≈ 3-5% total plants/plot). The plant type has improved compare to the previous generation, and about 80% of BC_1F_4 lines were erect with stiff straws. We evaluated the BC_1F_4 plots for plant height and grouped them into three classes of short (< 40 inches), medium (40 – 45 inches), and tall (> 45 inches). The results showed that 36% of BC_1F_4 lines were short, 58% were medium, and 6% were segregating. We traced back these segregated lines and found that they came from two BC_1F_3 plots which segregated for plant height. There were both medium and long-grain plants among the populations. Previous molecular studied showed that the gene associated with medium grain came from 236s while the gene associated with long grain came from Francis and RU1201102.

Synchronization of heading date between male-sterile plants and advanced cultivars is one of the main challenges in hybrid rice production. The heading date of BC_1F_4 lines ranged from 75 to 95 days. That provide a great opportunity to group BC_1F_4 lines into four groups based on heading date <80, 81-85, 86-90, and 90-95 days. In 2018, we will select the superior male-sterile lines from each of these four groups. At the end of 2017 growing season, a total of 41 BC_1F_4 lines were selected, ratooned and seeds from each plot were harvested as BC_1F_5 seeds.

A total 47 BC_1F_3 lines from four populations from the crosses between 236s and 811s, with Francis, Cocodrie, and RU1201102, were grown in a field in 2017 at the RREC. These lines were derived from 47 BC_1F_2 plants which were evaluated via a molecular study for cooking quality, disease resistance, and the semi dwarf trait. The lines were space planted, so it was easier to evaluate each BC_1F_4 single plant within a plot. Each plot was evaluated for heading date, uniformity, overall plant type, shattering, lodging, and overall plant height, which was an average height of three plants randomly selected within a plot. The single plants from each plot were evaluated based on plant type, stiff straw, percentage of sterility, panicle exertion rate, and seed size. A total 184 BC_1F_3 plants were selected, ratooned, and transferred to the greenhouse to get BC_1F_4 seeds.

Three-hundred fifty F_2 plants were selected from the 4100 plants in the greenhouse and field for development of new two line system male-steriles, the selected F_2 plants were ratooned to produce F_3 seeds, which will be planted in summer 2018.

Three-line System

Developing Maintainer Lines. Currently we are growing the BC_1F_1 plants resulting from cross with 873B which will be backcrossed with its correspondent maintainer line in greenhouse condition in 2018. A number of crosses between U of A maintainer (B) and restorer (R) and high yield, semi dwarf, and non-aroma cultivars or advanced lines were made for developing B and R lines which will be used for three line hybrid production. The F_1 plants will be grown in a greenhouse and will be crossed with their corresponded B and R line to get BC_1F_1 seeds.

Developing Restorer Lines. More than 2500 F_2 single plants for R line development were grown in a greenhouse and tested for several agronomic traits. More than 400 F_2 plants were selected. The F_3 seeds were sent to the winter nursery for advancement and the F_4 populations will be tested for their crossing ability with CMS lines in the summer 2018. Furthermore, we made several crosses to develop new restorer lines as described in 2016. The F_1 plants will be planted in greenhouse in January-February 2018.

Heterosis Study. To analyze the percentage of cross combinations, several BC_1F_3 plants from the plots mentioned above, along with 811s plants, a male-sterile line developed by RREC, were crossed with Arkansas long grain cultivars or advanced lines. Overall, there were 33 combinations with 811s and 26 combinations with the BC_1F_3 plants resulting in 61 new hybrid lines. The F_1 (hybrid) seeds were carefully collected from each female (male-sterile) plant. The F_1 seeds (hybrid seeds) along with their male parental lines were planted in a field condition in 2017 to evaluate hybrid performance.

More than 35% of hybrids resulting from 811s severely lodged while none of experimental hybrid rice resulting from BC_1F_3 lines lodged. Fifteen experimental rice hybrids including four resulting from 811s and 11 from BC_1F_3 produced higher yields (8.9 to 53.1%) compare to Lakast, which performed better than other checks. The results revealed that the hybrids resulting from the experimental BC_1F_3 showed improved phenotypic characteristics over 811s hybrid lines. All experimental BC_1F_3 demonstrated better stands, larger panicle size, stiff straw, better plant type, and no lodging compare the 811s hybrid lines (Table1). Moreover, heading dates ranged between 82-92 days.

Phenotypic Evaluation. There was a significant plant height reduction observed (18.7cm) between BC_1F_3 male-sterile hybrid lines (133.3cm) compare to 811S hybrid lines (152.0cm). Such plant height reduction can be attributed to from BC_1F_3 male-sterile's semi dwarf genes. The results revealed that majority of BC_1F_3 hybrids demonstrated sturdy straw and as a result, no lodging in these experimental hybrids was observed. Generally, the 811s hybrid lines showed weak straw and as a result, severe lodging was observed. It should be noted that a severe thunderstorm resulting from hurricane Harvey affected rate of lodging in these cultivars.

We observed improved plant type in the B_1F_3 experimental hybrids. All except one line of the BC_1F_3 experimental hybrid lines were classified in groups as erect or intermediate. These results showed that the process of selection for desirable plant type in the BC_1F_3 male-sterile line was successful. In contrast, the majority of 811s hybrids were classified in groups of semi-erect or lodged.

Yield Performance. Milling yield was evaluated. The standard % total milling yield (% head rice + broken rice) of a desirable rice line is ≥70. The milling number of all BC_1F_3 hybrid lines ranged from 72.8/89.7 for total rice. This result showed a considerable outperformance of several BC_1F_3 hybrid line compare to 811s and the checks. The result also showed that the percent total head rice (whole kernels + ¾ kernel and greater) in BC_1F_3 hybrid lines was above 60% for all of the lines outperforming the checks.

The results showed that 15 experimental hybrid rice lines produced higher rough rice grain-yields than checks, ranging from 8.7% to 27.5% greater yield over the checks. Of 15 experimental hybrid rice, 12 were BC_1F_3 hybrids. This result showed that the new male-sterile has genes associated with heterosis for yield (Table 1).

Evaluation of Seed Characteristics. The ratio of seed length to width for long-grain rice should be above 3.0. Our results showed that except for one line (L/W = 2.70), the L:W ratio of all BC_1F_3 hybrid lines were above 3.0 ranging from 3.22 to 3.73. Except for two of the 811s hybrid lines, the L:W ratio was above 3.0 ranging from 3.13 to 3.71.

Chalk is one of the major challenges in rice breeding. In our breeding program the threshold for chalkiness is ≤2. All BC_1F_3 hybrid lines, except for two, had chalkiness below two. In this group of hybrid lines the chalk number of four were below 0.5 and two lines were below 1.5 which is considerably better than the results from the checks. It can be assumed that such improvement is related to the genes associated with low chalk in Francis and RU1201102. .In addition, the chalk number of more than 54% of 811s hybrids were above 2.

Evaluation of Eating Characteristics. Amylose content one of the important traits associated with eating quality is classified in three groups: low amylose (12-19%), intermediate (20-25%), and high amylose (≥26%). Long-grain hybrid rice like long grain rice, needs to have an intermediate amylose content. The results should 72% of BC_1F_3 hybrid lines had intermediate amylose content. In addition the amylose content of two other lines were above 19.5 which still can be considered for further in the breeding program. This is a great achievement in our hybrid breeding program since the eating quality especially amylose content has been one of the major issues in hybrid rice development. Such improvement is a result of genetic improvement of the BC_1F_3 male-sterile line. About 39% of 811s male-sterile lines had intermediate amylose content. Looking at the check, as expected that the medium grain cultivars exhibited low amylose content between 13-15%. Three long grain checks fall into the intermediate category.

Another important eating characteristics is gelatinization temperature which has an acceptable range for long-grain rice between 70-75 °F and for medium grain 60 to 65

°F. The results showed in gelatinization temperature for 13 BC_1F_3 hybrid lines between 70 to74, seven lines between 69.4 to 69.9 and two line were between 68.7% to 69%. Majority of 811s hybrids also had an acceptable gelatinization temperature.

We crossed two male-sterile lines of 236s and 811s and several plants from the experimental BC_1F_4 population with a number of high yield, semi dwarf, and non-aroma cultivars or advanced lines to produce F_1 (hybrid seeds). We collected F_1 seeds from these crosses. The F_1 plants will be grown and evaluated next year through a heterosis study in summer 2018.

Significance of Findings

We have developed a male-sterile line that comprises genes associated with several agronomic traits such as semi-dwarf, lodging and shattering, seed size, aroma, medium amylose content, intermediate gelatinization temperature, and disease resistance. A heterosis study showed that several experimental hybrid rice resulted from this male sterile line and several rice cultivars produced high seed yield with good milling and typical southern U.S. cooking quality. Seeds from the superior experimental hybrid rice soon will be increased in summer 2018 and will be used for the Arkansas Rice Performance Trial.

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Literature Cited

Amandakumar, C.R. and S.R Sreehangasamy. 1984. Studies on heterosis in rice hybrid involving different dwarfs. Madras Agric. J. 713:189-190.

Chang, W., E. Lin, and C. Yang. 1971. Manifestation of hybrid vigor in rice. J. Taiwan Agric. Res. 20:8-23.

Devarathinam, A.A. 1984. Study of heterosis in relation to combining ability and per se performance in rainfed rice. Madras Agric. J. 71:568-572.

Lyman, N. and L.L. Nalley. 2013. Economic analysis of hybrid rice performance in Arkansas. Agron. J. 105:977-988.

Virmani, S.S. 2003. Advanced hybrid rice research and development in the tropics. pp. 7-20 *In*: S.S. Virmani, C. X. Mao, B. Hardy (eds). Hybrid rice for food security, poverty alleviation, and environmental protection.

Table 1. Agronomic data for 24 experimental hybrids and check cultivars grown at the Rice Research and Extension Center in 2017.

Entry	Gener.	Hybrid Combin.	Germin. date	Days to head.	Stiff straw	Plant ht.	Seg.	Plant shape (1-7)	Lodg.	Shatter.	Yield	bu/ acre	Yield
			(day)	(days)	(1-7)	(in.)				(1-7)	(g/plot)		(%)
1	BC1F3	Roy J/KM MS	5/1/2017	87	1	54.8	N	1	N	1	5565.0	236.7	27.53
2	BC1F3	RU1501176/ KM MS	5/1/2017	90	3	51.5	N	1	N	1	5501.4	215.6	16.16
3	BC1F3	Francis/KM MS	5/1/2017	87	1	53.1	Y	1	N	1	5203.5	211.7	14.06
13	BC1F3	RU1501007/ KM MS	5/1/2017	87	3	52.0	Y	3	N	1	5283.3	209.66	12.96
4	MS	RU1401067/811s	5/1/2017	84	3	58.3	Y	5	N	3	5050.2	203.9	9.86
5	BC1F3	STG13L-19- 248/KM MS	5/1/2017	85	3	53.1	Y	3	N	1	5002.5	221.42	19.30
6	BC1F3	Taggart/KM MS	5/1/2017	90	3	56.7	Y	1	N	3	4925.9	231.71	24.84
7	BC1F3	STG13L-18- 255/KM MS	5/1/2017	83	1	52.2	Y	3	N	1	4922.0	193.63	4.33
8	BC1F3	RU1501139/ KM MS	5/1/2017	92	1	55.7	Y	1	N	1	4865.4	193.63	4.33
10	MS	RU1501148/811s	5/1/2017	83	3	60.35	N	5	Y	1	4681.5	197.12	6.21
11	BC1F3	STG13L-24- 085/KM MS	5/1/2017	87	3	50.8	Y	1	N	1	4444.8	226.93	22.27
12	BC1F3	KM MS/ RU1501176	5/1/2017	84	1	53.4	Y	1	N	1	5520.4	210.77	13.56
13	BC1F3	Mars/KM MS	5/1/2017	90	3	62.6	Y	1	N	1	4120.2	216.1	16.43
14	MS	CPRS/811s	5/1/2017	87	1	52.4	Y	3	N	3	4113.9	201.83	8.74
15	MS	Lakast/811s	5/1/2017	82	3	59.0	N	5	Y	1	3957.8	213.47	15.02
*	Check	Lakast	5/1/2017	86	3	47.0	Y	1	N	1	4549.0	185.6	0.00
*	*DD50*	Lakast	5/2/2017	*	*	*	*	*	*	*	*	180	-3.02
*	Check	Titan	5/1/2017	86	1	37.4	N	3	N	1	*	178.8	-3.66
*	*DD50*	Titan	5/2/2017	*	*	*	*	*	*	*	*	186	0.22

Abbreviations: Gener. = generation; Hybrid Combin. = hybrid combination; Germin. = germination; head. = heading; Plant ht. = plant height; Seg. = segregation; Lodg. = lodging; Shatter. = shattering.

ARoma 17, an Aromatic Jasmine-Type, Long-Grain Rice Variety

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Abstract

ARoma 17, a new high yielding Jasmine-type aromatic, mid-season, long-grain rice cultivar, originated from the cross 'Jazzman'/PI 597046. The aromatic line has been approved for release for the 2018 growing season. ARoma 17 offers a Jasmine-type rice adapted to Arkansas growing conditions for rice producers who want to serve that consumer market.

Introduction

ARoma 17 was developed in the rice improvement program at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark. and has been released for the 2018 growing season. ARoma 17 has good milling yield and is similar in maturity and plant height to 'Jazzman-2'. ARoma 17 was advanced with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

Procedures

ARoma 17 rice (*Oryza sativa* L.) is a high yielding Jasmine-type aromatic, mid-season, long-grain rice cultivar developed by the Arkansas Agricultural Experiment Station. ARoma 17 originated from the cross Jazzman/PI 597046 (cross number 20090392), made at the RREC in 2009. The name, ARoma 17, was derived from the two-letter designation of Arkansas (AR), and the aromatic characteristic of the line, and the year of 2017 when it was selected for release. Jazzman is a high yielding, con-

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ventional height, Jasmine-type aromatic, long-grain rice with very good milling and excellent grain quality developed at Crowley, La. (Sha et al., 2011). PI 597046 is a plant introduction donated 1994 by R. Zeiger of IRRI (PI 597046, 1994). The experimental designation for early evaluation of ARoma 17 was STG12L-30-145, starting with a bulk of F5 seed from the 2012 panicle row L-30-145. ARoma 17 was observed in the Arkansas Rice Performance Trials (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN) from 2014 to 2017 as entry RU1401105 (RU number specifies Cooperative Uniform Regional Rice Nursery; 14 recognizes the year entered was 2014; 01 is the Stuttgart, Ark. designation; and 105 identifies the entry number).

In 2014, the ARPT was conducted at four locations in Arkansas: RREC; University of Arkansas System Division of Argriculture's Pine Tree Experiment Station (PTES), near Colt, Ark.; Clay County producer field (CL CO) near Corning, Ark.; and Desha County producer field (DE CO) near Dumas, Ark. In 2015, the tests were conducted at RREC; University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark.; PTES; CL CO; and DE CO. In 2016, the ARPT was conducted at RREC; NEREC; PTES; University of Arkansas System Division of Agriculture's Newport Experiment Station (NES), Newport, Ark.; and CL CO. In 2017, RREC; NEREC; PTES; CL CO; and DE CO were the ARPT locations. The yield trials had four replications per location to reduce soil heterogeneity effects and to decrease the amount of experimental error. ARoma 17 was also grown in the URRN at the RREC; Crowley, La.; Stoneville, Miss.; Beaumont, Texas; and Malden, Mo. from 2014 to 2017. The URRN had three replications per location. Data collected from these trials included plant height, maturity, lodging, percent head rice, percent total rice, grain yield adjusted to 12% moisture, and disease reaction information. Cultural practices varied to some extent among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service Rice Production Handbook MP192 (CES, 2013). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development of specific diseases, have been reported on a scale from 0 = least susceptible to 9 = most susceptible, or as very susceptible (VS), susceptible (S), moderately susceptible (MS), moderately resistant (MR), and resistant (R). Straw strength is a relative estimate based on observations of lodging in fields trials using the scale from 0 = very strong straw to 9 = very weak straw, totally lodged.

Results and Discussion

Rough rice grain yields of ARoma 17 have been consistently outstanding in the ARPT. In 19 ARPT yield trials from 2014 to 2017, the average yield of ARoma 17 was 163 bu/acre (Table 1). In 2014 (the only year other aromatic lines were entered in the ARPT), ARoma 17, Jazzman-2, and 'CL Jazzman' averaged yields of 173, 171, and 164 bu/acre, respectively. Data from the URRN conducted at Arkansas during 2014 to 2017, showed ARoma 17 had an average grain yield of 172 bu/acre, compared to the average yield of Jazzman-2 and 'Della-2' at 144 and 162 bu/acre, respectively (Table

2). The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. ARoma 17 milling yields from 14 ARPT yield trials (2014 to 2016) averaged 67/71 %HR/%TR (Table 1). In 2014 (the only year other aromatic lines were entered in the ARPT), milling yields of ARoma 17, Jazzman-2, and CL Jazzman averaged 69/72, 68/71, and 67/71, respectively. Milling yield (%HR/%TR) reports from the URRN in Arkansas during the same time period, 2014 to 2017, averaged 66/71, 63/68, and 62/68, respectively for ARoma 17, Jazzman-2, and Della-2 (Table 2).

ARoma 17 is a mid-season variety similar in maturity to Jazzman-2. ARoma 17 has excellent straw strength comparable to 'Roy J', 'Taggart', and 'Wells', according to 2016 ARPT data. The plant height of ARoma 17 is 39.8 inches tall which is similar to Jazzman-2 (Table 1).

ARoma 17, like Jazzman-2 and Taggart, is moderately susceptible to common races of rice blast (*Pyricularia grisea* (Cooke) Sacc.). ARoma 17 is rated moderately susceptible to sheath blight (*Rhizoctonia solani* Kühn) which compares with Jazzman-2 (S), Della-2 (S), Roy J (MS), and Wells (S), using the standard disease ratings R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and VS = very susceptible to disease. Under high nitrogen fertilization, ARoma 17 is susceptible to false smut (*Ustilaginoidea virens* (Cooke) Takah). ARoma 17 is rated moderately resistant for bacterial panicle blight (*Burkholderia glumae*) compared to Jazzman-2 (VS), Della-2 (MS), Roy J (S), and Taggart (MS). Reactions to straighthead, narrow brown leaf spot, stem rot, black sheath rot, and sheath spot are unknown at this time.

Plants of ARoma 17 have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with red apiculi, many of which fade to straw at maturity. Milled kernels of ARoma 17 are similar in size to Wells, 7.31 mm and 7.28 mm, respectively. Individual milled kernel weights of ARoma 17, 'Mermentau', Roy J, Taggart, and Wells averaged 21.7, 20.0, 20.7, 22.7, and 21.9 gms/1,000 seeds in the 2014 to 2016 ARPT (14 locations, two replications per test), in data provided by Riceland Grain Quality Laboratory.

The endosperm of ARoma 17 is nonglutinous, aromatic, and covered by a light brown pericarp. Rice quality parameters indicate that ARoma 17 has Jasmine-type characteristics (Webb et. al., 1985). ARoma 17 has an average apparent starch amylose content of 16.65 g kg-1 and a low gelatinization temperature of 63.66°C, as indicated by an average alkali (17 g kg-1 KOH) spreading reaction of 6 to 7, according to data provided by Riceland Grain Quality Laboratory.

Significance of Findings

The release of ARoma 17 provides producers with a high yielding, Jasmine-type aromatic, mid-season, long-grain rice. The major advantages of ARoma 17 are its high yield potential in the specialty aromatic market.

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Literature Cited

CES. 2013. Cooperative Extension Service. Arkansas Rice Production Handbook. J.T. Hardke (ed). University of Arkansas System Division of Agriculture, MP 192, Little Rock, Ark.

PI 597046. 1994. Donated by R. Zeiger of IRRI. U.S. National Plant Germplasm System. Access date: November 2017. Available at: www.npgsweb.ars-grin.gov

Sha, X.Y., S.D. Linscombe, F. Jodari, Q.R. Chu, D.E. Groth, S.B. Blanche, D.L. Harrell, L.M. White, J.H. Oard, M.H. Chen, S.J. Theunissen, and B.J. Henry. 2011. Registration of 'Jazzman' Aromatic Long-Grain Rice. J. Plant Regist. 5:304-308.

Webb, B.D., C.N. Bollich, H.L. Carnahan, K.A. Kuenzel, and K.S. McKenize. 1985. Utilization characteristics and qualities of United States rice. P. 25-35. In: Rice grain quality and marketing. IRRI, Manila, Philippines.

Table 1. Four-year yield average and three-year agronomic data average of ARoma 17 and other cultivars from the 2014 to 2017 Arkansas Rice Performance Trials.

Cultivar	Grain type[a]	Yield[b] 2014	2015	2016	2017	Mean	Height[c]	50% Heading[c]	Milling[d]
		-------------------(bu/ac)------------------					(in.)	(days)	(%HR/%TR)
ARoma17	A	173	142	162	176	163	39.8	86	67/71
Jazzman-2[e]	A	171	n/a	n/a	n/a	n/a	39.2	87	68/72
CL Jazzman[e]	A	164	n/a	n/a	n/a	n/a	39.4	88	67/71
Antonio[e]	L	176	141	n/a	n/a	n/a	36.5	81	69/71
Mermentau[e]	L	181	161	159	n/a	n/a	38.3	83	67/70
Roy J	L	172	169	167	196	179	41.6	89	65/70
Taggart	L	169	167	179	183	183	43.8	88	66/71
Wells	L	186	161	171	182	173	41.5	86	65/71

[a] Grain type A = aromatic, L = long-grain.

[b] Yield trials in 2014 conducted in four locations, Rice Research and Extension Center (RREC), Stuttgart, Ark.; Pine Tree Experiment Station (PTES), near Colt, Ark..; Clay County producer field (CL CO) near Corning, Ark.; and Desha County producer field (DE CO) near Dumas, Ark. In 2015, trials were conducted at RREC; Northeast Research and Extension Center (NEREC), Keiser, Ark.; PTES; CL CO; and DE CO. In 2016, ARPT locations were RREC; NEREC; PTES; Newport Experiment Station (NES), Newport, Ark.; and CL CO. In 2017, RREC; NEREC; PTES; CL CO; and DE CO were the ARPT locations.

[c] Height and Heading data collected from 2014 to 2017.

[d] Milling figures are %HR/%TR = %head rice and % total rice; data collected from 2014 to 2016 yield trials and analyzed at Riceland Grain Quality Laboratory. Milling data presented from RREC in 2014, 2015, 2016; NEREC in 2015, 2016; NES in 2016; PTES in 2014, 2015, 2016; CL CO in 2014, 2015, 2016; and DE CO in 2014, 2015.

[e] Jazzman-2 and CL Jazzman yield and milling data presented from 2014; Antonio data from 2014, 2015. Mermentau data from 2014, 2015, 2016; ARoma 17, Roy J, Taggart and Wells yield data presented from 2014, 2015, 2016, 2017.

Table 2. Yield and agronomic data from the 2014 to 2017 Arkansas Uniform Regional Rice Nursery for ARoma 17 and other cultivars.

Cultivar	Grain type	Yield[a] 2014	2015	2016	2017	Mean	Height	50% heading	Milling[b]
		----------------------(bu/ac)----------------------					(in.)	(days)	(%HR/%HR)
ARoma 17	A	213	174	139	162	172	41.6	90	66/71
Jazzman-2	A	175	149	115	137	144	36.2	87	63/68
Della-2	A	175	172	137	165	162	42.3	91	62/68
Mermentau	L	221	202	125	197	186	39.8	88	64/71
Wells	L	251	189	162	209	203	44.1	88	63/71

[a] Arkansas = Rice Research and Extension Center, Stuttgart, Ark.

[b] Milling figures are %Head Rice and %Total Rice.

Rice Breeding and Pathology Technical Support

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Abstract

Development of disease resistant rice is one of many goals rice breeders work on at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The center's plant pathology group assists by screening preliminary to advance breeding entries against rice diseases under greenhouse and field conditions. Breeding materials are evaluated using artificial inoculation for sheath blight and blast diseases at the RREC and University of Arkansas Systems Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Large amounts of disease inocula are prepared in the laboratory and applied to plants using specific protocols. Sheath blight is screened under field conditions, but blast screening utilizes both greenhouse and field environments. The breeding programs utilize these data to make selections. Selected lines are used either to transfer genes for resistance into adapted and high yielding varieties or to advance entries for further agronomic testing. The breeding and pathology technical support group also assists extension plant pathology programs with applied research to manage major prevailing and newly emerging diseases, including collaborative interdepartmental, industry, and multi-state research endeavors.

Introduction

Rice breeders and pathologist work together to develop varieties having desirable disease resistance along with desired agronomic traits. Disease evaluation of rice against major diseases begins in the early generations of plant selection and is a required activity for a successful breeding program. Lines having some potential traits that do not meet the threshold for release may become parents to develop other new varieties.

Rice blast, caused by *Magnaportha grisea* (T.T. Herbert) M.E. Barr, is still an important disease. Emphasis is given to evaluate breeding materials for both leaf and neck/panicle blast. Rice seedlings from the greenhouse are used to evaluate leaf blast while mature plants in the field determine a plant's resistance to neck/panicle blast. Screening plants for blast requires desired environmental conditions prior to and after inoculation for the pathogen to cause disease.

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Sheath blight (*Rhizoctonia solani* Kuhn), another major fungal disease of rice, is evaluated on fully-grown plants in the field at the RREC. While no quantitative resistance to this pathogen exists, knowledge of whether a variety can tolerate infection through reduced spread of the pathogen is valuable to breeding programs. Sheath blight inoculum also requires massive amounts of a corn/ryegrass seed mixture to be prepared and stockpiled for field application.

Bacterial panicle blight (BPB) caused largely by *Burkholderia glumae* (Kurita and Tabei), formerly known as *Pseudomonas glumae* has gained attention since many of the conventional rice varieties are susceptible to the bacterium. Research in the laboratory, greenhouse, and field focuses on developing practical management techniques to minimize the impact of this disease on rice yields.

Procedures

Evaluation of Breeding Materials for Blast Resistance in the Greenhouse

Entries of the Arkansas Rice Performance Trials (ARPT), Aromatics, Imidazolinone ARPT (IMI-ARPT), Stuttgart Initial Test (SIT), and Cooperative Uniform Regional Rice Nursery (URRN) were evaluated as triplicate hill plots for their resistance to leaf blast. Over 324 flats of soil were prepared to produce 3 to 4 leaf seedlings that were spray inoculated with a spore suspension representing one of six races of *M. grisea*: IB-1, IB-49, IC-17, IB-17, IE-1 and IE-1K. Inoculum production and disease establishment followed earlier described procedures (Kelsey, et al., 2016). Disease data were collected after 7 to 10 days using both a disease severity rating scale of zero (healthy tissue) to nine (elongated necrotic tissue) and an incidence scale to score relative amounts of lesion coverage i.e. one (single leaf or lesion) to 100 (all leaves necrotic with multiple lesions). Tests were duplicated which generated six disease observations per entry. For entries of IMI-SIT and Preliminary Test (Prelims), a similar protocol was followed as just described except a bulk spore suspension was prepared using five races of the pathogen minus the IE-1K, which was sprayed separately. An additional 42 additional flats of soil were needed to produce the plants for screening.

Evaluation of Breeding Materials for Blast and Sheath Blight in the Field

The blast disease nursery at the PTRS was established on May 10 in a secluded area which had a forested border on three sides. The study included 283 entries from URRN/ARPT collection as six replicated hill plots surrounded by a spreader mixture of susceptible lines to encourage spore multiplication and disease spread within the nursery. Several planted rows of corn on the non-forested side of the nursery acted as a windbreak. The nursery started as a flooded paddy but later changed to upland conditions before inoculating plants with the pathogen. A total of 96 gallons of corn chops/ryegrass media was created using a mixture of four pathogen races. Over the course of two field visits July 28 (panicle initiation) and August 22 (beginning boot split), semi-dried seed media was broadcast to inoculate rice plants. Inoculated plants were rated a month later for head and panicle blast development with a count of infected panicles.

A new type of blast nursery designated as "fast track" was established at the RREC with the purpose of collecting more extensive blast data throughout the growing season on advanced breeder lines nearing a possible commercial release. On June 1, five advance breeder lines with three varietal checks were planted using an 8-row Almaco planter to create 24 five by seven foot row plots. The nursery was inoculated on August 11 and August 25 (near boot split) with approximately 16 gallons of inoculum composed of freshly harvested blast agar plates mixed into corn/ryegrass seed media. Plants were grown under upland conditions throughout the test. A month after inoculation, the number of panicles with head/panicle blast were counted to determine the percent infected panicles.

In testing for sheath blight tolerance, a nursery at the RREC was planted on April 26 in four adjacent bays. Each bay contained two replications of entries for the ARPT, Aromatics, IMI-ARPT, SIT, IMI-SIT, Prelims, and URRN for a total of 1150-hill plots per rep. Due to a poor stand of plants, the original plan of using "fast" growing *R. solani* inoculum was abandoned so only "slow" growing *R. solani* inoculum (approximately 32 gallons) was hand applied on July 25 at the panicle differentiation growth stage, at a rate of 24 g per six hill plot rows. A month later, fungal disease assessment of each hill plot was made with a rating scale of zero (no disease) to nine (severe disease that surpassed the flag leaf).

Assistance to the Cooperative Extension Service Rice Pathology Program

Breeding pathology technical support assisted with the planting of 9 field experiments designed to collect data for rice disease control of sheath blight, early season seedling disease, and bacterial panicle blight. Six tests were in collaboration with chemical industries and required assistance with inoculating plants with *R. solani* and spraying 188 rice plots around the early boot stage of rice to evaluate 28 chemical treatments to control sheath blight. Along with these industry studies, additional field-tests to study the economics and efficacy of fungicides on sheath blight created another 76 plots. Approximately 100 gallons of the "fast" growing *Rhizoctonia* inoculum seed media was produced in the laboratory to meet the needs of these tests. In addition, the breeding-pathology technical group provided assistance to applied research on a six-month survival study of *B. glumae* in soil and seed/crop residues.

Results and Discussion

The disease assessment of rice for resistance/tolerance to sheath blight and blast was completed for the breeding program. For each of the tests, several tolerant entries to sheath blight were identified (Table 1). Use of slower colonizing isolates of *R. solani* continued to meet the objectives for sheath blight screening since more than 50% of the entries were classified to be susceptible.

The field blast nursery showed several promising entries from URRN and ARPT to be tolerant to head/panicle blast (Table 1). Overlapping tolerant entries for both diseases showed zero for ARPT, but 10 entries from the URRN test (Table 1). Although this outcome was encouraging, continued evaluation is needed to confirm these results. The blast nursery benefited greatly from the warm moist conditions of tropical depressions in August/September which coincided with inoculation of plants nearing the boot split growth stage. In addition, the "fast track" blast nursery showed encouraging results with the use of small row plots to evaluate advanced lines under field conditions. Additional refinement is needed to enhance development of the blast epidemic.

Of the 1150 experimental lines tested for leaf blast in the greenhouse with individual races of blast, several were rated as disease tolerant (Table 2). Collection of incidence data along with the usual severity data was helpful in distinguishing entries that were a mixture or still segregating. Ramping up testing to include six reps also provided more data that the breeder could use in deciding whether to advance or discard an entry.

The breeding–pathology tech support group provided support to the success of research activities in extension pathology starting from preliminary to complete studies of applied research, collaborative research with industries and interdepartmental research.

Significance of Findings

The goal of the rice breeding-pathology technical support group will always be to provide support towards increasing the efficiency of rice breeders in developing maximum yielding cultivars with expected levels of disease resistance. In addition, the group plays an important role in extension plant pathology by assisting with applied research. Disease evaluations remain a beneficial aspect of the breeding program for disease resistance. A strong applied research approach also provides dependable and practical solutions to rice producers in Arkansas and other rice producing states. Therefore, this tech support group is actively working with breeders and the extension pathology program to enhance rice productivity.

Acknowledgments

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Literature Cited

Kelsey, C.D., S.B.Belmar, K.A.K Moldenhauer, and Y.A. Wamishe. 2016. Rice breeding and pathology technical support. *In:* R.J. Norman and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agriculture Experiment Station Research Series 634:103-109. Fayetteville, Ark.

Table 1. Number of entries rated disease tolerant in 2017 field disease nurseries.

Test	Total entries	Sheath blight[a]	Head/panicle blast[b]	Both diseases
ARPT	68	12	20	0
URRN	197	60	44	10
Aromatics	111	47	na[c]	na
SIT	132	51	na	na
IMI-ARPT	66	17	na	na
IMI-SIT	271	76	na	na
Prelims	305	135	na	na

[a] Rating scale of 0 (no disease) to 9 (severe disease) was used. A "6" represents disease progression of approximately 60% up the plant and considered tolerant for average scores of 6.3 or less.

[b] Four races bulked together for blast field screening. Rating scale of 0 (no disease) to 9 (dead plant) was used. Up to a "4" rating was tolerant.

[c] Not available.

Table 2. Number of entries rated disease tolerant[a] for 2017 greenhouse leaf blast testing.

Test	Total Entries	Combined across all races tested	IE-1K	IC-17	IB-17	IB-49	IB-1	IE-1
ARPT	68	7	33	44	26	19	33	62
URRN	197	29	76	122	97	77	95	190
Aromatics	111	47	87	97	81	59	76	108
SIT	132	40	77	100	96	72	87	132
IMI-ARPT	66	25	32	46	32	32	34	66
				Bulked across the individual races				
IMI-SIT	271		158			169		
Prelims	305		153			162		

[a] Disease severity rating scale of 0 (no disease) to 4 (small diamond shaped lesion with ashy center).

Studies on Management Strategies to Reduce Autumn Decline in Rice

Y.A. Wamishe[1], J.T. Hardke[2], T.L. Roberts[3], T. Gebremariam[1], T. Mulaw[1], S.B. Belmar[1], and C. Kelsey[1]

Abstract

Hydrogen sulfide toxicity or autumn decline, also referred to as akiochi, shows black root rotting usually with stunted and yellowish rice foliage starting as early as two weeks following establishment of the permanent flood. In severe conditions, root crowns rot and are invaded by opportunistic fungi rendering dark brown discoloration. Rotting of root crowns specifically is referred to as autumn decline/akiochi and hinders the rice plant's ability with upward nutrient translocation from the roots. This paper reports on progress for two project objectives: 1) to search for practical methods to prevent or correct the root blackening and rotting associated with autumn decline; 2) to evaluate the degree of resistance or tolerance of common rice cultivars to autumn decline under greenhouse or field conditions. A field with a history of hydrogen sulfide toxicity and autumn decline was identified in Humphrey, Ark. for the purpose of conducting the following three tests. Two formulations of anoxygenic phototrophic bacteria products namely, spectrum PC and Spectrum PTB were tested in micro-plots (half barrels). At the same time, pot experiments were established to test cultivar tolerance differences and a greenhouse test was conducted to evaluate the effects of water temperatures, soil, and water sources on symptom development. The products PC and PTB were not effective in reducing the percent of root mass discoloration which was consistent with previous year's experiments. Spectrum PC did reduced root crown rot by 20% while Spectrum PTB lowered the damage by 40%. From the cultivar evaluation test, those that showed crown root rot above 3 on the 0-9 scale fell in the category of susceptible regardless of the intensity of root mass discoloration. Nearly 75% of the cultivars showed less than 35% root mass discoloration.Only 55% of the cultivars showed root crown damage that ranged from 5% to 30%. Root crown damage among the cultivars ranged from 0.5 to 9. The greenhouse test showed water temperature for flooding had much lower impact on

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hydrogen sulfide toxicity symptom or autumn decline than soil and water sources. Soil from a field with a history produced symptoms with either well water or chlorinated city water. However, the greenhouse soil with no history of toxicity or autumn decline showed no disease symptoms with the city water. Instead, it showed the autumn decline symptom with the well water.

Introduction

Reports on hydrogen sulfide toxicity or autumn decline, also referred to as akiochi have increased in recent years from rice fields in Arkansas. Autumn decline often appears in rice fields affected by hydrogen sulfide in anaerobic/flooded conditions. Symptoms include black roots believed to be caused by iron sulfide and root rotting which results from hydrogen sulfide toxicity. The affected rice plants are stunted with yellowish foliage showing up as early as two weeks following the establishment of a permanent flood. The problem is often most severe where cold well water first enters a rice field and may later spread throughout the field, but plants on levees remain healthy. The phenomenon was reported in Arkansas in a limited number of fields in 2004 (Delta Farm Press; Wilson and Cartwright, pers. comm.). However, several more reports of autumn decline occurred across Arkansas from 2012 to 2017. Although the problem may be aggravated in the anaerobic/flooded conditions, there is no clear understanding of why this phenomenon is occurring in different soil types across several rice growing counties in Arkansas. Observations have shown fields having a clay loam soil texture are more prone to the autumn decline phenomenon than other soil textures commonly cropped to rice. The root rotting symptoms often start a few weeks after flood establishment and become progressively worse throughout the season. In situations where root rotting is severe, fungi grow into the crown which limits the function of the whole root system and prevents translocation of water and nutrients from the soil to the plant resulting in crop decline. In moderate to severe cases, tillers break off easily and plant death may occur rapidly leading to significant yield losses. Ongoing field and greenhouse investigations started in 2015 have the following objectives: 1) to search for practical methods to prevent or correct the root blackening and rotting associated with autumn decline; 2) to evaluate the degree of resistance or tolerance of common rice cultivars to autumn decline under greenhouse and field conditions; and 3) to evaluate the effect of soil drainage (the current preventative/rescue strategy) on autumn decline severity and cultivar survival rate.

Procedures

Studies on Strategies to Reduce Hydrogen Sulfide Toxicity and Autumn Decline

Field Tests to Evaluate Products in 2017. Spectrum PC and Spectrum PTB were two formulations of anoxygenic phototrophic bacteria under test. These formulations have been tried since 2015 in both greenhouse and two fields in Woodruff County, Ark.

In 2017, they were tested again in a field with a history of hydrogen sulfide toxicity and autumn decline at Humphrey, Ark. in a field of cultivar CL153. Similar to the last two seasons, the tests were carried out in micro-plots under field conditions. A half barrel with 2ft diameter and a foot high was fixed into the soil to a depth of 4 inches. The barrels were fixed into the soil a few days before the producer applied pre-flood nitrogen to his field. Nine barrels were used to accommodate three treatments in three replications. The treatments included: Spectrum PC, Spectrum PTB and an untreated control. All barrels were positioned near the bar ditch to allow for easier refilling with water throughout the growing season. All barrels were in a bay in about 6 ft proximity to each other and positioned based on seedling density. The number of seedlings within each barrel showed similar plant density of 35 to 40 plants per barrel area. Treatments were applied a day after the producer's field was flooded. These micro-plots were checked for refill twice a week maintaining a flood depth of at least 4 inches. Data were collected when the crop reached flowering.

Field Evaluation of Commercial Cultivars for Tolerance in 2017. To evaluate rice for degree of resistance or tolerance to autumn decline, a test was carried out consisting of 20 commercial cultivars in two replications. The commercial rice cultivars tested in 2016 at Woodruff County were used for comparison in 2017. Gallon sized pots were filled with soil collected from the Humphrey farm that was used for the first experiment. About 10 seeds were planted per pot and were consistently watered from the barrow ditch that was filled with well water. When the rice plants were ready to be flooded, they obtained pre-flood nitrogen and were placed in the barrow ditch. The pots were kept irrigated either by rain or by refilling from the barrow ditch until data collection. At flowering, plants were pulled up carefully from each pot, thoroughly washed to expose the root system, and rated immediately before the blackening disappeared with oxidation. Two rating scales, 0 to 9 for root crown damage and 0 to 5 for root mass discoloration were used as described in the addition-matrix scale developed by Wamishe et al 2018. The highest reading of damage was recorded for the cultivar wherever root crown damage showed variability among sub-samples. In addition, percentage estimates for both root mass discoloration and crown damage were collected. All readings for root crown damage were recorded in reference to crown length (Table 1).

Greenhouse Tests on Effects of Soil/Water Source and Temperature. Soil from Humphrey, Ark. was collected, at the beginning of October 2017 (approximately a month after rice from the field was harvested). Although top soil with rice stubble was desired, a backhoe gathered more of the deeper subsoil profile. A susceptible rice cultivar CL153 was selected based on its field response in 2016 as a susceptible cultivar and planted in gallon sized pots. Eight sets of two pots were prepared to accommodate different combinations of soil types, water sources and water temperatures: Set 1. Field soil + Cold 4 ºC well water; Set 2. Field soil + room 25 ºC well water; Set 3. Field soil + cold 4 ºC Tap water, Set 4. Field soil + room 25 ºC Tap water; Set 5. Greenhouse soil + cold 4 ºC Well water, Set 6. Greenhouse + room 25 ºC well water; Set 7. Greenhouse soil + cold 4 ºC Tap water; Set 8. Greenhouse + room 25 ºC Tap water. The greenhouse soil referred to as silt loam soil, collected presumably from virgin ground, was mixed with sand and vermiculite peat moss in the ratio of 3:1:1, respectively. The well water used to keep the pots flooded throughout the test period was brought from the field of interest in Humphrey. The well water at 4 ºC was kept in a refrigerator and the tap water was brought down to 4 ºC using ice. The plants were flooded five weeks after planting, NPK fertilizer applied as needed and pots kept flooded for about two months. Due to the frequent overcast days in the winter, six of 1000 watts bulbs were hung over the pots and were tuned on for 9 h from 7.00am to 5.00pm. At boot stage, plants were pulled up, roots washed and percent root mass discoloration were estimated immediately before roots lose their black color due to exposure to atmospheric oxygen. A subset of 10 randomly chosen rice plants were split vertically down the length of the stem and percentage root crown damage was determined.

Results and Discussion

Studies on Strategies to Reduce Hydrogen Sulfide Toxicity and Autumn Decline

Field Tests to Evaluate Products. Spectrum PC showed 20% while Spectrum PTB showed 40% reduction in the number of rice plants with crown rot in micro-plots (half barrels) compared to the untreated control (Fig. 1). These formulations contain anoxygenic phototrophic bacteria that claimed to consume sulfur in soil solutions in addition to being photosynthetic. No noticeable differences were observed between the treated and untreated rice plants in root mass colors. This was in agreement with the results from previous years' field and greenhouse tests. There is continued interest in these products for reduction of root crown damage rather than root mass discoloration. Root crown rot has been proven more damaging to crop yield because it is irreversible while root mass discoloration can be reversed by allowing oxygen into rice rhizosphere. By lowering flood depth or using a "drain and dry" strategy for the field helps to replenish depleted oxygen supplies in the soil. This strategy works well for some fields where problems are already known and is used as a protective strategy if done at the right timing to alleviate stress on the plants. However, it may not be a reliable option if the field sizes are too big to drain and re-flood as needed. Moreover, it would be a difficult practice where water resource and pump capacities are limited. Compared to the two fields in Woodruff County for 2016, both hydrogen sulfide toxicity and autumn decline appeared to be more severe at the field in Humphrey, Ark in 2017. In general, after three years of field testing, there is clearly perceived effectiveness of these formulations that varies with different soil types.

Field Evaluation of Commercial Cultivars for Tolerance. A select group of commercial cultivars often included in Producers Rice Evaluation Program (PREP) in replicated plots was to be planted at Humphrey, Ark. Due to the narrow planting window caused by the heavy and frequent early season rain, the test was modified to one-gallon pots filled with soil collected from the planned field. Each rice cultivar was replicated twice. About 10 seeds were planted in each pot. After seedlings were well established, pots were kept in the barrow ditch adjacent to the producer's rice, CL153. Although the cultivars in pots were meant to be treated similar to the adjacent field, the fact that they were kept in a barrow ditch in pots with no holes underneath did not allow the cultivars to be equally exposed to the well water like the producer's rice. Pots did not lose much water so there was less need to refill them. The frequent rain added more water to pots contributing to less well water exposure. When roots were pulled up and evaluated, the maximum root mass discoloration recorded was 60%. Moreover, nearly 75% of the cultivars showed less than 35% root mass discoloration; whereas the CL153 plants in the field showed up to 85% discoloration. Only 55% of the cultivars showed root crown rot in rice plants that ranged from 5% to 30%. Using the 0 to 9 scale, root crown rotting ranged from 0.5 to 9 and all cultivars showed root mass discoloration (Fig. 2). Root mass discoloration is often considered less damaging to the crop yield than root crown damage. Based on the matrix-addition scale developed by Wamishe et al., 2018, cultivars that showed root crown rot above 30% are categorized as intolerant/ susceptible regardless of the percentage of root mass discoloration (Fig. 2).

Greenhouse Tests on Effects of Soil/Water Source and Water Temperature. Since the cultivar tolerance screening in section 2 above rendered less intensity of root mass discoloration and root crown damage, it raised questions on sources of impact factors -- whether it is the water, the soil, a combination of the two or water temperature which caused the mild symptoms in the pot experiment. Because the pots were kept flooded by rain, more than by well water and also more from barrow ditch than from well direct, designing a test that separates and shows the impact of the water source was deemed necessary. A greenhouse test was designed consisting of 8 sets of treatments in two replications. Soil and water were collected from the field in Humphrey, Ark. The eight treatment comprised the following combinations: Field soil + cold 4 ºC well water; Field soil + room temp well water; Field soil + cold 4 ºC Tap water; Field soil + room temp Tap water; Greenhouse soil + cold 4 ºC well water; Greenhouse + room temp well water; Greenhouse soil + cold 4 ºC Tap water; Greenhouse + room temp Tap water. The greenhouse soil was mixed in a ratio of 3:1:1 soil: sand: Vermiculite peat moss. The greenhouse soil was known to have no history of hydrogen sulfide toxicity or autumn decline.

When roots were examined, they were not as black as expected. This was likely due to excessive loss of water particularly during weekends from the heat coming from the light bulbs. The 1000 watts bulbs were hung over the pots to simulate the summer field light intensity for 9 hrs. Unless pots are kept full of water, the oxidation process can occur which reverses reduction to hydrogen sulfide and FeS. The FeS is known to be responsible for coating the root system black.

Although root mass blackening was not as intense as expected, blackness in crown root bases and root crown browning were evaluated for symptoms of autumn decline that may have followed from hydrogen sulfide toxicity in the course of flood treatment. As shown in Table 2, saturated soil flooded with well water at room temperature or 4 ºC treatments showed more than 80% of the plants with a black root crown base. Among these, up to 27% of the rice plants had damaged root crowns. Contrarily, none of rice plants in pots treated with greenhouse soil and flooded with tap water at either temperature showed any symptom of crown base discoloration or root crown rotting. On the other hand, rice plants in pots treated with field soil and flooded with tap water showed positive symptoms to demonstrate that the soil alone could cause the symptoms even if the water source was different. The most interesting result from this test was that the well water and greenhouse soil combination showing the symptoms of root crown base blackening with nearly 4% of the plants showing root crown damage. The effect of water temperature in this or other treatments was erratic and appeared to have less impact (Table 2). Although this test is preliminary, it needs to be repeated to definitively determine the role of each treatment factor either alone or in combination.

Significance of Findings

Every year, from Arkansas rice production fields, more reports on root blackening and crown rotting associated with hydrogen sulfide toxicity and autumn decline have occurred. In some fields, draining surface flooded water improved the situation. However, in other fields the "drain and dry" approach did not improve the situation enough to salvage the crop. A better understanding of this problem and alternative ways of managing the problem in various soil types would permit growers to make the best decisions possible to avoid losses due to the failure of the "drain and dry" strategy. Additionally, the "drain and dry" approach does not work if a field is not in a manageable size because of water resource and pump capacity. Knowledge of cultivars susceptibility/intolerance and the discovery of additional management options could prevent significant losses that have occurred to some rice fields.

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Literature Cited

Delta Farm Press Sept 24, 2004 at http://deltafarmpress.com/rice-malady-identified-hydrogen-sulfide-toxicity.

Dobermann, A. and T. Fairhurst. 2000. Rice: Nutrient disorders and nutrient management. Sulfide Toxicity. Oxford Graphic Printers Pte LTD. PP126-128.

Wamishe YA, Hardke J, Mulaw T, Gebremariam T, Belmar S, Kelsey C1 , Roberts, T and Fryer J. 2018 . A Method to Estimate Field Response to Hydrogen Sulfide Toxicity and Autumn Decline in Rice Cultivars. J Soil Sci Plant Health 2:2.

Table 1. Rating scales used to rate crown discoloration and root discoloration in cultivars grown in soil with history of autumn decline/hydrogen sulfide toxicity in Ark.

Rating	Crown Length Discolored[a]	Rating	Root Mass Blackened[a]
(0-9 scale)	(%)	(0-5 scale)	(%)
0	0	0	Clean as in levee roots
1	10	1	10
2	20	2	25
3	30	3	50
4	40	4	75
5	50	5	75 or >
6	60		
7	70		
8	80		
9	90 or >		

[a] Roots need to be washed well and rated immediately, up to 10 root crowns need to be examined. Numbers shown under % columns refer to range of estimate.
For instance: 10 refers to discoloration percentage > 0 =10.

Table 2. Effect of soil source, water source, and temperature on the severity of autumn decline in the greenhouse.

Soil source	Water source	Water temperature	Plants with black crown base	Plants with crown rot
			-------------------%	--------------------
Field	Well	4 °C	83	5
Field	Well	room	88	27
Field	Tap	4 °C	64	50
Field	Tap	room	100	4
GH	Well	4 °C	83	0
GH	Well	room	100	4
GH	Tap	4 °C	0	0
GH	Tap	room	0	0

GH: Greenhouse; Well: Well water from Humphrey and Tap: chlorinated city water; Room: room temperature either of the lab or the greenhouse.

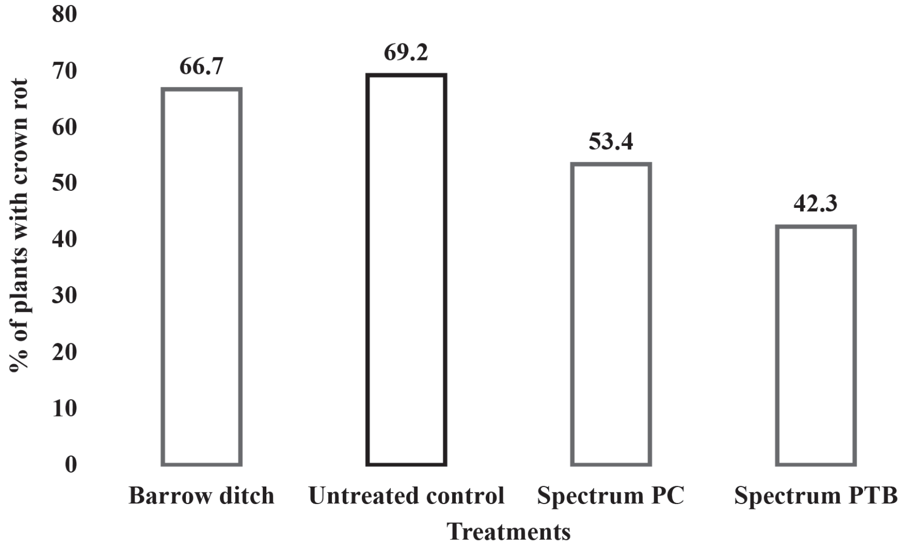

Fig. 1. Effects of two bio-formulations in reducing crown rot in rice plants grown in a field with a history of hydrogen sulfide toxicity and autumn decline. Note: plants in barrow ditches often are highly affected.

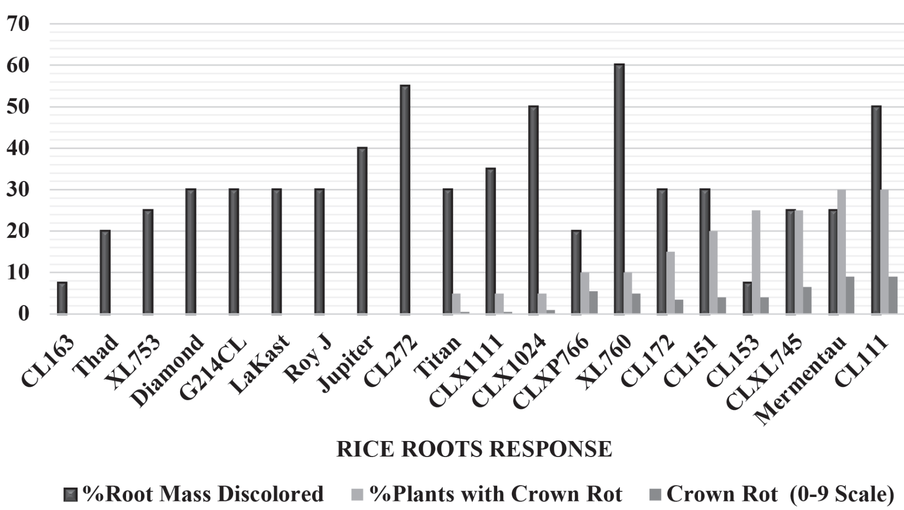

Fig. 2. Percentage root mass discolored, plants with crown rot and extent of crown rot as estimated in 0-9 scale in a field test using pots filled with soil with a history of hydrogen sulfide toxicity and autumn decline.

Studies on Variables Related to the Survival and Severity of *Burkholderia glumae*, the Major Pathogen for Bacterial Panicle Blight of Rice in Arkansas (Year 2)

Y.A. Wamishe[1], T. Mulaw[1], T. Gebremariam[1], and S.B. Belmar[1]

Abstract

Bacterial panicle blight (BPB) is one of the most threatening diseases for rice production in Arkansas and other southern rice producing states. The disease is caused by *Burkholderia glumae* and possibly other *Burkholderia* species. As part of a short term strategy to manage BPB, two objectives were addressed in this study. 1) to evaluate survival of *B. glumae* from infected rice residues, inoculated soil, and ”overwintering rice” 2) to evaluate the effect of dew associated with severity and incidence of BPB in the field, greenhouse, and shaded areas of the field along tree lines. Despite the high initial population density in artificially inoculated soils, *B. glumae* appeared to be short lived. In 2015, no colonies of *B. glumae* were recovered from soil that had been inoculated a month earlier and left on the surface of the field or buried. In 2016, a two weeks sampling time was included and *B. glumae* was recovered at a much smaller population density compared to the initial time point. In 2017, a similar trend of declining number of positive florets was observed. Based on these results *B. glumae* appeared less important in the overwintering infection of new rice plants. When tested using infected panicles placed on the soil surface or buried in the field, none of the florets tested positive after a month in 2015 for BPB in either case. In 2016, no BPB infected kernel/chaff was obtained from the panicles on the surface. A similar declining *B. glumae* recovery was observed in 2017. However, a low number but positive recovery of BPB extended into February when artificially inoculated rice plants were left as volunteers to overwinter, the number of positive seeds dropped from 34% to 4% by January. The field mist test, greenhouse dew test, and the tree line shade test agreed on increment of incidence of BPB disease. In 2017, tree shade on the west side rendered more BPB symptomatic panicles than that of the east side unlike what was observed in 2016. The mist, dew and tree line shade test results were in agreement with years of field observation suggesting moisture in a form of dew, mist, fog, shade favor BPB development and spread within a rice plant or between plants.

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Introduction

Bacterial panicle blight (BPB) disease of rice is caused by *Burkholderia glumae*, *B. gladioli*, and a few other species of *Burkholderia*. BPB is often associated with extended hot and dry daytime weather and warm nighttime temperatures. Under favorable environmental conditions for pathogen development and spread, up to a 60% yield loss can occur in susceptible rice cultivars. Panicle symptoms typically develop late in the season during grain fill, which makes visual prediction of disease occurrence and severity difficult to minimize damage. Infected panicles have a two-tone discoloration where the blighted florets appear white to light gray with a dark-brown margin on the basal third of the tissue. As the season tapers, infected florets turn straw-colored and may further darken with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. Weather variables of temperature, moisture and wind are believed to play an important role in BPB disease. Although the life cycle of the bacterium is not completely understood, it has been found in residue, soil and water. However, longevity and infectivity from these sources have not been well studied. The objectives in this study are 1) to evaluate survival of *B. glumae* from infected rice residues, inoculated soil, and ”overwintering rice” ; 2) to evaluate the effect of dew associated with severity and incidence of BPB in a field, greenhouse, and shaded areas of the field along tree lines.

Procedures

Research on the Survival of *B. glumae* in Soil

In 2017, three batches of approximately 4.5 lbs. of silty loam soil were air dried and pulverized to obtain a homogenous mixture of soil. A 48 h culture of *B. glumae* on King’s medium B Base (KB medium) was washed to prepare 20.3 fl.oz. of a bacterial suspension with optical density (O.D.) transmittance of 9 and 78. Each O.D. suspension was added separately to a batch of soil and thoroughly mixed. A subsample representing each O.D. was removed to quantify *B. glumae* present at the beginning of the experiment. The remaining soil for each O.D. was divided into 7 oz. samples and shaped to form 10 columns that were individually wrapped with nylon mesh and used as treatments of “surface” and “2 inch buried”. A negative control was also prepared using sterile water. For the next five months, a column of soil for each of three treatments was removed from the field and brought to the laboratory to determine the *B. glumae* population. Enumeration of bacteria from soil was performed using 1 g soil per 10 ml sterile water in a culture tube. The soil suspension was vortexed for 5 sec prior to removal of a 1 ml aliquot to create a series of 1:10 dilutions. For each dilution, 100 µL was plated onto each of two CCNT plates (Kawaradani et al., 2000). Plates were incubated at 38-40 °C for 48 h before plates were checked for colonies producing a distinct yellow pigment in the CCNT agar. Colony forming units (CFU)/ ml were determined only for plates with distinct yellow forming colonies. This test was also carried out in 2015 and 2016.

Research on the Survival of *B. glumae* in Rice Residue

Rice panicles previously inoculated with *B. glumae* and observed with classic symptoms of bacterial panicle blight were selected to create 10 bundles each with five panicles. Twenty seeds were randomly selected across each panicle to obtain 100 seeds per bundle. Seeds were embedded into CCNT medium and placed in an incubator at 38-40 °C for 48 h. The number of seeds with a transparent yellow pigment were counted as positive. Each bundle of panicles was carefully wrapped in nylon mesh and tagged for use in "surface" and "2 inch buried" residue treatments. For the next 5 months, a bundle of panicles for each of two treatments was removed from the field and brought to the laboratory to determine the number of seed positive for *B. glumae*. This test was also carried out in 2015 and 2016.

Off-Season Survival of *B. glumae* With Inoculated Rice

B. glumae-inoculated rice plants that showed a high level of BPB disease in the Uniform Regional Rice Nursery (URRN)/Arkansas Rice Performance Trials (ARPT) bay were tagged to remain out in the field after harvest. Starting in October, 5 panicles were randomly chosen every month. From each panicle, 5 seed were again randomly removed and plated on CCNT medium. In the absence of seeds, glumes/chaff were cultured. The number of florets that tested positive were counted and recorded. This test was also carried out in 2015 and 2016.

Effect of Dew on Severity/Incidence of Bacterial Panicle Blight

Dew Chamber Versus Greenhouse Bench Study. One variety namely, Bengal was grown in 10-gallon size pots until flowering in the greenhouse at University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The first 3 panicles that flowered in a pot were inoculated with a *B. glumae* suspension at approx.10^8 CFU (colony forming units). Five pots were kept in a dew chamber at 78 °F and 100% humidity for 24 h after inoculation; while the remaining 5 pots were placed on a greenhouse bench after inoculation. The plants from the dew chamber were removed after 24 h and kept on the greenhouse bench. Symptom development for BPB were checked regularly and symptomatic florets with BPB were counted at grain fill.

Mist and No Mist Treatment Study in a Field on Incidence and Severity of Bacterial Panicle Blight. Two sets of three treatments that included plots planted with inoculated seeds, spray inoculated foliage, and non- inoculated control were designed to study the effect of moisture in the form of mist on development of BPB caused by *Burkholderia glumae*. The experiment was carried out with four replications. A susceptible rice cultivar, Bengal was used. One set of the three treatments obtained moisture in the form of mist starting a week after spray inoculation. The other set was planted a little further from the mist system and obtained no mist except natural rain and dew. At grain filling and when symptoms were evident, the number of symptomatic panicles per plot were counted. Panicle counts in no-mist plots were taken before and after the tropical storm, Harvey, to evaluate the role of windy rain in BPB disease spread. Panicle counts were analyzed using SAS v. 9.3 (SAS Institute, Inc., Cary. N.C.).

East and West Side Tree Line Effect on Incidence of Bacterial Panicle Blight. The same horseshoe shaped field surrounded by trees selected in 2016 was used in 2017 at the University of Arkansas System Division of Agriculture's Pine Tree Experiment Station (PTRS) near Colt, Ark. Bengal seeds were planted in 3 separate and parallel bays spaced across the field: one close to the eastern tree line, the second near the western tree line, and the third at the center of the field that received no tree line shade. Artificially inoculated seeds and non-inoculated seeds were planted in four plots (5 ft by 15 ft) for each bay. All 3 bays were maintained and managed similarly. Number of panicles showing clear BPB symptoms on more than 25% across panicle length were recorded at early grain fill. Panicle counts were analyzed using SAS v. 9.3 (SAS Institute, Inc., Cary. N.C.).

Results and Discussion

Research on the Survival of *B. glumae* in Soil

Regardless of the high initial CFU/g in the infested soils, *B. glumae* appeared to be short lived. In 2015, no colonies of *B. glumae* were recovered from the soil when tested a month after the infected soils were left on the surface of field soil or buried. In 2016, a 2 week sampling time was included that showed declining numbers of *B. glumae* CFUs on CCNT agar medium. In subsequent tests there was no recovery of the bacterium. However, in 2017, *B. glumae* was recovered from Oct, to Jan, 2018 (Table 1). The number of infected seed from the panicles and number of colonies of *B. glumae* from soil samples drastically declined every month. Survey results in 2015, 2016 and 2017 from BPB sample collection across Arkansas showed *B. glumae* as the major causal of BPB disease in Arkansas. Based on these results, *B. glumae* seemed less likely to over-season in soil and infect new rice plants.

Research on the Survival of *B. glumae* in Rice Residue

Positive florets/kernels for BPB in the initial samples ranged from 26% to 32% in 2015, 17% to 29% in 2016, and 18% to 40% in 2017. Although the number of positive florets declined every month, this year's result showed some positives hits on CCNT media until December for both inoculated panicles placed on the surface or buried out in the field. These results were a bit different from those in 2015 and 2016. In these years, the positive counts went to zero within a month's time. In 2016, no positive kernel/chaff was obtained for the panicles placed on the soil surface after a month. However, with buried panicles a 2% recovery continued until December and then went down to zero by March. Similarly, in 2017, positive kernel/chaff declined to 33% in samples placed on soil surface and to 13% in buried panicles by December and 0% by February (Table 2).

Off-Season Survival of *B. glumae* With Inoculated Rice

In 2015, artificially inoculated rice plants left to overwinter dropped from 25% to 10% positives within the first month of the study and was 0% during the remaining sampling months. Similarly inoculated plant material left in the field during the fall and winter seasons of 2016 showed a gradual drop in *B. glumae* populations to 0 by the 5th month of sampling from the initial sample of 26% positive. In 2017, the number of positive florets dropped to 4% by Jan. 2018 compared to the initial 34% recovery (Table 3). Results from the overwintered plants of 2017 are in agreement with the buried treatment residue test of 2017 showing higher probability of *B. glumae* survivorship in residues, particularly kernel residues, than in soils depending on fall and winter weather conditions.

Effect of Dew on Severity/Incidence of Bacterial Panicle Blight

Dew Chamber Versus Greenhouse Bench Study. BPB infected florets ranged from 61 to 79 per plant when rice plants were incubated in a dew chamber for 24 h after spray inoculation. Artificial inoculation was carried out at the flowering developmental stage of the susceptible rice cultivar Bengal. The number of florets with BPB symptoms ranged from 25 to 39 per plant when they were left on the bench after inoculation. The purpose of the latter was to simulate a no rain or dew condition after inoculation. Except for the dew exposure for 24 h, other conditions were maintained similarly. Results from this study clearly showed the positive role of dew in enhancing infection (Fig. 1). While BPB is favored by hot and dry conditions, BPB disease symptoms appeared more pronounced in the presence of moisture. Field observations agree with these findings where BPB appeared high in conditions where moisture was available in the form of dew, mist, rain or windy rain.

Mist and No Mist Treatment Study in a Field. Overall, when spray inoculation at the flowering stage was compared with seed inoculation at planting, BPB infected panicle count/plot was 7 times higher in the spray inoculated plot compared to seed inoculated plot. Symptomatic florets in seed inoculated plots were higher than the non-inoculated plots by only 19% and was statistically insignificant (Fig 2). When mist and no mist treatments were compared, spray inoculated plots showed significant difference in mean symptomatic panicle counts. The BPB symptomatic panicle counts were 33x more in mist treated than no mist treated. The mist treatment appeared to have no effect in plots planted with seed inoculated plots and the control (Fig. 3).Interestingly, when the number of symptomatic panicle counts were compared before and after the 2017 tropical storm Harvey, spray-inoculated plots with no mist treatment showed the number of infected panicles increased nearly 10 fold. Even in the non-inoculated control and seed inoculated plots the number of BPB panicles increased by 2 or 3 times (Fig. 4). These results agree with what was observed in earlier years along with the greenhouse experiment.

Comparison of East and West Side Tree Line Effect on Incidence of Bacterial Panicle Blight. Three bays planted with inoculated and non-inoculated Bengal seeds showed no significant differences in disease levels due to inoculations. No significant differences were also obtained among replications or the interactions of inoculation and locations in symptomatic panicle counts. However, the locations related to shade (East, West) verses no shade showed significant differences in infected panicle count (Fig 5). Unlike the test in 2016, the west side plots that received shade in the early evening hours showed higher number of infected panicles compared to the east side shaded plots that extended morning hour shade. However, the east side also had more BPB infected panicles than unshaded plots. These findings agree with the observation in 2012 where Jazzman 2 in Lee County that showed severe BPB near trees and bayou areas but greatly lessened in areas away from the trees. This experiment will be repeated in the same location in 2018.

Significance of Findings

Managing bacterial panicle blight of rice is very important to reduce the potential yield losses. With lack of resistance in current commercial rice cultivars and absence of chemical options, knowledge of the biology of the bacteria is critical to the discovery of effective management strategies for the disease. Cultural management options can always be integrated with host resistance. These studies and findings are important both from scientific and practical point of view. Rice plants are most susceptible at the flowering growth stage and any form of moisture under extended hot night temperature at this stage can make rice prone to BPB disease. Knowledge on the short survival of *B. glumae* in soil and residue is pertinent towards the knowledge of inoculum sources.

Acknowledgments

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Literature Cited

Kawaradani, M., K. Okada, and S. Kusakari. 2000. New selective medium for isolation of *Burkholderia glumae* from rice seeds. J. Gen. Plant Pathos. 66:234-237.

Table 1. Colony forming units (CFU) of *B. glumae* found in soil inoculated with two levels of bacterial density and left on the surface and buried at 6 inches depth to evaluate survival through 5 months (Oct-March) in 2015, 2016, and 2017.

		O.D.[a]	Initial CFU/g of soil	2 wk[b]	Feb
2015 Soil	Surface	9	6.9×10^9	NA	0
		78	5.3×10^8	NA	0
		Control	0	NA	0
	Buried	9	6.9×10^9	NA	0
		78	5.3×10^8	NA	0
		Control	0	NA	0
2016 Soil	Surface	9	3.6×10^6	2×10^5	0
		78	1.7×10^6	7×10^3	0
		Control	0	0	0
	Buried	9	3.6×10^6	0	0
		78	1.7×10^6	0	0
		Control	0	0	0
2017 Soil	Surface	9	3.6×10^6	12×10^3	0
		78	1.7×10^6	12×10^3	0
		Control	0	0	0
	Buried	9	3.6×10^6	27×10^3	0
		78	1.7×10^6	20×10^3	0

[a] O.D. = optical density.
The March 2017 data was not available at the time of reporting.
[b] The two weeks test was added in 2016 since no *B. glumae* was detected in 2015 after one month. The differences in initial *B. glumae* population recovered could be the differences in soil sources in the respective years.

Table 2. Percentage of initial infected seeds recovered as positive with *B. glumae* compared to positive seeds recovered after on surface and buried in soil treatment in a field condition across 5 months in 2015, 2016 and 2017.

			2 wk	Nov	Dec	Jan	Feb	Mar
2015 Panicle	Surface	% Initial positives	NA[a]	28	26	26	32	30
		% positives across time		0	0	0	0	0
	Buried	% Initial positives	NA	35	27	31	33	24
		% positives across time		0	0	0	0	0
2016 Panicle	Surface	Initial positives%	20	19	16	19	18	20
		% positives across time	0	0	0	0	NA	NA
	Buried	Initial positives %	24	26	20	26	29	17
		% positives across time	0	2	2	0	NA	NA
2017 Panicle	Surface	% Initial positives	32	27	36	18	40	NA
		% positives across time	15	16	13	6	0	NA
	Buried	% Initial positives	25	30	23	19	34	NA
		% positives across time	22	10	3	0	0	NA

[a] NA = not available, either was not included in the tests or not tested by the time of this report.

Table 3. Percentages of initial seeds infected and recovered as positive to *B. glumae* from inoculated rice as compared to positive seeds/chaff recovered in subsequent sampling timings across 5 months.

	Seeds Positive to *B. glumae* (%)						
Year	Oct	2 weeks	Nov	Dec	Jan	Feb	Mar
2015	25	NA[a]	10	0	0	0	0
2016	26	12	11	5	2	0	NA
2017	34	21	28	14	4	2	NA

[a] NA = not available either was not included in the tests or not tested by the time of this report.

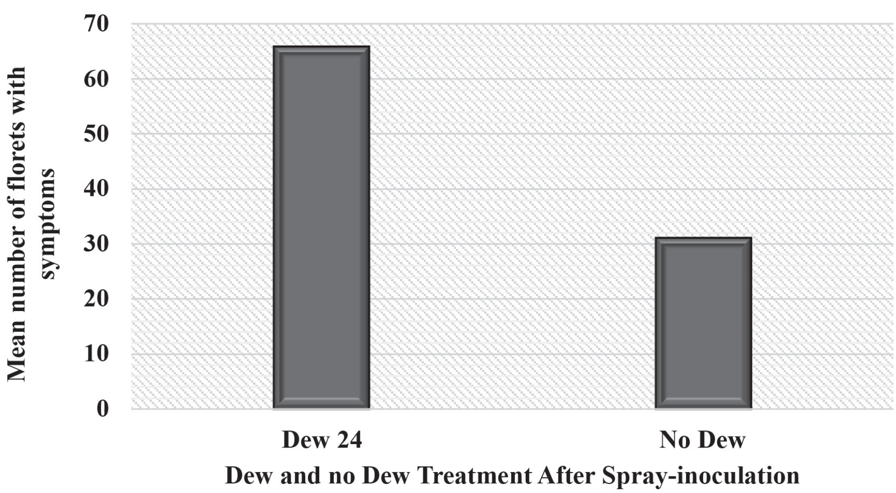


Fig. 1. Mean number of seeds that had bacterial panicle blight (BPB) symptoms when treated with dew in a dew chamber for 24 hours right after inoculation and no dew treatment.

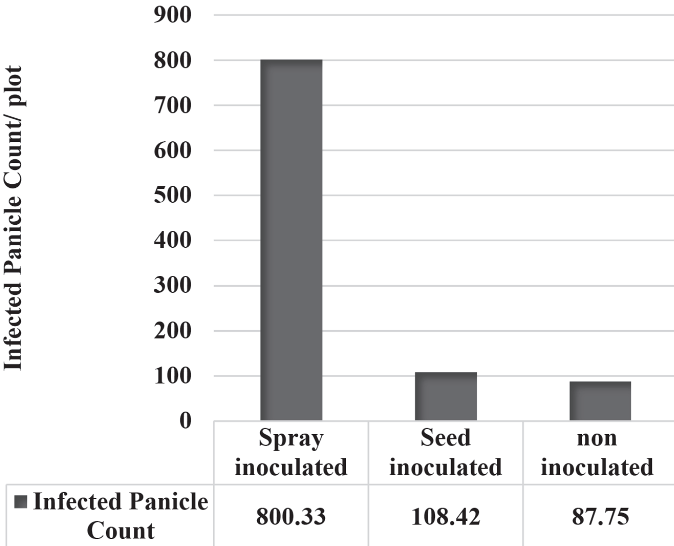


Fig. 2. Mean bacterial panicle blight (BPB) infected panicle count per plot area. Least significant difference at 0.05 = 55.6.

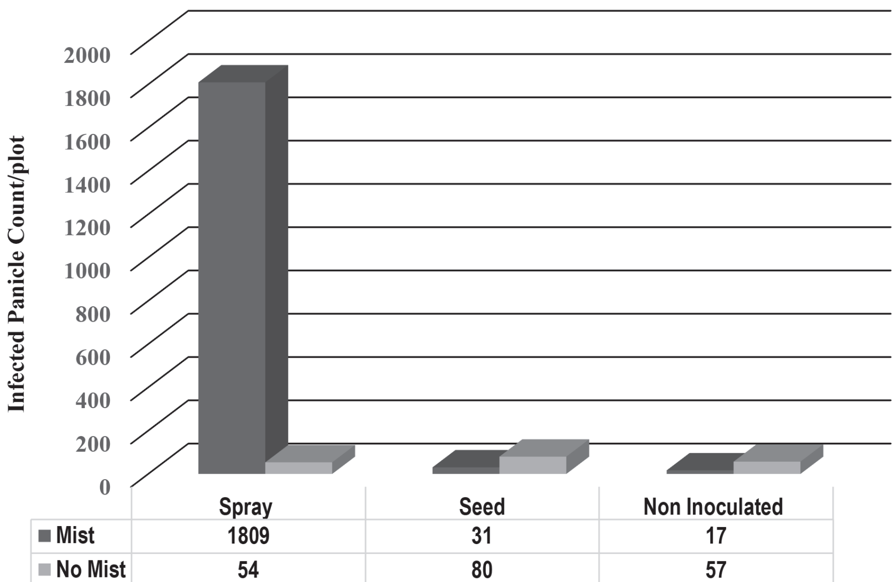
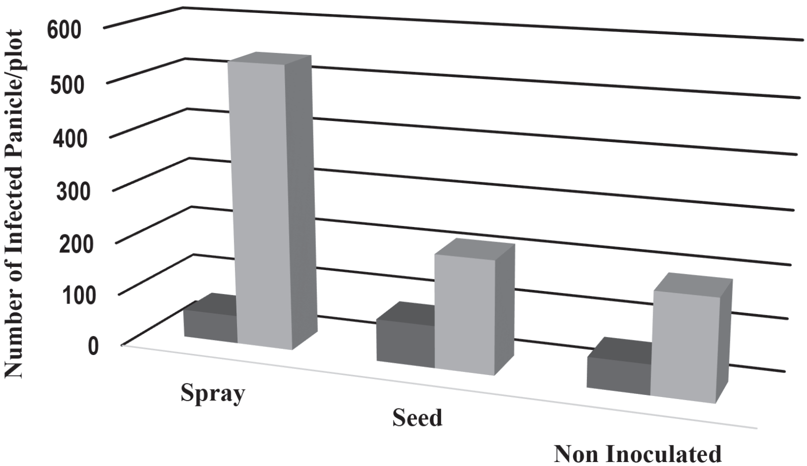
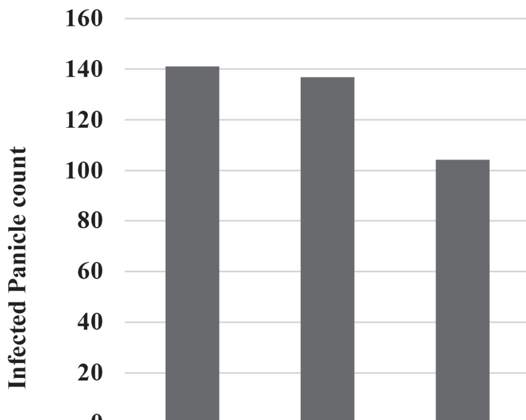


Fig. 3. Comparison between sequential field mist and no mist treatments on rice bacterial panicle blight incidence and severity where mist was started a week after spray inoculation with *Burkholdria glumae* for two weeks. Spray = spray inoculation with suspension of *Burkholderia glumae* at flowing stage; Seed = Seed inoculation before planting; Non-inoculated = Control, no bacterial inoculation in any form but it is possible the seed source has some level of infection.



	Spray	Seed	Non Inoculated
Before Harvey	54	80	57
After Harvey	538	215	190

Fig. 4. Mean number of symptomatic panicle counts in plots in three inoculation treatments before and after the tropical storm (Harvey) in 2017. Spray = spray inoculation with suspension of Burkholderia glumae at flowing stage; Seed + Seed inoculation before planting; Non- inoculated = Control, no bacterial inoculation but seed sources may have some level of infection.



	West Treeline	East Treeline	No Treeline
Infected Panicle Count/Plot	141.03	136.86	104.14

Fig. 5. Mean bacterial panicle blight infected panicle count per plot area. Least significant difference at 0.05 = 17.9.

Field Germplasm Evaluation, and Development of Diagnostic Methods for Bacterial Panicle Blight Disease of Rice in Arkansas

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Abstract

Bacterial panicle blight (BPB), caused mainly by the bacterial pathogen *Burkholderia glumae* posed a higher level of threat to rice production worldwide in recent years. Here, we report the response of over 290 rice entries evaluated by artificially inoculating with a bacterial suspension under field conditions. From the Uniform Regional Rice Nursery (URRN) field screening, nearly 10 percent and 6 percent of the entries showed a resistant and moderately resistant reaction, respectively. A subset of 10 entries showed lower BPB disease in both the URRN and Arkansas Rice Performance Trials (ARPT). From 60 symptomatic samples screened on semi-selective medium, 52 were further evaluated by molecular test. Among these, 45 isolates were confirmed as *B. glumae*. The remaining seven were bacteria other than *B. glumae* and none of these seven isolates matched to *B.gladioli*. The three methods of inoculation (clip, direct injection and panicle) tested showed distinct disease phenotypes between cultivars that traditionally have been considered resistant or moderately resistant. Direct injection of bacterial inoculum into the sheath caused pathogen-related necrotic spots around the site of inoculation but not in sheaths injected with water alone. The genes Os1g32460, Os05g30500, Os11g31190, Os11g12340, Os11g12330, Os11g12040, Os11g12300, Os11g12000 and Os08g25050 were tested to determine if they are differentially expressed between the moderately resistant cultivar Jupiter and the susceptible cultivar Bengal after inoculation with *B. glumae*. While several of the genes were found to be upregulated after pathogen infection, none of the genes tested were differentially expressed between resistant and susceptible cultivars and the results were highly variable depending on the time of inoculation. Therefore, more optimization is needed.

Introduction

Bacterial panicle blight (BPB) is relatively new disease to the U.S. and is threatening rice production in southern rice states. Bacterial panicle blight disease of rice is mainly caused by the gram-negative bacteria *Burkholderia glumae* and *Burkholderia*

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gladioli. Although several other factors including weather can result in rice panicle sterility, the symptoms associated with BPB are usually evident if detected early at grain filling. The brown discolorations on the bottom one-third of developing florets change with time and as saprophytes grow on sterile or dead floret tissues. Therefore, symptoms could be confusing at later stages of the rice grain filling stages. Overall, symptoms detected at the right timing include panicle discoloration, grain rot, and aborted or sterile florets. Panicles remain upright in a field during grain fill due to BPB disease (Nandakumar et al., 2009). BPB is favored by prolonged high night-temperatures during heading and flowering as they are the most susceptible developmental stages to the disease. Although BPB can be severe in some seasons with extended high night-time temperature, to date, severe BPB incidences have not been reported on hybrid rice in Arkansas. In 2017, no commercial field planted with conventional rice was reported to have BPB. Chemical options are not yet available to manage BPB for the U.S. rice production system. This report provides the summary on 2017 cultivar evaluations for BPB disease using artificial inoculation, a survey on *B. glumae* distribution in rice, greenhouse and laboratory techniques attempted to phenotype cultivars for resistance, and an update of functional marker development.

Procedures

Field Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

In 2017, rice in the Arkansas Rice Performance Trial (ARPT) and Uniform Regional Rice Nursery (URRN) consisting of 70 and 200 entries, respectively and 20 other selected rice lines from previous years and wild types were evaluated for BPB at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. Two sets of 290 entries were planted in 2-inch pot one month apart in a greenhouse. The early planted entries were hand-transplanted to a field bay on April the 20th, and the late on 12 June 2017. They were planted in duplicate in hill plots interspaced with Jupiter and Bengal after each 10 test entries. Jupiter and Bengal were included as reference plots for comparison to a moderately resistant and susceptible cultivar response, respectively. Entries were spray-inoculated using *B. glumae* bacterial suspension following the procedure in Wamishe et al. (2012). Disease reactions were evaluated three weeks after the last inoculation in each set using a 0 to 5 scale, where 0 is no disease and 5 severe disease. Later, the data were translated to the standard 0 to 9 scale (Table 1) for data analysis using SAS 9.3 Proc Glimmix.

Isolation and Identification of *Burkholderia* Species from Arkansas Rice

Nearly 60 panicle-samples that either showed some level of blanking or brown floret discoloration similar to BPB symptoms were collected from research stations where the ARPT and URRN were planted and from field plots of the Producers Rice Evaluation Program (PREP). No samples were collected from commercial production fields since there were no reports of BPB in 2017. Collected panicle samples were kept in brown paper bags to dry at room temperature until processed. About 100 seeds from each sample were randomly picked up and plated on CCNT, a semi-selective medium for *B. glumae* (Kawaradani et.al. 2000). Ten seeds were placed per plate which were incubated at 39 °C under dark. Seeds with a typical morphological symptom to *B. glumae* were counted and bacterial colonies were sub cultured to King's B medium for purification. Pure cultures were kept at -80° for further DNA extraction and molecular identification. The molecular identification included a known *B. glumae* isolate from RREC collection as positive control and specific primer pairs for *B. glumae* and *B. gladioli* described in Yukiko et. al. (2006).

Comparison of Methods to Evaluate Bacterial Panicle Blight in Rice Cultivars in a Greenhouse

We compared three methods of inoculation: clip inoculation, sheath injection and panicle inoculation to identify a reliable procedure that discriminates between the moderately resistant cultivar Jupiter and susceptible cultivar Bengal. For that purpose, *B. glumae* was grown on King's B (KB) broth at 30 °C overnight, cultures were washed twice with sterile water and bacterial concentration adjusted to OD_{600} = 0.2 and used for plant inoculation using the three different methods. For clip inoculation, rice plants were cut with scissors that had been dipped in a suspension of *B. glumae* or water, as control. For sheath injection, rice plants were injected in the sheath with 50 µL of bacterial inoculum. Panicle inoculation, panicles were dipped in bacterial inoculum. For the three methods of inoculation, plants were kept under conditions of high humidity in growth chambers.

Progress on Molecular Marker Search

Cultivars Jupiter and Bengal were inoculated with *B. glumae* or mock-inoculated with water. Inoculated plants were collected at 1 and 2 days after inoculation for RNA extraction and cDNA synthesis. Quantitative RT-PCR reactions were conducted with primers specific for the following genes: Os1g32460, Os05g30500, Os11g31190, Os11g12340, Os11g12330, Os11g12040, Os11g12300, Os11g12000 and Os08g25050 and using as a housekeeping gene ubiquitin 5. Expression of a given gene of interest was normalized against the housekeeping gene and comparing pathogen-inoculated plants versus mock-inoculated plants.

Results and Discussion

Evaluation of Rice for Resistance Against Bacterial Panicle Blight Disease

With the absence of chemicals to control BPB, development and use of improved disease resistant rice varieties remains the most important disease management strategy. After growing seedlings in the greenhouse for transplanting, there were several missing from the late planted hill plots. Therefore, the data were summarized from the early planted set. From the early planted URRN, there was only one missing (RU1703190) hill plot. Among the early planted URRN 21 entries were grouped as resistant (R) and

11 as moderately resistant (MR). Nearly 84% of the entries were in the susceptible categories, either MS (moderately susceptible), S (susceptible) or VS (very susceptible) (Fig. 1, Table 1). In previous years, it was shown that BPB disease was less severe when planting was done early in the season (Wamishe et al., 2015). Our early planting was mainly to catch the reactions of late maturing rice entries before missing the optimal weather condition at flowering stage where the crop was most susceptible. Nevertheless, in our late planted set, we were not able to get complete information because several entries died. The early death of rice in hill plots in this set was probably due to heat-herbicide combination effect.

From ARPT 18 entries were grouped in R and MR category (Table 2). Since some entries in ARPT were subsets in URRN, only 10 entries showed low BPB consistently and were grouped as R and MR (Table 3). There is a possibility of reading false negative (low disease) for BPB in late maturing rice even when they are planted early. BPB disease symptoms can be absent or minimal if the weather conditions are not favorable to the pathogen for multiplication. Therefore, repeated tests are required to ensure true BPB resistance in later maturing rice. For instance, Roy J, one of our susceptible variety had relatively low BPB for the past 3 years. However, historically, it is a susceptible variety. From entries repeated from previous years, RU1602115, RU1603153, RU1401105 from URRN were consistently R or MR and one entry from ARPT, STG14IMI-06-195 showed MR reaction (Table 4). The rest including Jasmine 85, Cocodrie, Lagrue, Lemont, Katy, Mars were either non consistent between replications or missing (Table 4).

Isolation and Identification of *Burkholderia* Species in Arkansas Rice

Of the 60 samples collected from rice fields in 2017, 52 were positive to BPB based on the semi -selective culture medium, CCNT. Of these, 3 samples had as high as 67% positive seeds and 49 of them up to 33% positive seeds on CCNT medium. Although the bacteria that grew on CCNT medium and then subcultured on KB medium for purification were thought to be *B. glumae*, further confirmation was required for definitive identification. Therefore, DNA was extracted and PCR based molecular technique was followed using specific primers for *B. glumae* and *B. gladioli*. Among the isolates, nearly 87% were confirmed as *B. glumae* while the remaining percent indicated bacteria other than *B. glumae*. However, none of these 13% matched to *B. gladioli*. Based on previous similar studies, although culture based identification has been useful as a first step process, molecular identity confirmation appeared to be very important for definitive identification (Mulaw et al., 2018).

Comparison of Methods to Evaluate Bacterial Panicle Blight in Rice Cultivars in a Greenhouse

The three methods of inoculation tested showed distinct disease phenotypes between the cultivar Jupiter, that traditionally has been considered resistant, in comparison with the cultivar Bengal, that has been considered susceptible. Sheath injection showed to be a promising method to evaluate the range of responses in germplasm collections. Panicle inoculation is an easy method of inoculation that allows for manipulation of a large number of rice cultivars at a given time. Previously published results showed that the genes Os1g32460, Os05g30500, Os11g31190, Os11g12340, Os11g12330, Os11g12040, Os11g12300, Os11g12000 and Os08g25050 were found to be differentially expressed between the moderately resistant cultivar CL161 with the susceptible cultivar CL151 after inoculation with *B. glumae* (Magbanue et al., 2014). When these genes were chosen for analysis in cultivars Jupiter and Bengal, several of the genes were found to be upregulated after pathogen infection. However, none of the genes tested were differentially expressed between resistant and susceptible cultivars and the results were highly variable depending on the time of inoculation. Therefore, more optimization is needed.

Significance of Findings

Development of a working toolbox to evaluate genetic resistance remains to be an important priority toward combating BPB disease in rice. Rice resistance to BPB would provide long-term control especially in years of increased disease pressure. The continuous surveys for *Burkholderia* species across Arkansas would provide information useful for research. Efforts in understanding of virulence, pathogenicity and epidemiology of the *Burkholderia* pathogens on rice should be helpful to identify effective BPB disease management strategies.

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Literature Cited

Kawaradani, M., K. Okada and S. Kusakari. 2000. New selective medium for isolation of *Burkholderia glumae* from rice seeds. J. Gen. Plant Pathol. 66:234-237.

Magbanue, Z.V., Arick, M. II., Buza, T., Hsu, C.Y., Showmaker, K.C., Chouvarine, P., Deng, P., Peterson, D. G., Lu, S. (2014). Transcriptomic dissection of the rice-Burkholderia gluma interaction. BMC genomics, 15: 755.

Mulaw, T. Wamishe, Y. and Jia, Y. 2018. Characterization and in Plant Detection of Bacteria that Cause Bacterial Panicle Blight of Rice. Am. J. Plant Sci., Special Issues Plant Pathology, Vol.9 No.4, Mar 2018 (In print).

Nandakumar, R., A.K.M. Shahjahan, X.L. Yuan, E.R. Dickstein, D.E. Groth, and C.A. Clark. 2009. *Burkholderia glumae* and *B. gladioli* cause bacterial panicle blight in rice in the southern United States. Plant Dis. 93:896-905.

Wamishe, Y.A., Y. Jia, C. Kelsey, S. Belmar, and M. Rasheed. 2012. Development of panicle diagnostic methods for monitoring rice bacteria panicle blight disease and evaluation of rice germplasm for resistance. *In:* R.J. Norman and K.A.K. Moldenhauer (eds). B.R.Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 609:103-108. Fayetteville.

Wamishe, Y.A., T. Gebremariam, S. Belmar, C. Kelsey, and T. Mulaw. 2015. Studies on cultural management options for rice bacterial panicle blight disease. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2014. University of Arkansas Agricultural Experiment Station Research Series 626:118-126. Fayetteville.

Yukiko Maeda, Hirosuke Shinohara, Akinori Kiba, Kouhei Ohnishi, Naruto Furuya, Yoshiaki Kawamura, Takayuki Ezaki, Peter Vandamme, Seiya Tsushima and Yasufumi Hikichi. (2006). Phylogenetic study and multiplex PCR-based detection of *Burkholderia plantarii*, *Burkholderia glumae* and *Burkholderia gladioli* using gyrB and rpoD sequences. Int. J. System. Evolut. Microbiol., 56:1031–1038. DOI 10.1099/ijs.0.64184-0.

Table 1. Resistant and moderately resistant entries to bacterial panicle blight disease in April field planted URRN rice and spray-inoculated twice between boot split and flowering in 2017.

Entry #	Cultivar	Mean (0 to 9)†	Entry #	Cultivar	Mean (0 to 9)
69	RU1603144	1.8 C‡	104	RU1703104	2.7 C
73	RU1704073	1.8 C	149	RU1702149	2.7 C
84	RU1701084	1.8 C	150	RU1703150	2.7 C
85	RU1702085	1.8 C	176	RU1701176	2.7 C
90	RU1701090	1.8 C	193	RU1704193	2.7 C
96	RU1701096	1.8 C	37	JUPITER	3.6 BC
107	RU1603126	1.8 C	7	RU1701007	3.6 BC
148	RU1701148	1.8 C	64	RU1401105	3.6 BC
153	RU1603153	1.8 C	80	TITAN	3.6 BC
179	RU1701179	1.8 C	93	RU1701093	3.6 BC
15	RU1604193	2.7 C	100	RU1704100	3.6 BC
16	RU1604197	2.7 C	118	CL172	3.6 BC
46	RU1303153	2.7 C	124	RU1701124	3.6 BC
77	RU1704077	2.7 C	139	RU1701139	3.6 BC
79	ROYJ	2.7 C	140	RU1702140	3.6 BC
102	RU1501102	2.7 C	180	RU1702180	3.6 BC
			126	RU1703126	3.6 BC

† The standard 0-5 was used to evaluate the entries where 0 represented no diseases and 5 severe disease were later translated to a 0 to 9 scale for analysis.

‡ Rice entries followed by the same letter are not significantly different at 0.05 level. Entries followed by a letter C alone were considered relatively better in resistance than those followed by BC and were grouped as R and MR, respectively due to continuous and relative resistance levels.

Table 2. Resistant and moderately resistant entries to bacterial panicle blight disease in April field planted ARPT rice and spray-inoculated twice between boot split and flowering in 2017.

Entry #	Cultivar	Mean (0 to 9)†	Entry #	Cultivar	Mean (0 to 9)
213	CL172	2.7 C‡	247	RU1701179	3.6 BC
222	CPS2	2.7 C	252	RU1501102	3.6 BC
240	RU1701084	2.7 C	253	RU1701105	3.6 BC
248	STG14L-01-005	2.7 C	257	RU1701050	3.6 BC
203	Roy J	3.5 BC	262	RU1601111	3.6 BC
228	RU1701090	3.6 BC	266	RU1701130	3.6 BC
241	RU1701081	3.6 BC	267	16SIT594	3.6 BC
243	RU1601070	3.6 BC	275	RU1601185	3.6 BC
246	RU1701176	3.6 BC	276	JUPITER	3.6 BC

† The standard 0-5 was used to evaluate the entries where 0 represented no diseases and 5 severe disease were later translated to 0 to 9 scale for analysis.

‡ Rice entries followed by the same letter are not significantly different at 0.05 level. Entries followed by a letter C alone were considered relatively better in resistance than those followed by BC and were grouped as R and MR, respectively due to continuous and relative resistance levels.

Table 3. Rice entries selected as sub-set of 2017 Arkansas Rice Performance Trials and Uniform Regional Rice Nursery consistent in their resistant and moderately resistant reactions to artificial inoculation with a suspension of *Burkholderia glumae* in field test in 2017.

Entry #	Cultivar	URRN (0 to 9)	ARPT (0 to 9)
84	RU1701084	1.8	2.7
90	RU1701090	1.8	3.6
96	RU1701096	1.8	4.5
179	RU1701179**	1.8	3.6
102	RU1501102	2.7	3.6
176	RU1701176	2.7	3.6
118	CL172	3.6	2.7
37	JUPTER	3.6	3.6
64	RU1401105**	3.6	5.4
139	RU1701139**	3.6	4.5

Although the readings were not exactly the same, the fact that they rated consistently low is a good indication that it may be as shown.

Table 4. Select group of rice entries that showed promising resistance to bacterial panicle blight from the Uniform Regional Rice Nursery and Arkansas Rice Performance Trials in 2017.

		Reaction	
Source	**Cultivar**	**Rep -1**	**Rep -2**
URRN	RU1401105	MS	MR
URRN	RU1503003	S	MISSING
URRN	RU1003123	MISSING	S
URRN	RU1404156	VS	MISSING
URRN	RU1601070	MISSING	MR
URRN	RU1602115	MR	MR
URRN	RU1603116	MISSING	MISSING
URRN	RU1603126	MR	MISSING
URRN	RU1603153	R	MR
ARPT	RT XL760	MR	MISSING
ARPT	RU1501176	S	S
ARPT	STG14IMI-06-195	MR	MR
	Jasmine 85	S	S
	Cocodrie	MR	MS
	Lagrue	S	MR
	Lemont	R	MR
	Katy	MISSING	MISSING
	Mars	S	VS
	Tequing	MISSING	MISSING
	Wild rice	MISSING	MR
	Jupiter	MR	MR
	Bengal	S	S

Older varieties mostly used as parents of current conventional rice at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center breeding programs and a few other wild types were also tested along with ARPT and URRN in 2017.
MS = moderately susceptible; S = susceptible; VS = very susceptible; MR = moderately resistant; R = resistant.

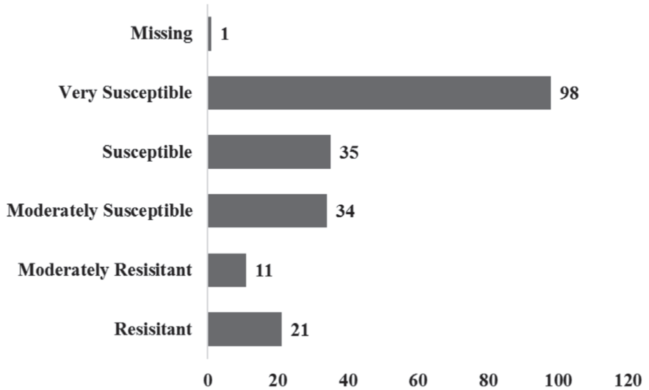

Fig. 1. Number and reaction categories of Uniform Regional Rice Nursery rice entries tested in 2017 for bacterial panicle blight disease of rice using artificial spray inoculation between boot split and flowering developmental stage.

Economics of Fungicide Application for Rice Sheath Blight Disease in Arkansas (Year 2)

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Abstract

Sheath blight disease of rice caused by *Rhizoctonia solani* AG1-1A is one of the major diseases of rice in Arkansas. Fungicides are often recommended if established threshold levels are reached and the disease progresses into the upper canopy during reproductive growth stages. The economic benefit of these applications must periodically be re-evaluated based on changes in cultivars, management practices, and fungicide efficacy. The effect of fungicide application timing was evaluated on the cultivars LaKast and Jupiter at two seeding rates. Fungicide timings consisted of an untreated control and applications at panicle differentiation or boot split. All plots were artificially inoculated with the sheath blight fungus. Similar to 2016, both fungicide application timings resulted in reduced sheath blight incidence and higher grain yields compared to the untreated control. However, mean monetary gains were variable based on trial location and fungicide application timing.

Introduction

Sheath blight is one of the major diseases of rice in Arkansas. The disease is caused by *Rhizoctonia solani* AG1-1A, a soilborne fungus that has several host plants. The fungus causes prominent diseases in corn and soybean and prevails in any rice field under favorable conditions. Prolonged periods of high humidity and high temperatures favor the sheath blight disease of rice to initiate infection and progress throughout the foliar canopy. The fungus survives as mycelia or mycelial mass known as “sclerotia”. These fungal structures are capable of floating on surfaces of flooded rice fields. Infection begins when the floating sclerotia contact the growing rice sheath at or just above the waterline. Later, the infection progresses upward to the canopy and spreads sideways to neighboring plants during physical contact of plant parts. Hence, rice fields with thick

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plant stands and/or excessive nitrogen rates that encourage vegetative growth often show severe sheath blight disease. In favorable environmental conditions, the disease usually starts between the panicle initiation (green-ring) and panicle differentiation (1/2 inch internode elongation) growth stages of rice. Disease development and spread can continue throughout the season if favored by weather. Therefore, scouting the field for sheath blight is recommended starting at green ring and needs to be continued to pre-heading. Due to the nature of sheath blight disease progress vertically up the plant canopy, relatively shorter or semi-dwarf varieties can be damaged more severely than taller varieties. Likewise, due to its potential to progress in horizontal directions, rice cultivars that are leafy and form a closed canopy can create a favorable microenvironment for the development of sheath blight.

Sheath blight disease has increased in Arkansas through the years with higher use of fungicides. Sheath blight is often well managed when using integrated approaches by planting tolerant cultivars and best management practices. A onetime fungicide application is recommended only if a treatment threshold warrants. The optimum timing of a fungicide application to Arkansas rice is often 7-14 days past panicle differentiation. This timing can be impacted by varietal susceptibility, height of the variety, favorability of weather conditions, treatment threshold, and seeding and nitrogen fertilizer rates. To date, the commercially available and recommended fungicides for sheath blight in Arkansas have been shown to slow down the disease progress considerably. In most cases, more than a single fungicide application to manage sheath blight alone is not economical to Arkansas rice production.

Regardless of the threshold levels and frequency of application issued by the University of Arkansas System Division of Agriculture, Cooperative Extension Service for managing sheath blight disease in rice, unneeded fungicide application is not uncommon. Such a practice adds additional expense to rice producers and at the same time risks the longevity of the fungicides with development of pathogen insensitivity. Although several factors need to be considered to make the decision on fungicide application, the main objective of this study was to assess the monetary gains/losses of sheath blight control with a onetime fungicide application under alternative seeding rates and fungicide application timing related to rice developmental stages.

Procedures

Two trials were conducted at the University of Arkansas System Division of Agricultures' Rice Research and Extension Center (RREC) near Stuttgart, Ark. and Pine Tree Research Station (PTRS) near Colt, Ark., similar to 2016. Two cultivars, LaKast and Jupiter, represented tall and short rice cultivars. Each cultivar was planted at both an optimum and maximum seeding rate of 72 and 109 pounds per acre for LaKast, and 73 and 111 pounds per acre for Jupiter. Two fungicide application timings at panicle differentiation and boot split were evaluated. This resulted in a 2 × 2 × 2 factorial (cultivar × seeding rate × fungicide timing). Trials were drill-seeded on 19 and 25 April at RREC and PTRS, respectively. Plot size was 8 rows on 7.5-inch spacing and 15 ft in length. Plots at RREC were artificially inoculated with fresh inoculum of *Rhizoctonia* *solani* Ag1-IA on 7 July and 11 July close to the panicle differentiation growth stage of rice. The first fungicide application at RREC was made on 14 July. Quadris fungicide (active ingredient azoxystrobin) was applied at 12.5 oz per acre at panicle differentiation. A second fungicide application was made to different plots at boot split on 21 July. Treatments of plots at PTRS were handled similarly to those at the RREC. Plots were inoculated on 11 July at the green ring stage. The first fungicide application was made on 18 July and the boot split application on 27 July.

At both locations, sheath blight disease progression began seven days after inoculation. Two disease readings were recorded at the RREC and only one reading at PTRS 28 days after the first fungicide application (DAA) and prior to harvest. Disease ratings included both the vertical and horizontal spread of sheath blight. A 0 to 9 scale was used to estimate the vertical disease progress where 0 (no disease) and 9 (disease at panicle). Horizontal infection was estimated by the percentage of plants infected. All measured parameters of disease index, grain yield, milling yield (whole kernel and total rice yields), and financial gain or loss were analyzed statistically using PROC GLM procedure in SAS 9.3.

Monetary gains or losses associated with sheath blight disease control were calculated as gross returns (rice price × yield) less the cost of fungicide application and cost of seed. A rice price of $5.22/bushel was used in the analysis and represented the average U.S. farm price for rice for the months of August through October 2017 (USDA, NASS, 2018). The cost of fungicide application included both the cost of the fungicide itself and the cost of making one aerial fungicide application. Fungicide product cost was calculated at $1.95 per ounce for Quadris (Azoxystrobin) multiplied by the fungicide application rate (12.5 oz per acre). A cost of $7 per acre was charged for custom aerial application. The cost of seed was calculated as the product of the seeding rates used for each cultivar multiplied by a seed price of $0.43 per pound. Costs per unit for fungicide, seed, and aerial application were obtained from 2017 Arkansas crop enterprise budgets (Flanders et al. 2017). Monetary gains to fungicide application were calculated by location, cultivar, seeding rate, and fungicide application. Monetary gains of sheath blight control were also analyzed statistically using the PROC GLM procedure in SAS 9.3.

Results and Discussion

Although the season started wet in early spring, sheath blight disease progressed very slowly due to the hot and dry weather conditions in June and July. Regardless, the disease reached its peak in unsprayed plots after the rain brought by tropical storm Harvey towards the end of August (Fig. 1). The tropical storm also forced some of the rice to lodge particularly in plots planted with the taller variety, LaKast. Due to clear differences in disease levels at the end of the season, only the sheath blight disease rating taken prior to harvest at RREC was used in the analysis. Plant stands at PTRS were visually thinner in 2017 compared to 2016; therefore, sheath blight disease development was poor and erratic even after the rain. Plant lodging at RREC was related more to the wind force associated with tropical storm, Harvey than with the sheath blight disease. There were significant differences in sheath blight disease levels between sprayed and unsprayed plots for both cultivars at RREC. However, there was no significant difference in disease levels between the timing of fungicide applications (Figs. 2 and 3). Results of the fungicide timing at RREC agreed with the results in 2016 that showed fungicide application either at PD or boot split stage of the crop as adequate (Wamishe et al., 2016). On the other hand, the lower and erratic incidence of sheath blight disease at PTRS did not show conclusive results (Fig. 3). Jupiter produced significantly higher mean grain yields than LaKast at RREC similar to 2016, but there was no yield difference at PTRS (Table 1). Averaged across cultivars, the maximum seeding rate did not result in significantly higher grain yield compared to the optimum seeding at both locations. At RREC and PTRS both fungicide application timings resulted in insignificant differences in grain yields compared to the untreated control which accounted for lesser effect of the disease on yield since it progressed late in the season. Milling yields, percent whole kernel rice, and total milled rice were not significantly different between the cultivars at RREC compared to the results of 2016. No differences in milling qualities at PTRS agreed with year 2016 findings. There were no significant differences for percent whole kernel rice, and total milled rice based on cultivar, seeding rate, or fungicide spray timings at either location (Table 2).

For the RREC location, mean monetary gains of sheath blight control varied primarily by variety (Table 3). Mean monetary gains were largest for Jupiter than for LaKast for five of six spray timing/seeding rate combinations. The boot split/maximum seeding rate combination was the only exception, as the mean monetary return for this combination was less for Jupiter than for LaKast. The largest monetary gain for LaKast occurred for the optimum seeding rate when spraying fungicide at panicle differentiation ($915.02/acre, Table 3). Alternatively, the largest monetary gain for Jupiter occurred for the maximum seeding rate when the fungicide was sprayed at panicle differentiation ($1023.21/acre, Table 3). For the PTRS location, mean monetary gains tended to be largest numerically when no fungicide was sprayed (Table 4). The only exception was with Jupiter under the optimum seeding rate. Under the optimum seeding rate, the largest mean monetary gain for Jupiter occurred when spraying fungicide at boot split ($1094/acre, Table 4). The optimum seeding rate/boot split combination also produced the largest overall mean monetary gain for Jupiter. For LaKast, the largest mean monetary gain occurred for optimum seeding when spraying no fungicide ($1053.69/acre, Table 4).

Statistical analysis results of differences in mean monetary gains are presented for both locations by cultivar, seeding rate, and fungicide spray timing in Table 5. Mean monetary gains were significantly larger for Jupiter than for LaKast at the RREC. However, no significant differences in mean monetary gains occurred for any other comparison.

This is the second year of the study which will be repeated in 2018. Again, if the sheath blight disease progressed earlier in the season, it may have had a greater effect on the crop causing weak stems and subsequently lodging. However, lodging of plants at RREC was associated with the tropical storm Harvey than with the severity of sheath blight rice disease because the yield in unsprayed plots would have been considerably reduced and grain quality affected by the sheath blight disease. However, two years of results from RREC shows that grain quality was not affected as much as the yield. In some years, weather factors such as heavy rain storms, strong wind, and management practices such as amount and timing of nitrogen fertilization and flooding play role in the severity level of the disease. Although there was no significant grain yield difference between the two fungicide spray timings, both timings resulted in increased grain yields compared to the untreated control. These results suggest the current recommended fungicide application timing of panicle differentiation through heading is generally appropriate for use in Arkansas.

Significance of Findings

Threshold levels and frequency of fungicide application issued by the University of Arkansas System Division of Agriculture, Cooperative Extension Service for managing sheath blight disease in rice, need to show economic benefit of these applications with periodic re-evaluation based on changes in cultivars, management practices, and fungicide efficacy. Unneeded fungicide application adds additional expense on rice producers and at the same time risks the longevity of the fungicides associated with development of pathogen insensitivity.

Acknowledgments

The authors appreciate the funding support from the rice growers of Arkansas administered by the Arkansas Rice Research and Promotion Board; support also provided by the University of Arkansas System Division of Agriculture. We also appreciate the assistance of Shawn Clark and Yihalem Liyew at the Pine Tree Research Station.

Literature Cited

USDA-NASS. 2018. United States Department of Agriculture, National Agricultural Statistics Service. Quick Stats (Searchable Database). Access Date: 8 February 2018. Available at: https://quickstats.nass.usda.gov/

Flanders, A. and B. Watkins. 2017. 2017 Crop Enterprise Budgets for Arkansas Field Crops Planted in 2017. University of Arkansas Division of Agriculture, Cooperative Extension Service. Available at: https://www.uaex.edu/farm-ranch/economics-marketing/farm-planning/budgets/2017%20Manuscript.pdf

Wamishe, Y., K.B. Watkins, J. Hardke, T. Gebremariam, T. Mulaw, and S. Belmar. 2016. Economics of fungicide application for rice sheath blight disease in Arkansas. *In:* R.J. Norman and K.A.K. Moldenhauer (eds). B.R.Wells Rice Research Studies 2017. University of Arkansas Agricultural Experiment Station Research Series 643:137-146. Fayetteville.

Table 1. Differences in mean yields from sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station, 2017.

Class	RREC†	PTRS
	--------------------bu/ac--------------------	
Variety		
LaKast	179.0 B‡	207.0 A
Jupiter	194.0 A	205.4 A
LSD‡	12.8	12.9
Seeding Rate		
Optimum	185.1 A	209.0 A
Maximum	188.0 A	203.4 A
LSD	12.8	12.9
Spray Timing		
No Spray	181.7 A	207.0 A
PD	191.0 A	205.7 A
BS	186.8 A	205.8 A
LSD	15.6	15.8

† RREC = Rice Research and Extension Center, Stuttgart; PTRS = Pine Tree Research Station, near Colt; LSD = least significant difference; PD = panicle differentiation; and BS = boot split.

‡ Means within a column followed by different letters are significantly different at the $P = 0.05$ level.

Table 2. Differences in mean total milled yield percent and head yield percent from sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station, 2017.

	RREC		PTRS	
Class	TYD†	HYD	TYD	HYD
Variety				
LaKast	70.8 A‡	56.7 A	70.3 A	56.2 A
Jupiter	70.8 A	56.6 A	70.6 A	56.4 A
LSD	1.21	0.97	0.61	0.49
Seeding Rate				
Optimum	70.8 A	56.7 A	70.3 A	56.3 A
Maximum	70.8 A	56.6 A	70.5 A	56.4 A
LSD	1.21	0.97	0.61	0.49
Spray Timing				
No Spray	71.8 A	57.4 A	70.2 A	56.1 A
PD	70.1 B	56.1 B	70.5 A	56.4 A
BS	70.6 AB	56.4 AB	70.6 A	56.5 A
LSD	1.49	1.19	0.75	0.61

† RREC = Rice Research and Extension Center, Stuttgart; PTRS = Pine Tree Research Station, near Colt; LSD = least significant difference; PD = panicle differentiation; BS = boot split; TYD = total rice yield; and HYD = head rice yield.

‡ Means within a column followed by different letters are significantly different at the *P* = 0.05 level.

Table 3. Monetary gains of sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center, 2017.

Variety	Seeding rate	Spray timing†	Gross return	Seed cost	Fungicide cost	Monetary gain
			($/ac)			
LaKast	Optimum	No Spray	899.11	30.96	0.00	868.15
		PD	952.39	30.96	31.41	890.01
		BS	977.39	30.96	31.41	915.02
	Maximum	No Spray	884.33	46.87	0.00	837.46
		PD	951.01	46.87	31.41	872.73
		BS	940.88	46.87	31.41	862.60
Jupiter	Optimum	No Spray	1033.99	31.82	0.00	1002.17
		PD	982.37	31.82	31.41	919.13
		BS	951.09	31.82	31.41	887.86
	Maximum	No Spray	976.41	47.73	0.00	928.68
		PD	1102.35	47.73	31.41	1023.21
		BS	1031.13	47.73	31.41	951.99

† No spray = control; PD = panicle differentiation; BS = boot split.

Table 4. Monetary gains of sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Pine Tree Research Station, 2017.

Variety	Seeding rate	Spray timing†	Gross return	Seed cost	Fungicide cost	Monetary gain
			-------------------------	-------$/ac-------	-------------------------	
LaKast	Optimum	No Spray	1084.65	30.96	0.00	1053.69
		PD	1077.28	30.96	31.41	1014.90
		BS	1099.85	30.96	31.41	1037.48
	Maximum	No Spray	1090.25	46.87	0.00	1043.38
		PD	1075.74	46.87	31.41	997.45
		BS	1054.86	46.87	31.41	976.57
Jupiter	Optimum	No Spray	1055.60	31.82	0.00	1023.78
		PD	1070.47	31.82	31.41	1007.23
		BS	1157.91	31.82	31.41	1094.68
	Maximum	No Spray	1092.32	47.73	0.00	1044.59
		PD	1072.36	47.73	31.41	993.21
		BS	985.33	47.73	31.41	906.18

† No spray = control; PD = panicle differentiation; BS = boot split.

Table 5. Differences in mean monetary gains of sheath blight control by variety, seeding rate, and spray timing, University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Pine Tree Research Station, 2017.

Class	RREC†	PTRS
	----------$/ac----------	
Variety		
LaKast	874.33 B‡	1020.58 A
Jupiter	952.17 A	1011.62 A
LSD	66.64	67.32
Seeding Rate		
Optimum	913.72 A	1038.63 A
Maximum	912.78 A	993.57 A
LSD	66.64	67.32
Spray Timing		
No Spray	909.12 A	1041.36 A
PD	926.27 A	1003.20 A
BS	904.37 A	1003.73 A
LSD	81.62	82.46

† RREC = Rice Research and Extension Center, Stuttgart; PTRS = Pine Tree Research Station, near Colt; LSD = least significant difference; No spray = control; PD = panicle differentiation; BS = boot split.

‡ Means within a column followed by different letters are significantly different at the *P* = 0.05 level.

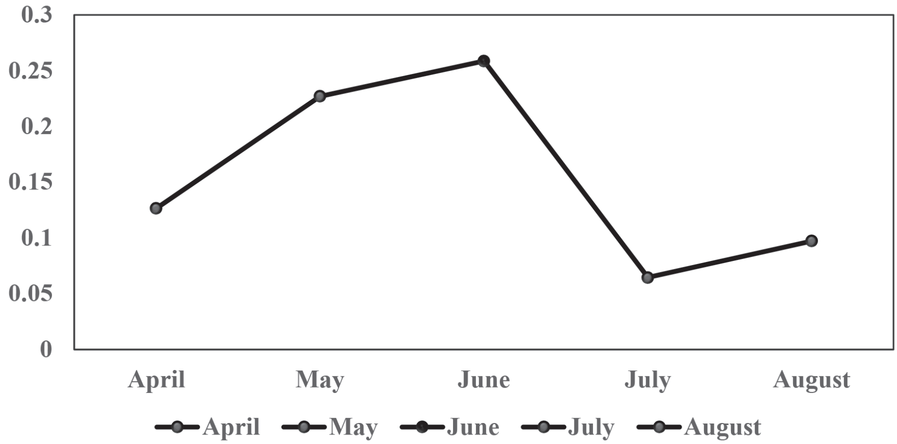

Fig. 1. Monthly mean rainfall (inch) of 2017 from April until August.

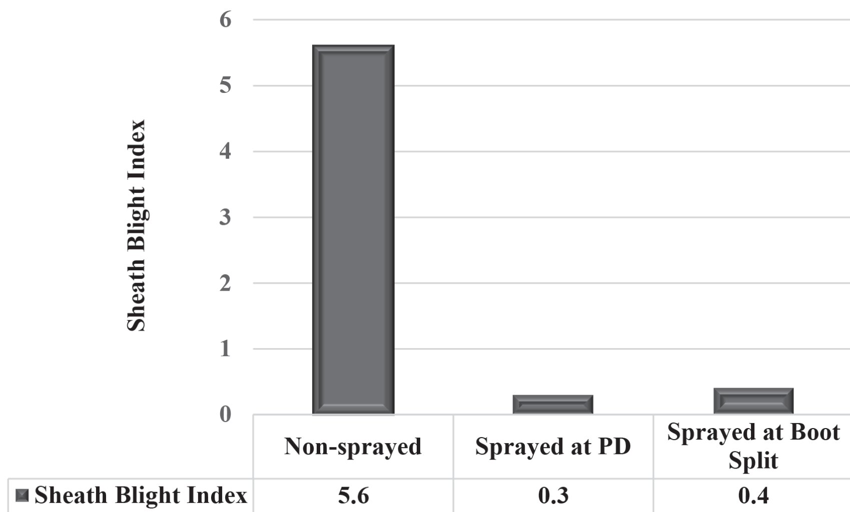

Fig. 2. Sheath blight disease index as affected by spray timing in rice varieties Lakast and Jupiter at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark., in 2017. 0 = unsprayed control; PD = panicle differentiation. Least significant difference = 0.82 at 0.05.

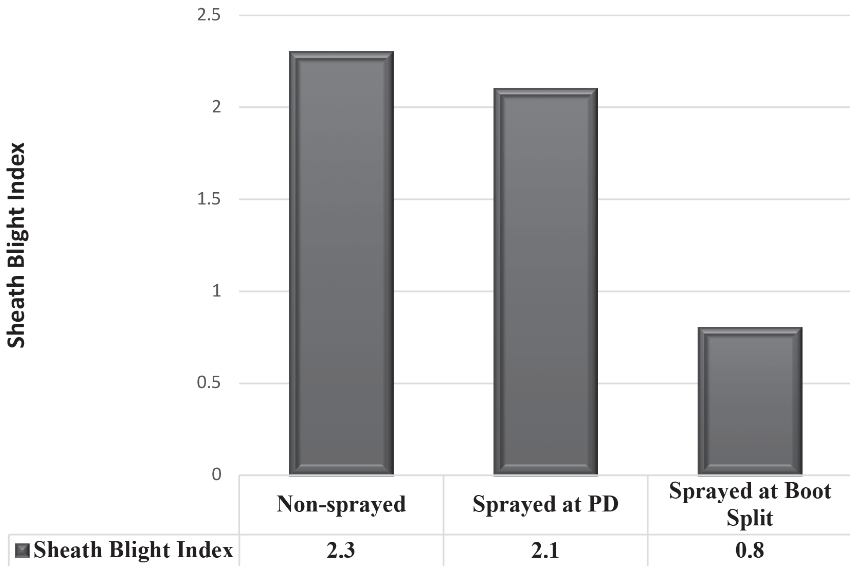

Fig. 3. Sheath blight disease index as affected by spray timing in rice varieties Lakast and Jupiter at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt. Ark., in 2017. PD = sprayed at panicle differentiation. Least significant difference = 1.06 at 0.05.

Impact of Insecticide Seed Treatments across Multiple Planting Dates of Rice

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Abstract

Studies were conducted to evaluate insecticide seed treatments for control of rice water weevil and evaluate yield benefits across a wide planting window from 2015 to 2017. A reduction in rice water weevil densities was observed for Cruiser® and Dermacor® X-100 compared to the fungicide only seed treatment, particularly for plantings in mid-May and early-June. A greater increase in yield was observed for earlier plantings compared to later plantings. Cruiser® yielded greater than the fungicide only seed treatment across all planting dates.

Introduction

Approximately 1.1 million acres of rice, *Oryza sativa* L., are planted annually in Arkansas, making it one of the state's top commodities (NASS 2017). Due to the large acreage dedicated to rice production, it is planted over a relatively broad 4 month period from late-March through mid-June. Multiple studies have observed yield benefits in rice planted from early to mid-April, compared to May plantings (Hardke et al., 2018).

Rice water weevil, *Lissorhoptrus oryzophilus* (Kushel), and grape colaspis, *Colaspis brunnea* (F.), are the two most destructive insect pests in Arkansas rice (Lorenz and Hardke, 2013). Larvae of these pests feed on the roots and underground stem portion of the rice plant (Lorenz and Hardke, 2013). Grape colaspis is a pre-flood pest of rice, with overwintering larvae moving vertically in the soil profile to feed after germination has occurred. Rice water weevil adults are attracted to open water, such as when the

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permanent flood is applied to rice fields (Stout et al. 2002). Upon flood establishment, rice water weevil adults migrate into rice fields and begin feeding on the rice foliage. Foliage feeding from adult rice water weevils causes scarring on the leaf surface, but the scarring alone has not been directly associated with yield loss (Tindall and Stout, 2003). Larvae of the rice water weevil prune plant roots and have the potential to cause catastrophic yield loss. (Lorenz and Hardke, 2013). Insecticide seed treatments are the most effective control measures for both of these yield limiting pests (Lorenz and Hardke, 2013).

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart Ark., from 2015 through 2017 to evaluate insecticide seed treatments across multiple planting dates. Rice was planted approximately every 15 days from mid-March through early June. The experiments were arranged as a split-block within a randomized complete block design. The main plot factor was planting date and the sub-plot factor was seed treatment, with four replications within each planting. For each planting, Roy J was drill-seeded on 7.5 inch spacing at 75 pounds per acre. Four seed treatments were used; Cruiser (Thiamethoxam, Syngenta) at 0.034 mg ai/seed, Nipsit Inside (Clothianidin, Valent) at 0.16 mg ai/seed Dermacor X-100 (Chlorantraniliprole, DuPont) at 0.017 mg ai/seed, and a fungicide only seed treatment. The fungicide only seed treatment consisted of Apron XL (Mefenoxam, Syngenta), Maxim 4 FS (Fludioxonil, Syngenta), and Dynasty 83 FS (Azoxystrobin, Syngenta). The same fungicide package was also applied to the Cruiser, Nipsit Inside, and Dermacor treatments.

Rice water weevil densities were evaluated approximately 21 days after establishment of the permanent flood by taking 3 core samples per plot with a 4 inch diameter core sampler. Samples were processed at the University of Arkansas System Division of Agriculture's Lonoke Agricultural Extension and Research Center, by washing core samples with water into a 40 mesh sieve. Once cores were washed, the sieve was placed into a warm salt water solution allowing the larvae to float and then counted. Yield was recorded using a plot combine equipped with a harvest master system for all plots. An analysis of variance was conducted on all data in SAS 9.4 (Proc GLIMMIX, SAS Institute, Cary N.C.) with an alpha level of 0.05. Due to seed treating issues for Nipsit Inside during 2017, two analysis were conducted. The first analysis consisted of the data from 2015 and 2016 combined for all treatments. The second analysis was all data from 2015 through 2017 excluding Nipsit Inside.

Results and Discussion

Rice Water Weevil Efficacy

An interaction between planting date and seed treatment for rice water weevil densities was observed (Fig. 1). In general, greater densities of rice water weevil larvae were observed at later plantings (Fig. 1). The insecticide seed treatments did not differ from the fungicide only until the mid-May planting (Fig. 1). At the mid-May planting

Cruiser and Dermacor X-100 had fewer rice water weevil larvae than the fungicide only, although Nipsit Inside was not different from any of the other treatments (Fig. 1). At the early June planting, all insecticide seed treatments had fewer rice water weevil larvae than the fungicide only, with Dermacor X-100 have fewer rice water weevil larvae than all other treatments (Fig. 1).

A similar interaction between planting date and seed treatment for rice water weevil densities was observed when data was combined for Dermacor X-100, Cruiser, and the fungicide only from 2015-2017. In general, greater densities of rice water weevil larvae were observed at later plantings. Dermacor X-100 and Cruiser had fewer rice water weevil larvae than the fungicide only at the mid-May and early June plantings. Dermacor X-100 and Cruiser only differed from one another at the early-June planting, with Dermacor X-100 having fewer rice water weevil than Cruiser.

Yield

No interaction between planting date and seed treatment was observed for yield for the 2015-2016 data. An effect of planting date was observed for yield (Fig. 2). The mid-March planting yielded greater than all plantings except the mid-April planting (Fig. 2). The early April and mid-May plantings yielded less than all other plantings except the early May planting (Fig. 2). No effect of seed treatment was observed for yield, with all treatments yielding statistically the same.

No interaction between planting date and seed treatment was observed for yield when data was combined for Dermacor X-100, Cruiser, and the fungicide only from 2015-2017. An effect of planting date was observed for yield. Similar to the 2015-2016 data, the mid-March and mid-April plantings had greater yields than all other plantings. The early-June planting had less yield than all plantings except the early-May planting. An effect of seed treatment was also observed for yield (Fig. 3). Cruiser had greater yield than the fungicide only seed treatment (Fig. 3). Dermacor X-100 did not yield different than the fungicide only or Cruiser seed treatments (Fig. 3).

Significance of Findings

Rice planted in May or later is more likely to encounter yield limiting densities of rice water weevil. Insecticide seed treatments can effectively help growers combat these pests. Although Dermacor® X-100 had fewer rice water weevils than Cruiser® at the early June planting, overall Cruiser® was the only insecticide seed treatment to yield greater than the fungicide only seed treatment. An insecticide seed treatment should be considered at all planting dates because there are few effective methods to control rice water weevil larvae once an infestation has occurred.

Acknowledgments

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Literature Cited

Hardke, J.T., R. Baker, T. Barber, N.Bateman, M. Hamilton, C. Henry, G. Lorenz, R. Mazzanti, R. Norman, J. Norsworthy, T. Roberts, B. Scott, N. Slaton, and Y. Wamishe. 2018. 2018 Rice Farming for Profit. University of Arkansas System Division of Agriculture Cooperative Extension Service. Pg. 5. Available at: https://uaex.edu/farm-ranch/crops-commercial-horticulture/rice/2018%20Rice%20Farming%20for%20Profit.pdf

Lorenz, G. And J. Hardke. 2013. Insect management in rice. In: J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas Division of Agriculture Cooperative Extension Service. MP192 pp. 139. Available at: https://www.uaex.edu/publications/pdf/MP192 /MP192.pdf

NASS. 2017. United States Department of Agriculture-National Agricultural Statistics Service. Cropland Data Layer.

Stout, M.J., M.R. Riggio, L. Zou, R. and Roberts. 2002. Flooding influences ovipositional and feeding behavior of the rice water weevil, *Lissorhoptrus oryzophilus* (Coleoptera: Curculionidae) J. Econ. Entomol. 95, 715-721.

Tindall, K.V. and M.J. Stout. 2003. Use of common weeds of rice as hosts for the rice water weevil (Coleoptera: Curculionidae). Environ. Entomol. 32, 1227-1233.

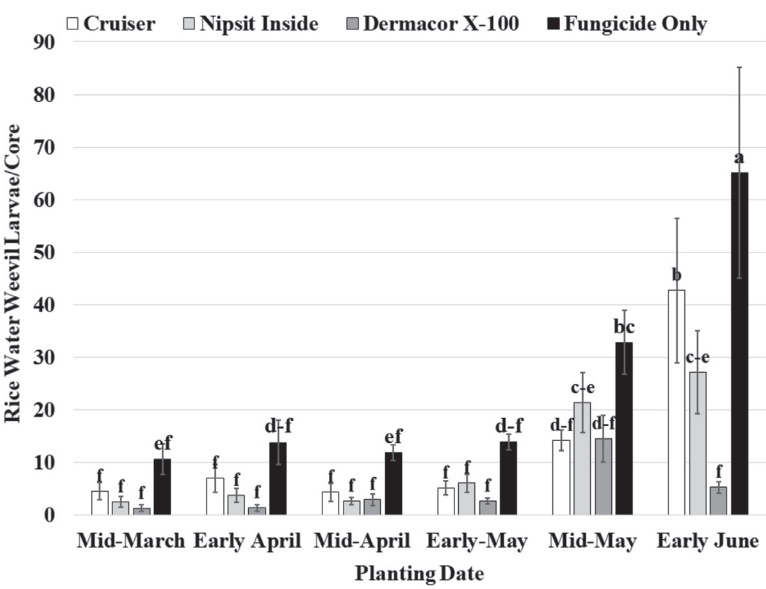

Fig. 1. Interaction between planting date and seed treatment for rice water weevil larvae densities for studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2015-2016. Means with the same letter are not significantly different at α = 0.05.

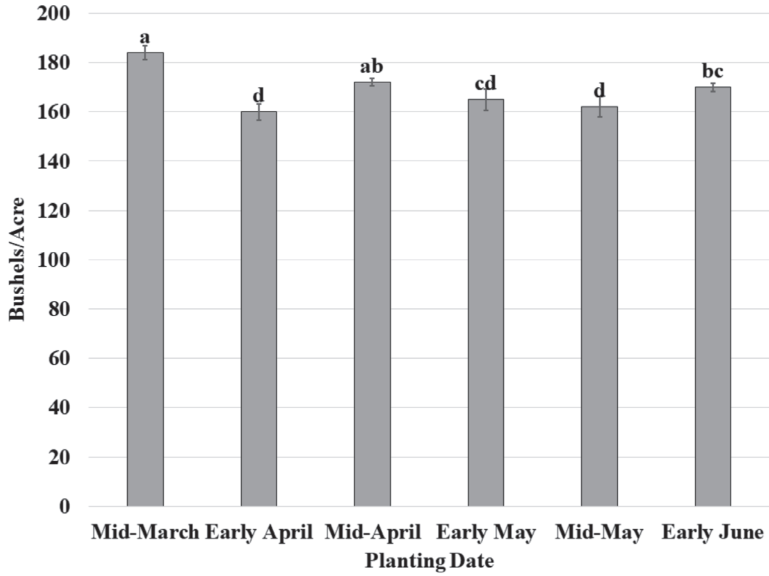

Fig. 2. Yield by planting date, across seed treatments, for studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2015-2016. Means with the same letter are not significantly different at α = 0.05

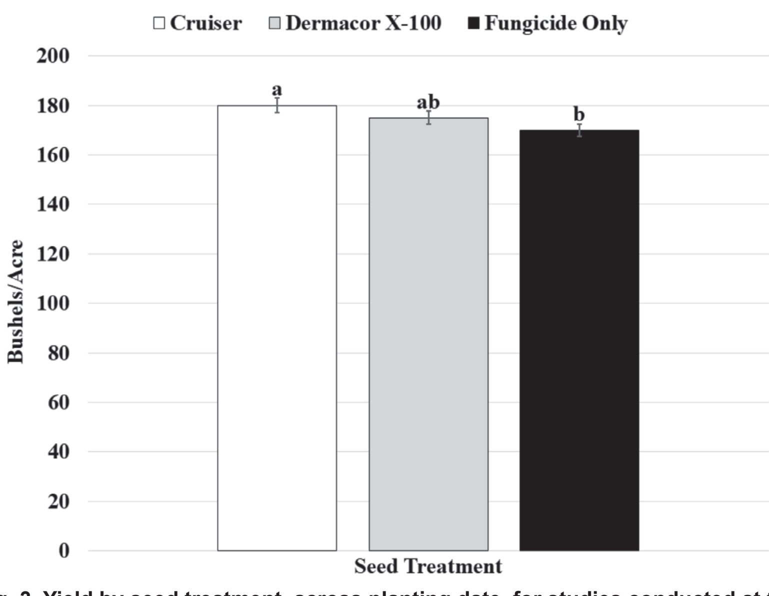

Fig. 3. Yield by seed treatment, across planting date, for studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2015-2017. Means with the same letter are not significantly different at α = 0.05

Evaluation of Rice Stink Bug, *Oebalus pugnax*, Damage to Maturing Rice Kernels

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Abstract

This study sought to determine the grain maturity level at which rice, *Oryza sativa* L., is no longer susceptible to damage from rice stink bug, *Oebalus pugnax* (F.), feeding. Data from this study indicates that rice is susceptible to damage through 60% hard dough, and that rice stink bug damage is significantly reduced between 60%-80% hard dough. More data is needed to determine the level of rice stink bug that needs to be controlled at earlier stages.

Introduction

The rice stink bug, *Oebalus pugnax* (F.) (Hemiptera: Pentatomidae), is a major pest of rice, *Oryza sativa* L., grown in Arkansas and many other southern states (Webb, 1920). The rice stink bug feeds on the developing kernels of rice and other grasses beginning at the heading phase when the panicle is exerted from the boot until the end of the ripening phase, known as hard dough (Swansom and Newsom, 1962). Feeding by the rice stink bug in the early stages of heading, especially emergence and flowering, can cause blanked kernels and direct rough rice yield loss (Swanson and Newsom, 1962; Bowling, 1963; Espino et al., 2007). At the later stages of heading, milk through soft and hard dough, feeding by the rice stink bug is associated with broken, chalky or pecky kernels. Pecky kernels can be a result of feeding by the rice stink bug, because the kernel is left more susceptible to invasion by fungi that are both present on the stinkbug itself and already present in the rice field (Ryker and Davis, 1938). If a high occurrence of pecky kernels is observed when rice is being sold, a USDA grade reduction is likely (Swanson and Newsom, 1962; Bowling, 1963; Espino et al., 2007).

Rice is most susceptible to rice stink bug damage during the milk and soft dough stages (Espino et al., 2007); however, the question of when rice stink bugs are no lon-

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ger capable of causing significant yield loss or damage is less clear. It has been shown that rice stink bugs can damage the rice plants in the soft dough stage and into the hard dough stage (when the kernels are considered mature) by causing an increase in pecky rice (Harper et al., 1993; Patel et al., 2006). However, the percentage of rice kernels in the hard dough stage on each plant that makes the plant no longer susceptible to damage from rice stink bug feeding is not known. This is important because consultants and producers often spray for significant populations of rice stink bug during hard dough, even though the past recommendation has always been "Hard dough, let it go" (Gus Lorenz, pers. comm.). Consultants and producers typically encounter issues concerning re-entry intervals (REI) and pre-harvest intervals (PHI) when they apply insecticides late in hard dough, but the fear of losses due to peck drive this decision-making process.

The first objective of this study was to determine the stages of hard dough that are susceptible to damage from rice stink bug feeding utilizing sleeve cages. The second objective of this study was to determine the level of rice stink bugs that need to be controlled at potentially susceptible stages to determine an insecticide termination stage.

Procedures

Plots were located at the University of Arkansas System Division of Agriculture Rice Research and Extension Center near Stuttgart, Arkansas. Plots consisted of a hybrid (XP753) and a conventional (Diamond) rice cultivar planted for both objectives of this study, with the same number of hybrid and conventional plots planted for both objectives. Plots measured 70 × 63 inches using a 7.5-inch drill spacing, 8 rows in total, and standard agronomic practices were used to maintain these plots.

Adult and late-instar rice stink bug nymphs caught with standard 15 inch sweep nets from heading rice and weedy grasses were utilized for both objectives in this study. To ensure viability of the individuals for the study, insects were given fresh plant material, moist paper towels, and cotton balls soaked in sugar water, and kept at 75 °F for at least 24 hours prior to utilization in sleeve cage trials. Healthy looking adults and late-instar nymphs were then added to sleeve and large cages. Mortality within sleeve cages was checked 24 hours after introduction, and then every 48 hours after that and replaced as needed.

Objective 1–Sleeve Cages

Applications of Warrior II at 2.5 oz/acre were applied using a backpack sprayer when heading initiated and continued weekly until one week prior to infestation. This pesticide application, and subsequent applications each week, were utilized to ensure plots did not accumulate high levels of peck before cages were added. Sleeve cages used were white insect rearing sleeves, 20 × 40 cm (BioQuip Products, Rancho Dominguez, Calif.). A bamboo rod was utilized to hold the sleeve cage and rice plant up due to the weight of the cages, and the cage and rice plant was zip-tied to the bamboo pole. Stinkbugs were then infested at appropriate timings.

The experiment design included 3 factors: number of rice stink bugs in the sleeve cage (0 or 2), the percent hard dough (straw-colored kernels) when stink bug infestations were initiated (20, 40, 60, 80, 100%), and the rice cultivar. For each combination of infestation level × infestation timing × cultivar, 10 replications were performed in both 2016 and 2017. Panicles for this experiment were chosen based on their individual growth stage. Infestation levels were then assigned randomly once a hard dough percentage was determined for each random panicle, with no single rice plant receiving more than one cage. At the time of harvest, panicles contained inside the sleeve cages were removed, put in paper bags, and placed in a dryer until moisture was at 12%. Panicles were removed from the paper bags, and rough rice kernels were then removed. Rough rice kernels from each panicle were then de-hulled and brown rice was observed with a light box to determine peck. Samples were weighed, sorted by damage, and a percentage of pecky kernels by weight was determined.

Objective 2–Large Cages

Plots were reduced to 3 ft × 3 ft and surrounded with 6 ft × 6 ft × 5 ft cages two weeks prior to emergence of the head from the boot. Cages were sprayed with both Warrior II at 2.5 oz/acre to kill any RSB already present and Quilt Excel at 27 oz/acre to prevent multiple diseases. Cages were left untouched until the infestation timing of each treatment was reached. The hard dough growth stage within each cage was determined to be the percent of straw-colored kernels present on at least 50% of the panicles within each plot, with 60% hard dough being the point in which 50% of the panicles in a cage had 60% or more straw colored kernels.

Three factors were considered: number of rice stink bugs infested in each cage (0, 13, or 25), percent hard dough when stink bug infestations were initiated (20, 40, 60, or 80%), and cultivar. Infestation levels were equivalent to 0, 2×, and 4× threshold when considering a 1 rice stink bug per sweep threshold for hard dough. Four replications were performed for each combination of infestation level × infestation timing × cultivar using a randomized complete block design within the cultivar. Eight untreated check of each cultivar were also utilized. Rice stink bugs were infested within cages when the timing of each treatment was reached and were allowed to feed until harvest. Cages were removed just before harvest and the entire 3 ft × 3 ft plot was harvested, weighed, and placed in a dryer until 12% moisture. A random 100 g sample was then taken and dehulled for determination of peck percentages. This sample was separated in to rice stink bug-caused peck as identified by a bullseye discoloration, total peck (all damaged kernels), and undamaged kernels, with a percentage of the total sample being determined for each. A random 162 g sample was also taken to evaluate the milling quality of each plot, with percent head rice (whole kernels) and percent total white rice (whole and broken kernels) being determined from this sample.

Data Analysis

Data were analyzed using an analysis of variance, PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Tukey's HSD post hoc analysis ($\alpha = 0.05$). For the first objective, data were also combined across the two cultivars using a two-way analysis of variance, PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Tukey's Honestly Significant Difference post hoc analysis (α = 0.05).

Results and Discussion

When considering the ability of the rice stink bugs to damage hard dough rice, as was explored in objective 1 using sleeve cages, a large amount of peck was observed (Table 1). The hybrid and the conventional cultivars both exhibited large amounts of peck at the 20%-60% hard dough stages, ranging from 17.78%-10.58% and 8.07%-3.60% at those stages respectively. Overall the hybrid cultivar received significantly higher amounts of peck, which is likely explained by a larger number of kernels available for rice stink bug feeding (Table 1). However, across cultivars little peck was observed at the 80% and 100% hard dough stages at a maximum percentage of only 2.57% (Table 1; Table 2). These data indicate that significant levels of peck will not be possible after 60% hard dough (Table 2).

When real-world rice stink bug infestations were explored during hard dough timings using large cages, as was determined by objective 2, only low levels of peck were observed across all stages and infestation levels. A maximum of 0.32% peck caused by rice stink bugs alone was observed across hybrid and conventional plots infested at 20% hard dough with 4× threshold (25 rice stink bugs (Table 3). Total peck for these plots were 0.62% and 0.93% for hybrid and conventional plots respectively (Table 3). All levels of peck observed were much lower than 2.5% peck needed for grade 3 rice (Table 3). More peck was observed in the conventional cultivar when compared to the hybrid cultivar, which is likely due to overall lower yields observed in the conventional plots (Table 3). Across all treatment combinations, no differences were observed in milling or head yield, and yield averages below 57–72 were not observed (Table 3).

Significance of Findings

It was clear that across cultivars rice stink bugsare capable of causing a significant amount of peck from 20%-60% hard dough at very large infestation levels. However, insignificant amounts of damage were observed from 80%-100% hard dough even at very high infestation levels. When real-world infestations of 2× and 4× threshold were used in large cages, significant damage was not observed. These data suggest that insecticidal applications should be terminated at 60% hard dough, and more data is needed to confirm the low amounts of damage seen at 2× and 4× threshold in 2017's data only.

Acknowledgements

We would like to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

Literature Cited

Bowling, C.C. 1963. Cage tests to evaluate stink bug damage in rice. J. Econ. Entomol. 56:197-200.

Espino, L., M.O. Way, and J. K. Olson. 2007. Most susceptible stage or rice panicle development to *Oebalus pugnax* (Hemiptera: Pentatomidae). J. Econ. Entomol. 100:1282-1290.

Harper, J.K., M.O. Way, B.M. Drees, M.E. Rister, and J.W. Mjelde. 1993. Damage function analysis for the rice stink bug (Hemiptera: Pentatomidae). J. Econ. Entomol. 86(4):1250-1258.

Patel, T., M.J. Stout, and J.R. Fuxa. 2006. Effects of rice panicle age on quantitative and qualitative injury by the rice stink bug (Hemiptera: Pentatomidae). Fla. Entomol. 89:320-327.

Ryker, T. C., and W. A. Douglas. 1938. Pecky rice investigations. pp. 19-20. *In:* Louisiana Agric. Expt. Stn. Biennial Report. Rice Expt. Stn, 1937-1938.

Swanson, M.C. and L.D. Newsom. 1962. Effect of infestation by the rice stink bug, *Oebalus pugnax*, on yield and quality in rice. J. Econ. Entomol. 55:877-879.

Webb, J.L. 1920. How insects affect the rice crop. U. S. Dept. Agric. Farmers Bull. 1086.

Table 1. Comparison of peck percentages between the hybrid and conventional cultivar across 2016 and 2017 (n = 397).

Cultivar	Timing	Infestation Level	Peck†
Hybrid	20% Hard Dough	2	17.78 a
Hybrid	40% Hard Dough	2	10.58 b
Hybrid	60% Hard Dough	2	11.17 b
Hybrid	80% Hard Dough	2	1.63 d
Hybrid	100% Hard Dough	2	1.78 d
Conventional	20% Hard Dough	2	8.07 cb
Conventional	40% Hard Dough	2	4.15 cd
Conventional	60% Hard Dough	2	3.60 cd
Conventional	80% Hard Dough	2	2.26 d
Conventional	100% Hard Dough	2	2.57 d
Hybrid	20% Hard Dough	0	0.57 d
Hybrid	40% Hard Dough	0	0.35 d
Hybrid	60% Hard Dough	0	0.45 d
Hybrid	80% Hard Dough	0	0.23 d
Hybrid	100% Hard Dough	0	0.21 d
Conventional	20% Hard Dough	0	0.17 d
Conventional	40% Hard Dough	0	0.13 d
Conventional	60% Hard Dough	0	0.24 d
Conventional	80% Hard Dough	0	0.41 d
Conventional	100% Hard Dough	0	0.15 d

† Peck percentages within each cultivar followed by the same lowercase letter are not significantly different at $\alpha = 0.05$ using Tukey's honestly significant difference post hoc analysis.

Table 2. Percent peck in brown rice when combined across cultivars (n = 397).

Timing	Infestation Level	Peck Percentage†
20% Hard Dough	2	12.93 a
40% Hard Dough	2	7.37 b
60% Hard Dough	2	7.38 b
80% Hard Dough	2	1.94 c‡
100% Hard Dough	2	2.17 c‡

† Peck percentages within each cultivar followed by the same lowercase letter are not significantly different at α = 0.05 using Tukey's honestly significant difference post hoc analysis.

‡ Peck percentage is not significantly different than the 0 infestation level at α=0.05 using Tukey post hoc analysis.

Table 3. Comparison of damage, yield, and milling yields of all treatment combinations in large cage trials from 2017 (n = 77).

Cultivar	Infestation Timing	Infestation Level	RSB Peck†	Total Peck‡	Yield§	%TR¶	%HR¶
			(%)	(%)	(bu/ac)		
Hybrid	-	0 RSB	0.04 b	0.34 a	279	74	57
	20% HD	2× Threshold	0.09 ab	0.35 a	237	74	58
		4× Threshold	0.22 ab	0.49 a	234	74	58
	40% HD	2× Threshold	0.12 ab	0.41 a	249	73	59
		4× Threshold	0.11 ab	0.42 a	251	73	57
	60% HD	2× Threshold	0.06 ab	0.34 a	242	73	59
		4× Threshold	0.15 ab	0.62 a	256	74	60
	80% HD	2× Threshold	0.04 b	0.28 a	259	74	59
		4× Threshold	0.09 ab	0.43 a	254	73	58
Conventional	-	0 RSB	0.10 b	0.49 a	220	73	58
	20% HD	2× Threshold	0.21 ab	0.71 a	232	72	58
		4× Threshold	0.32 a	0.93 a	223	72	59
	40% HD	2× Threshold	0.14 ab	0.58 a	213	72	58
		4× Threshold	0.14 ab	0.53 a	206	72	58
	60% HD	2× Threshold	0.13 ab	0.68 a	217	72	58
		4× Threshold	0.23 ab	0.73 a	205	73	58
	80% HD	2× Threshold	0.21 ab	0.65 a	207	73	59
		4× Threshold	0.27 ab	0.77 a	225	73	58

† Rice stink bug peck percentages within each cultivar followed by the same lowercase letter are not significantly different at α = 0.05 using Tukey's honestly significant difference post hoc analysis.

‡ Total peck percentages within each cultivar followed by the same lowercase letter are not significantly different at α = 0.05 using Tukey's honestly significant difference post hoc analysis.

§ No significant treatment x cultivar interaction was observed, but the hybrid rice did have significantly higher yield than conventional across treatment according to an analysis of variance at α = 0.05.

¶ %TR = % total rice; %HR = % head rice (whole kernels).

Effect of Rice Stink Bug, *Oebalus pugnax*, on Yield and Quality in Rice

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Abstract

The objective of this study was to determine the amount of damage that increasing densities of rice stink bug (RSB) could cause to different developmental stages of rice. Mesh field cages were used in established rice plots to contain introduced rice stink bugs which were infested at the following kernel development stages: flowering, milk, soft dough, and hard dough. Densities of 0, 17, 34, and 68 RSB per 10 sweeps were used for infestation densities. The first infestation timing was initiated at the flowering and milk stage. The second infestation timing was initiated at the soft and hard dough stages. No yield loss was observed for RSB density or infestation timing. Total peck and RSB peck observed on brown rice was greater with RSB densities of 68 per 10 sweeps and during the soft and hard dough infestation timing. Peck percentages never exceeded 1.5% peck even at the highest densities of RSB.

Introduction

The rice stink bug, *Oebalus pugnax* (F.), is a pest of rice that feeds on developing grains. Feeding by rice stink bug (RSB) during the flowering and milk kernel stages can cause kernels to become severely shrunken or be completely blank. When RSB feeding occurs during the soft dough and hard dough kernel stages, an area of chalky discoloration at the feeding site is often formed. This discoloration is known as 'pecky' rice and is caused by the invasion of fungi into developing rice kernels after the RSB has pierced the rice kernels during feeding (Swanson and Newsom, 1962; Hollay et

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al., 1987). The rice inspection handbook allows for no more than 0.5% damaged grain, including pecky rice, in a 500-g sample to be considered U.S. grade 1 (USDA-FGIS, 2009). Grade reductions due to increased amounts of damaged kernels can lead to losses to the value of the harvested grain with drastic economic impacts occurring at grade 3 rice or 2.5% peck (USDA-FGIS, 2009). Clayton et al. (2016) observed more damage to milk stage rice at RSB densities of 3 RSB per 10 sweeps and above compared to the non-infested control and 1.5 RSB per 10 sweeps. Espino et al. (2007) also found significant amounts of RSB damage at the soft dough infestation timing; although, much greater RSB densities were used than in Clayton's trials. The question of when RSB need to be controlled is still contested, with reports such as Espino et al. (2007) and Awuni et al. (2015) observing that increasing densities of RSB are able to cause damage to different kernel development stages of rice. The objective of this study was to determine the amount of damage that increasing densities of rice stink bug (RSB) could cause to different developmental stages of rice.

Procedures

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. The cultivar Diamond was drill-seeded on 25 April 2017 and grown according to standard agronomic practices for Arkansas. Plots were 60 inches wide, 8 rows on 7.5-inch drill spacing, and 70 inches in length. This experiment was designed as a randomized compete block with four replications per infestation timing.

Mesh field cages were placed over plots prior to heading and an application of Karate Z at 2.56 oz/acre was used to prevent natural infestations of RSB and to remove any beneficial insects present. An application of Quilt Xcel 27 oz/acre was used to prevent multiple diseases. When approximately 50% of the plants in a plot reached the desired growth stage of kernel development, RSB infestations were initiated. Rice stink bug adults and late-instar nymphs were collected with standard 15 inch sweep nets in heading rice fields and weedy areas surrounding rice fields. Insects were kept in small cages with fresh plant material, a cotton ball soaked in sugar water, and a moist paper towel in a laboratory at 75 °F for 24 h prior to infestation in field cages to reduce mortality rate. Cage frames were 6 ft × 6 ft × 6 ft made from 1-inch PVC pipe with 6 ft × 6 ft amber fabricated coverings (Lumite, Inc., Alto, Ga.). The desired number of RSB were placed in small foam cups and placed in the rice canopy and allowed to move freely. Two infestation timings were used consisting of: flowering to milk growth stages; and soft to hard dough growth stages. A sequential infestation of RSB was made 7 days after the initial infestation with the same level of RSB. Infestations were terminated 7 days after the second infestation within a growth stage, and then terminated with a foliar insecticide application. Cages were kept in place until harvest. Infestation levels were 0, 42, 84, and 168 RSB/plot, or a density of 0, 17, 34, and 68 RSB per 10 sweeps, respectively.

Ten rice panicles were removed from each plot and placed in a brown paper bag, then stored in a grain dryer until moisture was 12%. These panicles were harvested by hand by separating whole kernels from blank kernels (unfilled kernels), with partially filled kernels counted as whole kernels. The center 4 rows of each plot were harvested with a plot combine, and harvested seed was stored in a cloth bag and placed in a grain dryer until moisture was 12%. A random 100-g sample of seed harvested with the plot combine was dehulled for examination of ‘peck’ using a light box. Seed was separated into undamaged, damaged, and RSB damaged seed. The seed in each category was weighed and the percentage of damage for each plot was calculated. After harvest, a random sample of 162-g of rough rice from each plot was used to evaluate grain milling quality. Rice was milled to obtain percent head rice (whole kernels) and percent total white rice (whole and broken kernels).

Results and Discussion

A trend of decreasing yield with increasing RSB populations was observed in the bloom and milk infestation timing, but there was no difference ($P = 0.84$, Fig. 1). No yield trend was observed for the soft and hard dough infestation timing (Fig. 1). Awuni et al. (2015) found uninfested plots yielded higher than plots infested with 10 and 20 RSB per 10 sweeps. Bowling (1963) observed a difference in yield between the non-infested cage and the highest infested cage of 50 RSB per 10 sweeps.

No interaction was observed for infestation timing by infestation density for total damage on brown rice ($P = 0.17$). Differences were observed for total damage on brown rice for RSB density, with the 68 RSB per 10 sweeps infestation density having higher total damage than the 0 and 17 RSB per 10 sweeps infestation densities ($P < 0.01$, Fig. 2). Clayton et al. (2016) found higher damage in plots infested with 3, 10, and 17 RSB per 10 sweeps than plots infested with 0 or 1.5 RSB per 10 sweeps. The soft and hard dough timing had higher total damage on brown rice than the bloom and milk timing ($P < 0.01$, Fig. 3). No interaction was observed for infestation timing by infestation density for RSB damage on brown rice ($P = 0.18$). An effect of RSB density was observed for RSB damage on brown rice ($P < 0.01$, Fig. 4). The 68 RSB per 10 sweeps infestation density had more RSB damage on brown rice than all other densities of RSB (Fig. 4). The 34 RSB per 10 sweeps infestation density had more RSB damage than the 0 RSB per 10 sweeps infestation level (Fig. 4). The soft and hard dough infestation timing had higher RSB damage on brown rice than the bloom and milk infestation timing ($P < 0.01$, Fig. 5). Espino et al. (2007) also found an increase in damage at soft dough in two experiments.

No interaction was observed for percent total rice ($P = 0.81$) or percent head rice ($P = 0.36$) between infestation timing and infestation density. No differences were observed for percent total rice or percent head rice. This agrees with Clayton et al. (2017), where there was no difference in milling yields across density or timing. There were no differences observed for blank kernels for infestation timing or infestation density. Blackman (2014) also found no differences in unfilled kernels with RSB densities ranging from 2 to 37 RSB per 10 sweeps; although, Awuni et al. (2015) found an increase in blank kernels with an increase in RSB density.

Studies evaluating RSB damage potential have been conducted since the 1960s. In general findings are not consistent, with multiple studies observing yield loss and high percentages of damage from RSB infestation and others observing little to no damage from RSB. This is likely due to outside factors including weather and disease occurrence. Further research is needed to evaluate these other factors to determine the damage potential of RSB.

Significance of Findings

The rice stink bug is an important economic pest of rice. Approximately 10 million dollars annually is spent on insecticide applications targeting rice stink bug in Arkansas. Current studies are suggesting that the threshold for RSB still needs to be evaluated. It is important that growers are provided with a threshold for control of this pest to avoid yield and quality losses, but equally important to avoid making unnecessary applications for control to maximize profit for rice growers.

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Literature Cited

Awuni, G.A., J. Gore, D. Cook, F. Musser, A. Catchot, and C. Dobbins. 2015. Impact of *Oebalus pugnax* (Hemiptera: Pentatomidae) infestation timing on rice yields and quality. J. Econ. Entomol. 108(4):1739-1747.

Blackman, B.D. 2014. Evaluatin of economic injury levels and chemical control recommendations for rice stink bug (*Oebalus pugnax*) in Louisiana. Dissertation. Louisiana State University. Baton Rouge, La.

Bowling, C.C. 1963. Cage tests to evaluate stink bug damage to rice. J. Econ. Entomol. 56(2):197-200.

Clayton, T.L., G.M. Lorenz, J.T. Harke, G.J. Lee, E. Castaneda-Gonzalez, D.L. Frizzell, and H.M. Chaney. 2016. Evaluation of rice kernel damage and yields due to rice stink bug, *Oebalus pugnax*, population and infestation timing. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies. 2015. University of Arkansas Agricultural Research Station Research Series 634:137-145. Fayetteville.

Clayton, T.L., G.M. Lorenz, J.T. Hardke, A.J. Cato, G.J. Lee, H.M. Chaney,E. Castaneda-Gonzalez, D.L. Frizzell, N.M. Taillon, J.L. Black, and W.A. Plummer. 2017. Effect of rice stink bug, *Oebalus pugnax*, on Rice Quality and Yields. In: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies. 2016. University of Arkansas Agricultural Research Station Research Series 643:158-165. Fayetteville.

Espino, L., M.O. Way, and J.K. Olson. 2007. Most susceptible stage of rice panicle development to *Oebalus punax* (Hemiptera: Pentatomidae). J. Econ. Entomol. 100(4):1282-1290.

Hollay, M.A., C.M. Smith, and J.F. Robinson. 1987. Structure and formation of feeding sheaths of rice stink bug (Heteroptera: Pentatomidae) on rice grains and their association with fungi. Ann. Entomol. Soc. Am. 80:212-216.

Swanson, M.C. and L.D. Newsom. 1962. Effect of infestation by the rice stink bug, *Oebalus pugnax*, on yield and quality in rice. J. Econ. Entomol. 55(6):877-879.

USDA-FGIS. 2009. United States Standards for Rice. USDA Grain Inspection, Packers, and Stockyards Administration. Federal Grain Inspection Service (FGIS). Washington, D.C.

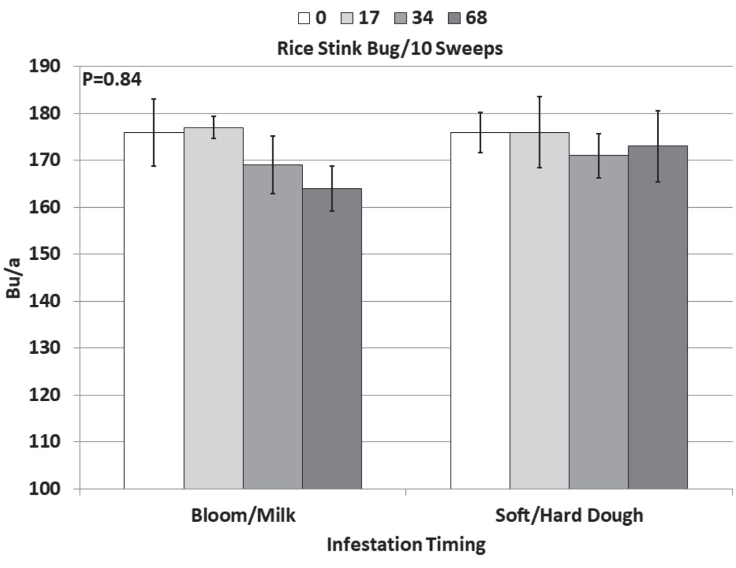

Fig. 1. Yield for multiple densities of rice stink bug at two infestation timings for studies conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center, near Stuttgart, Ark., in 2017.

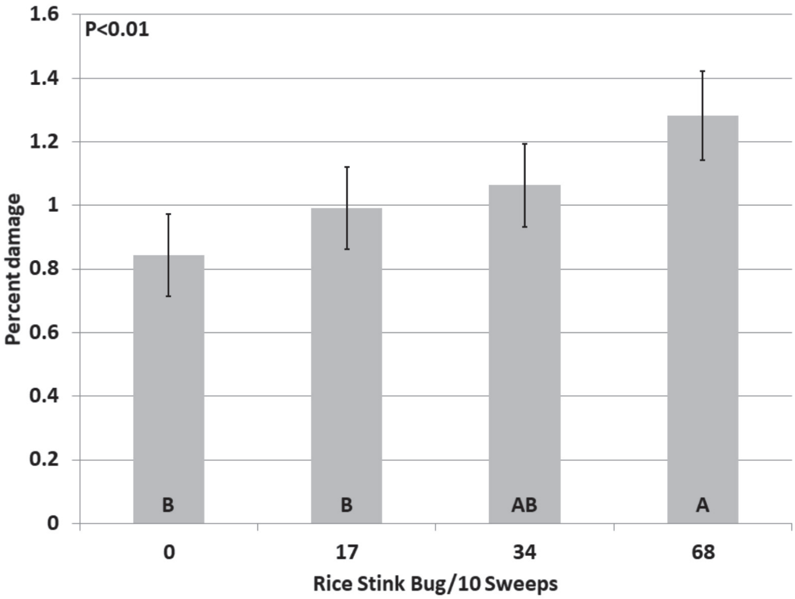

Fig. 2. Percent total brown rice damage for multiple densities of rice stink bug for studies conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center, near Stuttgart, Ark., in 2017. Means followed by different letters are significantly different at *P* = 0.05.

Fig. 3. Percent total brown rice damage for two infestation timings of rice stink bug for studies conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center, near Stuttgart, Ark., in 2017.

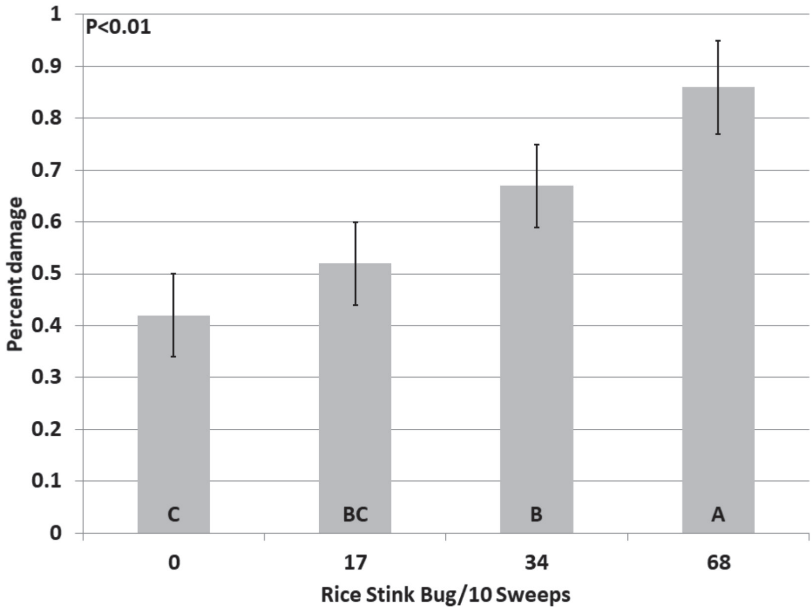

Fig. 4. Percent rice stink bug damage on brown rice damage for multiple densities of rice stink bug for studies conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center, near Stuttgart, Ark., in 2017. Means followed by different letters are significantly different at *P* = 0.05

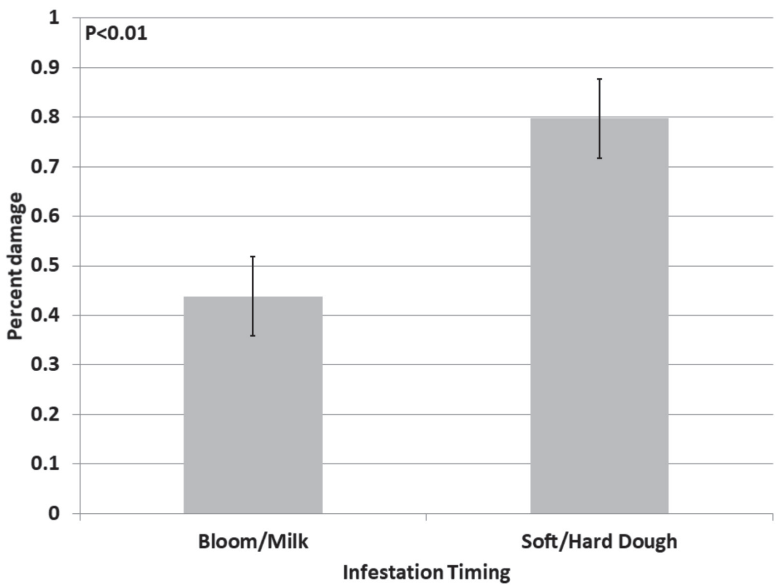

Fig. 5. Percent total rice stink bug damage on brown rice damage for two infestation timings of rice stink bug for studies conducted at the University of Arkansas System Division of Agriculture Rice Research and Extension Center, near Stuttgart, Ark., in 2017.

Potential Exposure of Honey Bees to Neonicotinoid Insecticides in Rice

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Abstract

Insecticide seed treatments and foliar clothianidin applications were evaluated from 2015 to 2017 for expression in the flag leaf and floral parts of rice, as well as grain in 2016 and 2017. Data analysis of samples indicated that insecticide seed treatments applied at planting and foliar applications made at pre-flood and post-flood were expressed at very low levels or were non-existent when samples were taken. Also, observations of bees visiting rice indicated extremely low levels of honey bees in rice fields.

Introduction

Recently, neonicotinoid insecticides used in agronomic crops have been scrutinized for their perceived impact on honey bee population decline in the U.S. In Arkansas, insecticides are essential to limit yield losses from insects in rice. Most notably, the neonicotinoid seed treatments CruiserMaxx Rice (containing thiamethoxam) and NipsIt INSIDE (containing clothianidin) are important for rice water weevil and grape colaspis control. To date, all of the research focusing on the fate of neonicotinoid insecticides has been done in other southern crops such as corn, soybean, and cotton (Stewart et al, 2014). No research has been conducted in rice to this point. As environmental groups continue to challenge the use of neonicotinoids in agriculture and pressure the U.S. Environmental Protection Agency to ban their use, it will become more important to generate factual information.

Procedures

Objective 1 – Measuring Levels of Neonicotinoid Insecticides in Rice Plants

Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart. The cultivar in these

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studies was 'CL152' in 2015 and 2016, and 'CL151' in 2017. Trials were drill-seeded on 6 May in 2015 and 2016, and 26 April 2017 and grown according to standard agronomic practices for Arkansas. Plots were 180 x 63 inches on 7-inch drill spacing in a randomized complete block design with four replications. The treatments included: an untreated check, thiamethoxam as CruiserMaxx Rice seed treatment (7 oz per cwt); clothianidin as pre-flood Belay foliar (4.5 oz per acre); clothianidin as post-flood Belay foliar (4.5 oz per acre); and clothianidin as NipsIt INSIDE seed treatment (1.92 oz per acre). Pre-flood foliar applications were made 10 June 2015, 8 June 2016, and 9 June 2017; post-flood applications were made 18 June 2015, 16 June 2016 and 13 June 2017.

Flag leaf and panicle samples were taken 5 August 2015 at 91 days after planting, 56 days after pre-flood foliar application, and 48 days after post-flood foliar treatment; 2 August 2016 at 88 days after planting, 55 days after pre-flood foliar application, and 47 days after post-flood foliar treatment; and 24 July 2017 at 69 days after planting, 45 days after pre-flood application, and 42 days after post-flood application. Additionally, grain samples were taken on 26 September 2016 and 13 September 2017. Standard laboratory practices were conducted to assure no contamination of samples occurred. Flag leaves from each plot were removed at the collar, placed in a labeled plastic bag, weighed, and stored on ice in a cooler. A sample size of 125 leaves was taken from the center rows of each plot to ensure enough tissue for testing.

Each treatment was processed separately to lessen the possibility of contamination. Between each treatment, hands were cleaned with a 5% bleach solution, rinsed with water, and new gloves were used. Panicles from each plot were removed, placed in a paper bag, stored on ice in a cooler, and brought to the laboratory for processing. To prepare for processing; tables, scales, and forceps were cleaned with a 5% bleach solution and wax paper was placed on each table to prevent contamination. A sample size of 50 panicles was removed to ensure enough tissue for testing. From 30 panicles, 15 florets were removed, placed in a labeled conical tube, and weighed to ensure 3g of tissue were present. If the sample weighed less than 3 g, more florets were removed from the remaining panicles and the sample was weighed again. Between each sample, the wax paper was removed, tables, forceps, and scales were cleaned with the bleach solution, and the tables were covered with a new piece of wax paper. Once processed, all samples were placed in a freezer until shipped.

Samples were analyzed to determine the levels of neonicotinoid residues by the USDA AMS Science and Technology Laboratory Approval and Testing Division of the National Science Laboratories' Gastonia Lab in Gastonia, N.C. This laboratory is accredited to ISO/IEC 17025:2005 for specific tests in the fields of chemistry and microbiology, including testing for pesticide residues. The samples were extracted for analysis of agrochemicals using a refined methodology for the determination of neonicotinoid pesticides and their metabolites using an approach of the official pesticide extraction method (AOAC 2007.01), also known as the QuEChERS method, and analyzed by liquid chromatography coupled with tandem mass spectrometry detection (LC/MS/MS). Samples were analyzed for the presence of 17 insecticides or their metabolites. Quantification was performed using external calibration standards prepared from certified standard reference material. Only detections of clothianidin, imidacloprid, and thiamethoxam were reported. The method detection limit for these compounds was 1 ng/g (1 ppb).

Objective 2 - Survey Conducted to Determine the Frequency at Which Honey Bees Visit Flowering Rice Plants

In late-September, 2015, 5 flowering rice fields in Arkansas County and 5 in Jefferson County were monitored for the presence of honey bees. Observations were made between the hours of 8:30 to 11:00 A.M. by traveling at least five transects of 300 ft. sections, slowly walking and looking for honey bees visiting rice panicles. Similarly in 2016, from late-July through September, fifteen flowering rice fields in Arkansas County were monitored for the presence of honey bees; however, observations were made between the hours of 10:00 A.M. to 12:00 P.M. and 1:30 to 3:30 P.M. by traveling at least four transects of 300 ft. sections. In 2017, 12 flowering rice fields in Arkansas County were monitored for the presence of honeybees between the hours of 10:00 A.M. to 12:00 P.M. and 1:00 to 2:30 P.M. All observations were recorded as well as the location, stage of rice, and crops surrounding each field (Tables 1-3). Data was processed using the latest version of Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.), Analysis of Variance, and Duncan's New Multiple Range Test ($P = 0.05$).

Results and Discussion

Objective 1 – Measuring Levels of Neonicotinoid Insecticides in Rice Plants

In 2015 flag leaf samples, CruiserMaxx Rice (thiamethoxam) was detected at 7.93 ppb, while NipsIt INSIDE and Belay foliar applications had no detection of clothianidin (Table 4). Thiamethoxam was also found in florets and pollen at a level of 2.23 ppb. No detection was deserved for any other treatments. In 2016, similar results were found with CruiserMaxx Rice (thiamethoxam) having 7.65 ppb in the flag leaf and none detected in the pollen or the grain. No detection was observed in the other treatments. In 2017 flag leaf samples, CruiserMaxx Rice (thiamethoxam) was detected at 5.5 ppb, and a trace amount of clothianidin was observed in the NipsIt Inside treatment. No detection was observed in the Belay foliar applications. Trace levels of thiamethoxam was detected in the CruiserMaxx Rice plots in the pollen and grain samples. Also, pollen samples from the untreated plots indicated low levels of thiamethoxam at 3.3 ppb. This study correlates well with a previous study (Stewart, et al 2014) on cotton, soybean and corn where very low levels of detections were found in pollen for these seed treatments.

Objective 2- Survey Conducted to Determine the Frequency at Which Honey Bees Visit Flowering Rice Plants

In 2015, a total of 57 transects were made. In those transects, only one bee was observed (Table 5). In 2016, a total of 157 transects were made. In those transects, two bees were observed (Table 6). In 2017, a total of 71 transects were made with 7 bees observed. The crops surrounding each field had no impact on the appearance of bees in rice fields, and there was no difference in bee population based on time of day. Rice, like most of our major row crops, is self-pollinated and from these studies does not appear to be attractive to bees.

Significance of Findings

In previous studies we have demonstrated that insecticide seed treatments not only provide protection of the rice plant from insects and reduce stress, but increase yields and profitability and are vital for rice production in Arkansas and the Mid-South (Taillon, et al., 2015). Although neonicotinoid insecticide seed treatments have been under fire recently for impact on honey bees, these and other studies continue to show it is largely unfounded and focus should be placed on the real issues impacting pollinators.

Acknowledgments

We would like to express our appreciation to Arkansas rice producers for funding this study through grower check-off funds administered by the Arkansas Rice Research and Promotion Board. Support also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

AOAC. 2007. Official Method 2007.01. Pesticide Residues in Foods by Acetonitrile Extraction and Partitioning with Magnesium Sulfate. Acess date: 1 June 2017. Available at: https://nucleus.iaea.org/fcris/methods/MRM_AOAC_2007_01.pdf

Stewart, S.D., G.M. Lorenz, A.L. Catchot, J. Gore, D. Cook, J. Skinner, T.C. Mueller, D.R. Johnson, J. Zawislak, and J. Barber. 2014. Potential exposure of pollinators to neonicotinoid insecticides seed treatments in the mid-southern United States. dx.doi.org/10.1021/es501657w Environ. Sci. Technol. 48:9762-9769.

Taillon, N.M., G.M. Lorenz, J. Black, W.A. Plummer, and H.M. Chaney. 2015. Insecticide seed treatments in rice: Is there value to the grower? *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2014. University of Arkansas Agricultural Experiment Station Research Series 626:137-144. Fayetteville.

Table 1. Field location by county of bee observations and surrounding crops or vegetation, 2015.

Field	Field location	North of field	South of field	East of field	West of field
1	Arkansas	soybeans	mature rice	mature rice	soybeans
2	Jefferson	mature rice	soybeans	mature rice	soybeans
3	Jefferson	tree line	soybeans	tree line	soybeans
4	Arkansas	soybeans	soybeans	tree line	mature rice
5	Jefferson	flowering rice	tree line	soybeans	mature rice
6	Jefferson	fallow	flowering rice	soybeans	mature rice
7	Jefferson	mature corn	tree line	mature corn	cut milo
8	Arkansas	soybeans	Soybeans & mature corn	soybeans	mature rice
9	Arkansas	soybeans	soybeans	flowering rice	soybeans
10	Arkansas	tree line	soybeans	tree line	flowering rice

Table 2. Field location by county of bee observations and surrounding crops or vegetation, 2016.

Field	Field location	North of field	South of field	East of field	West of field
1	Arkansas	tree line	soybeans	soybeans & tree line	soybeans
2	Arkansas	soybeans	soybeans	rice	soybeans
3	Arkansas	rice	soybeans	rice	soybeans
4	Arkansas	soybeans	rice	soybeans	soybeans
5	Arkansas	rice	tree line	rice	tree line
6	Arkansas	corn	soybeans & rice	soybeans	pasture
7	Arkansas	rice	rice	tree line	soybeans
8	Arkansas	soybeans & rice	rice	reservoir	soybeans
9	Arkansas	tree line	soybeans	tree line	rice
10	Arkansas	soybeans	soybeans	rice	corn
11	Arkansas	flowering rice	soybeans	flowering rice	cut rice
12	Arkansas	soybeans	flowering rice	flowering rice	cut rice
13	Arkansas	rice	soybeans	rice	rice
14	Arkansas	rice	soybeans	soybeans	rice
15	Arkansas	soybeans	rice	soybeans	rice

Table 3. Field location by county of bee observations and surrounding crops or vegetation, 2017.

Field	Field location	North of field	South of field	East of field	West of field
1	Arkansas	soybeans	corn	headed rice	soybeans
2	Arkansas	soybeans	rice/tree line	soybeans	soybeans
3	Arkansas	corn	rice	rice	soybeans
4	Arkansas	soybeans	soybeans	rice	soybeans
5	Arkansas	tree line	reservoir	rice	rice
6	Arkansas	soybeans	tree line	tree line	tree line
7	Arkansas	soybeans	rice	soybeans	soybeans
8	Arkansas	rice	soybeans	soybeans	soybeans
9	Arkansas	tree line	soybeans	rice	soybeans
10	Arkansas	tree line	tree line	rice	rice
11	Arkansas	rice	rice	soybeans	fallow
12	Arkansas	tree line	rice	rice	reservoir

Table 4. Levels of neonicotinoid insecticides (ppb) in the flag leaf and florets (2015 and 2016) and grain (2016) of rice from plots treated with thiamethoxam and clothianidin insecticide seed treatments at planting and clothianidin foliar applications made pre-flood or post-flood on rice at bloom.

	Neonicotinoid residues in rice							
	2015		2016			2017		
Treatment	Pollen	Flag leaf	Pollen	Flag leaf	Grain	Pollen	Flag leaf	Grain
	ppb							
UTC	0 b[†]	0 b	0 a	0 b	0 a	3.3 a	0 b	0 b
Cruiser Maxx Rice 7 oz/cwt	2.2 a	7.9 a	0 a	7.7 a	0 a	0.5 b	5.5 a	0.5 a
Nipsit Inside 1.92 oz/cwt	0 b	0 b	0 a	0 b	0 a	0 b	0.1 b	0 b
Belay Post flood 4.5 oz/ac	0 b	0 b	0 a	0 b	0 a	0 b	0 b	0 b
Belay Pre flood 4.5 oz/ac	0 b	0 b	0 a	0 b	0 a	0 b	0 b	0 b

[†] Means followed by the same letter in a column do not significantly differ, least significant difference *P* = 0.05.

Table 5. Observations of the number of bees observed in flowering rice fields at different times of the day using 300 ft transects across the field in Jefferson and Arkansas Counties (observations = 57) in 2015.

				Number of bees in transect					
Field	Growth stage	Date	Time	1	2	3	4	5	6
1	Flowering	9/21	8:30 A.M.	0	0	0	0	0	0
2	Flowering	9/24	9:15 A.M.	0	0	0	0	0	0
3	Flowering	9/24	10:00 A.M.	0	0	1	0	0	0
4	Flowering & Milk	9/24	10:50 A.M.	0	0	0	0	0	0
5	Flowering & Milk	9/25	9:10 A.M.	0	0	0	0	0	-
6	Flowering	9/25	9:35 A.M.	0	0	0	0	0	-
7	Flowering	9/25	10:00 A.M.	0	0	0	0	0	-
8	Flowering & Milk	9/28	9:20 A.M.	0	0	0	0	0	0
9	Flowering	9/28	10:00 A.M.	0	0	0	0	0	0
10	Flowering	10/1	10:00 A.M.	0	0	0	0	0	0

Table 6. Observations of the number of bees observed in flowering rice fields at different times of the day using 300 ft transects across the field in Arkansas County (observations = 157) in 2016.

				Number of bees in transect					
Field	Growth stage	Date	Time	1	2	3	4	5	6
1	Flowering	7/20	10:15 A.M.	0	0	0	0	0	0
1	Flowering	7/20	2:15 P.M.	0	0	0	0	0	-
2	Late Flowering	7/20	10:40 A.M.	0	0	0	0	0	0
2	Late Flowering	7/20	2:40 P.M.	0	0	0	0	0	-
3	Flowering	7/20	11:15 A.M.	0	0	0	0	0	0
3	Flowering	7/20	3:00 P.M.	0	0	0	0	0	-
4	Flowering	7/27	10:30 A.M.	0	0	0	0	0	-
5	Flowering	7/27	10:50 A.M.	1	0	0	0	-	-
6	Late Flowering	8/4	9:50 A.M.	0	0	0	0	-	-
6	Flowering	8/4	2:30 P.M.	0	0	0	0	-	-
7	Flowering	8/4	10:40 A.M.	0	0	0	0	-	-
7	Flowering	8/4	2:10 P.M.	0	0	0	0	0	-
8	Flowering	8/4	10:55 A.M.	0	0	0	0	0	-
8	Flowering	8/4	1:50 P.M.	0	0	0	0	-	-
9	Flowering	8/5	10:00 A.M.	0	0	0	0	-	-
9	Flowering	8/5	1:40 P.M.	0	0	0	0	-	-
10	Flowering	8/5	10:30 A.M.	0	0	0	0	0	0
10	Flowering	8/5	2:00 P.M.	0	0	0	0	0	0
11	Ratoon/Flowering	9/9	10:00 A.M.	0	0	0	0	0	0
11	Ratoon/Flowering	9/9	1:45 P.M.	0	0	0	0	0	0
12	Ratoon/Flowering	9/9	10:20 A.M.	0	0	0	0	0	0
12	Ratoon/Flowering	9/9	2:15 P.M.	0	0	0	0	0	0
13	Ratoon/Flowering	9/12	11:00 A.M.	0	0	0	0	0	0
13	Ratoon/Flowering	9/12	2:30 P.M.	0	0	0	0	0	0
14	Ratoon/Flowering	9/12	11:20 A.M.	0	0	0	0	0	1
14	Ratoon/Flowering	9/12	2:50 P.M.	0	0	0	0	0	0
15	Ratoon/Flowering	9/12	11:40 A.M.	0	0	0	0	0	0
15	Ratoon/Flowering	9/12	3:20 P.M.	0	0	0	0	0	0

Table 7. Observations of the number of bees observed in flowering rice fields at different times of the day using 200 ft transects across the field in Arkansas County (observations = 71) in 2017.

				Number of bees in transect					
Field	Growth stage	Date	Time	1	2	3	4	5	6
1	Flowering	7/11/2017	10:05A.M.	0	0	0	0	1[†]	0
1	Flowering	7/11/2017	2:30P.M.	0	0	0	0	-	-
2	Flowering	7/25/2017	10:00A.M.	0	0	0	0	-	-
3	Flowering	8/1/2017	10:00A.M.	0	0	0	0	-	-
3	Flowering	8/1/2017	2:10P.M.	0	0	0	0	0	0
4	Flowering	8/8/2017	11:25A.M.	0	0	0	0	-	-
5	Flowering	8/8/2017	2:07P.M.	2	0	3	0	-	-
6	Flowering/Milk	8/9/2017	10:45AM	1[†]	0	0	0	0	-
7	Flowering	8/9/2017	12:45P.M.	0	0	0	0	0	-
8	Flowering	8/9/2017	1:05P.M.	0	0	0	0	0	-
9	Flowering/Milk	8/15/2017	11:00 A.M.	0	0	0	0	0	0
10	Flowering/Milk	8/15/2017	11:20 A.M.	0	0	0	0	0	0
11	Flowering	8/15/2017	1:00 P.M.	0	0	0	0	0	0
12	Flowering	8/15/2017	2:24 P.M.	0	0	0	0	0	0

[†] carpenter bee.

The Impact of Defoliation by Armyworm on Select Growth Stages in Rice

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Abstract

This study was designed to determine the ability of the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) to damage rice, *Oryza sativa* L. across multiple growth stages of rice. Data from this study suggest that rice could be impacted by this pest throughout much of the growing season, but more data is needed to determine when insecticide applications are necessary. These and future studies will be used to provide producers in the MidSouth with a basis to make economically sound decisions for fall armyworm in rice.

Introduction

In Arkansas, rice is produced in 40 of the 75 counties (Hardke, 2017). Across this area insect pest complexes differ for rice, but generally the most serious pests are grape colaspis, *Colaspis brunnea* (F.), rice water weevil, *Lissorhoptrus oryzophilus* (Kuschel), and rice stink bug, *Oebalus pugnax* (F.). A large amount of research has created proper management strategies including economic thresholds for these pests. However, over the past few years the fall armyworm, *Spodoptera frugiperda*, (J.E. Smith), (FAW) has become more common in rice, and can be found in rice at high levels throughout the entire growing season. Although much is known about FAW in other crops including corn, grain sorghum, and soybeans, little research has been done to determine the level of damage that defoliation from this pest can cause in rice. Arkansas's current recommendation for FAW in rice is to treat at 6 larvae per square foot, and treatment is recommended when the FAW is observed feeding on the flag leaf, panicle, or stem (University of Arkansas System Division of Agriculture, 2017). Even though a recommendation is available, it is based on observations of its potential to cause damage on crops similar

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to rice, and when economic damage is actually occurring is still relatively unknown. Although the impact of feeding is unknown, a large number of insecticide applications are commonly made early in the season when defoliation is high and large numbers of larvae are present in the field, and late in the season when FAW is seen feeding on the flag leaf. Therefore, it is important to understand what level of defoliation leads to economic losses in rice. Also, it is important to understand to what extent damage is caused by feeding on the panicle. The first objective of this study was to evaluate the impact of defoliation caused by the FAW at three different growth stages of rice using both live infestations with cage studies and simulated defoliation. The second objective of this study was to determine the ability of FAW to damage rice through feeding on developing heads, as well as their affinity for head feeding compared to foliage feeding.

Procedures

To assess the impact of defoliation by the FAW, two separate methodologies were used: (1) cage studies with live infestations; and (2) manual defoliation to simulate FAW damage. For the cage study, 2 factors were used: infestation timing and infestation density. Infestation timings were: plots infested at 2-3 leaf, 2nd and 3rd tiller, and heading growth stages, and infestation density were 0, 6, and 12 larvae per square foot. Four replications were completed for all levels of infestation timing by infestation density, with a full factorial of 48 plots being evaluated using a randomized complete block design. Plots of 3 foot by 3 foot were used for the cage study, with a 6 foot by 6 foot cage being placed over all plots prior to the 2-3 leaf stage. Once the desired growth stage was reached for each plot, FAW larvae were infested and then monitored until no living larvae could be found. For the 2-3 leaf and 2nd-3rd tiller growth stage, larvae were placed in cups and placed in the middle of the plot and allowed to disperse on their own. Metal sheet flashing lined with petroleum jelly was secured around the outside of the plot, prior to infestation, to ensure the larvae stayed in the plot. For the heading growth stage, larvae were placed individually on the foliage scattered throughout the plot, as plots were flooded and larvae could not be placed on the ground. Data were analyzed with analysis of variance (ANOVA) using PROC GLIMMIX SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and least significant difference (LSD) post hoc analysis at $\alpha = 0.05$. The response variable of the yield harvested from each plot was used to compare treatments.

Manual defoliation was also conducted utilizing 2 main factors: defoliation timing and percentage defoliation. Defoliation timings included the 2-3 leaf, 2nd-3rd tiller, and heading stage. Defoliation levels were 0%, 25%, 50%, and 100%, where each plant from the plot was manually defoliated using shears. Four replications were completed for all levels of defoliation timing by defoliation percentage, with a full factorial of 48 plots being evaluated using a randomized complete block design. Plots of 3 foot by 3 foot were used for this study, but no cages were placed over the plots. The method of defoliation differed depending upon the defoliation timing. At the 2-3 leaf and 2nd and 3rd tiller stages, the entire plant was measured and the defoliation percentage was applied to that plant height, with 50% defoliation meaning that the entire plant was cut in half. At the heading stage, only the flag leaf was defoliated. Defoliation of the rice plant was simulated using shears, and agronomic practices before and after defoliation were the same for each plot. Data were analyzed using ANOVA in PROC GLIMMIX (SAS version 9.4) and LSD post hoc analysis at $\alpha = 0.05$. The response variable of the yield (percent of the untreated) was used to compare treatments.

Sleeve cages were used to both determine the ability of FAW to feed on and damage the developing heads of rice, as well as to determine feeding preference of larvae. Sleeve cages were placed around the flag leaf alone, the head alone, and both the flag leaf and the head together. Cages were placed on the rice plant just after plants reached flowering and each sleeve cage was infested with one FAW. Each larva was allowed to feed for 7 days and mortality was checked every 24 hours, where larvae were supplemented if mortality was discovered. For the cages that contained both a flag leaf and panicle, the location of the larvae was recorded every 24 hours to determine preference. A total of 15 replications were performed for each of the preference levels that were infested and 5 replications were performed for each uninfested preference level. Cages were then left on the plants until harvest. After being harvested the flag leaf was evaluated and rated for defoliation. The rice head was also evaluated and the number of blank seed in each head were used as a metric to determine the level at which the larvae were able to successfully feed on and damage the rice head. The location of the larvae when cages were checked and the amount of defoliation on each flag leaf were used to determine the feeding preference of the FAW. Data were analyzed using ANOVA in PROC GLIMMIX and LSD post hoc analysis at $\alpha = 0.05$.

Results and Discussion

In the cage trial, a reduction in yield was observed at the 2-3 leaf infestation timing when compared to the untreated check at both 6 and 12 larvae per ft^2 (Table 1). No difference was observed in any other treatments. In the manual defoliation trial, when plots were defoliated 100% at the 2nd-3rd tiller stage, yield was reduced by 26% below the untreated check (Table 2). These data suggest that damage can occur across multiple growth stages, but more replications are needed.

In the preference trial, no differences were observed for blank seeds (Table 3). However, when the FAW only had the panicles to feed on, the number of seed blanks increased significantly, being 18% higher than the seed blanks in the untreated check. When given a choice, FAW spent 63.5% of the time on the flag leaf (Table 4). These data suggest that FAW typically feed on foliage; however, panicle feeding can occur.

Significance of Findings

Significant yield losses were only observed in the cage infestations for the 2-3 leaf growth stage for both 6 and 12 larvae per ft^2, and 2nd-3rd tiller growth stage at only the 100% defoliation level for the simulated defoliation. Sleeve cage studies also indicated that infestations during the heading growth stages are more likely to cause any possible damage through defoliation rather than head feeding. Data from this study suggest that yield loss is possible from FAW infestations, but more work is needed to determine when FAW need to be controlled.

Acknowledgements

Appreciation is expressed to the Arkansas Rice Promotion Board, the Arkansas Plant Board, and the University of Arkansas for funding this project, as well as, all collaborators that helped with this project.

Literature Cited

Hardke, J. (ed.) 2017. "Introduction." Arkansas Rice Production Handbook, University of Arkansas System Division of Agriculture Cooperative Extension Service. MP 192:1–8.

Table 1. Comparison of yield of caged plots with infestations of fall armyworm (FAW) larvae at three different growth stages of rice.

Growth stage	FAW density/ft^2	Yield† (±SEM)	*P*-value
		(% of untreated)	
2-3 Leaf	0	100.0 (0.0) a	0.03
	6	91.7 (1.8) b	0.03
	12	89.6 (3.7) b	0.03
2nd-3rd Tiller	0	100.0 (0.0) a	0.81
	6	124.4 (72.1) a	0.81
	12	94.2 (16.2) a	0.81
Heading	0	100.0 (0.0) a	0.64
	6	101.9 (12.7) a	0.64
	12	90.8 (10.9) a	0.64

† Yields followed by a different letter are significantly different according to Fisher's protected least significant difference post hoc analysis at $\alpha = 0.05$. SEM = standard error of the mean.

Table 2. Comparisons of yield with simulated defoliation at three different growth stages of rice.

Growth stage	Percentage defoliated	Yield† (±SEM)	*P*-value
		(% of untreated)	
2-3 Leaf	0	100.0 (0.0) a	0.44
	25	106.3 (4.6) a	
	50	100.5 (4.0) a	
	100	99.7 (5.1) a	
2^{nd}-3^{rd} Tiller	0	100.0 (0.0) a	0.01
	25	94.1 (4.9) a	
	50	91.3 (1.5) a	
	100	74.0 (6.3) b	
Heading	0	100.0 (0.0) a	0.63
	25	103.8 (2.1) a	
	50	101.2 (1.0) a	
	100	98.8 (5.9) a	

† Yields followed by a different letter are significantly different according to Fisher's protected least significant difference post hoc analysis at α = 0.05. SEM = standard error of the mean.

Table 3. Comparisons of percent seed blanks associated with fall armyworm feeding on rice heads.

Treatment	Location	Percent blanks† (±SEM)
Uninfested	Both	35.4 (5.8) a
	Flag Leaf	20.8 (4.3) a
	Head	21.0 (3.5) a
Infested	Both	33.0 (4.7) a
	Flag Leaf	16.5 (2.4) a
	Head	38.8 (6.1) b

† Percent of blanks followed by a different letter are significantly different according to Fisher's Protected least significant difference post hoc analysis at α = 0.05. SEM = standard error of the mean.

Table 4. Preference test between the leaf and head for the sleeve cage with both plant parts.

Location	Percent of time† (±SEM)
Leaf	63.5 (6.4) a
Head	36.5 (6.4) b

† Percent of time followed by a different letter is significantly different according to Fisher's protected least significant difference post hoc analysis at α = 0.05. SEM = standard error of the mean.

Efficacy of Insecticide Seed Treatments for Control of Rice Water Weevil, *Lissorhoptrus oryzophilus*, in Large Block Field Trials in Arkansas

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Abstract

Rice water weevils are an early season pest of rice which can cause economic damage when larvae feed on the roots during permanent flood. An insecticide seed treatment study was conducted in a randomized strip block design to evaluate the efficacy of insecticide seed treatments for control of rice water weevil and the impact on grain yield in 2017. The results of this study indicate that insecticide seed treatments can provide control for rice water weevil larvae and have the potential to increase yield.

Introduction

The rice water weevil (RWW), *Lissorhoptrus oryzophilus*, is a major pest in rice. Once permanent flood is established, adults infest fields and feed on the leaves causing small linear scars where leaf tissue has been removed (Bernhardt and Richards, 2002). Leaf scarring can be heavy but even the heaviest scarring rarely results in economic damage (Wilf et al., 2008). Economic damage is most often associated with RWW larvae that feed on the root system causing nutrient deficiency, stunted growth, and delayed maturity (Hix et al., 1997). Plants with a severely pruned root system may lean in the water and float when physically disturbed causing a significant stand reduction and yield loss (Lorenz and Hardke, 2013). Seed treatments have been documented to increase plant stand, height, vigor, and provide significant benefits in terms of yield (Lorenz et al., 2013). The objective of this study was to evaluate the impact of insecticide seed treatments (IST) in large block field trials in typical grower fields for control of RWW larvae.

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[2] Rice Entomologist and Program Associate, respectively, Department of Entomology, Stuttgart.
[3] Graduate Research Assistant, Graduate Research Assistant, and Graduate Research Assistant, Department of Entomology, Fayetteville.

Procedures

Experiments were conducted at the University of Arkansas System, Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. and at on-farm sites in Lonoke County and Jefferson County: 2 at PTRS, 1 at Lonoke County, and 1 at Jefferson County. Treatments included: a fungicide only treatment (UTC) with Apron (mefenoxam) 0.365 fl oz/cwt and Maxim (fludioxonil) 0.046 fl oz/cwt; CrusierMaxx Rice (thiamethoxam) 7 fl oz/cwt, and NipsIt SUITE (clothianidin) 2.4 fl oz/cwt. Experimental design was a randomized complete strip block. Depending on available space, experiments included 3 or 4 replications. The RWW larvae were evaluated by taking 5 core samples per plot with a 4-in. core sampler 21 days after flood was established. Samples were transported and evaluated at the Lonoke Extension Center, Lonoke, Ark. Each core was washed, with water to loosen soil and remove larvae from the roots, into a 40-mesh sieve. The sieve was immersed in a warm saturated salt solution which caused the larvae to float for counting. Yield samples were collected and adjusted to 12% moisture. Data was analyzed using Agriculture Research Manager 2017 (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

In both the PTRS experiments and the Jefferson County experiment, both ISTs reduced RWW compared to the UTC (Table 1). RWW were extremely low in the Lonoke County experiment, therefore no differences were observed at that location. Although low levels of RWW were recorded, there was a trend for increased yield in 3 of the 4 experiments compared to the UTC (Table 2).

Significance of Findings

The purpose of this study was to determine the efficacy of ISTs for control of RWW larvae. At 3 of the 4 experiments, ISTs decreased RWW larvae numbers compared to the UTC. A trend of increased control of RWW larvae in treated plots compared to the UTC was observed in the Lonoke County experiment, but results were not significant. On average, yields increased in treated plots compared to the UTC even when low levels of RWW larvae were recorded. Many observations have noted that under stressful conditions, the seed treatment helped to moderate or buffer stress (Taillon et al., 2014). Due to these findings, future research will include the addition of new chemistry and chemistry combinations to control RWW larvae and other rice pests as well as evaluating the impact on grain yield and the value to the grower.

Acknowledgments

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Literature Cited

Bernhardt, J., Richards, T. 2002. Screening Rice Lines for Susceptibility to Rice Water Weevil. *In*: B.R. Wells Rice Research Studies 2002. pp. 135-139. Available at: arkansas-ag-news.uark.edu/pdf/504-23.pdf

Hix, R., Johnson, D., Bernhardt, J., Lavy, T., Mattice, J., Lewis, B. 1997. Development of an IPM Monitoring Program for Rice Water Weevil Adults. *In*: B.R. Wells Rice Research Studies 1997. pp. 95-98. Available at: arkansas-ag-news.uark.edu/pdf/460.pdf

Lorenz, G., Hardke, J. 2013. Insect Management in Rice. In: Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. MP192 pp. 139-162. Available at: www.uaex.edu/publications/pdf/mp192/chapter-12.pdf

Lorenz, G.M., N. Taillon, J. Hardke, and G. Studebaker. 2013. Rice insecticide seed treatments: Is there value to the Arkansas rice producer? *In*: University of Arkansas Agricultural Research and Extension Agriculture and Natural Resources. FSA7085. Available at: arkansas-ag-news.uark.edu/pdf/634.pdf

Taillon, N., Lorenz, G., Black, J., Plummer, W., Chaney, H. 2014. Insecticide Seed Treatments in Rice: Is There Value to the Grower? *In*: B.R. Wells Rice Research Studies 2014. pp. 137-144. Available at arkansas-ag-news.uark.edu/pdf/626.pdf

Wilf, H., Lorenz, G., Colwell, K., Taillon, N. 2008. Efficacy of Rice Insecticide Seed Treatments for Control of Grape Colaspis (*Colaspis brunnea*) and Rice Water Weevil (*Lissorhoptrus oryzophilus* Kuschel). *In*: B.R. Wells Rice Research Studies 2008. pp. 135-139. Available at arkansas-ag-news.uark.edu/pdf/571.pdf

Table 1. Effect of seed treatments for control of rice water weevil (average/5 cores) at selected locations.

	Treatments		
Locations	**UTC†**	**CruiserMaxx rice**	**NipsIt SUITE**
Lonoke County	1.53 a‡	0.73 a	0.87 a
Jefferson County	2 a	1 b	0.73 b
PTRS 1	17 a	6.81 b	6.69 b
PTRS 2	17.2 a	7.87 b	7.07 b

† UTC = untreated check. PTRS = University of Arkansas System Division of Agriculture's Pine Tree Research Station.

‡ Means followed by the same lowercase letter in a column do not significantly differ, least significant difference *P* = 0.10.

Table 2. Effect of seed treatments on yield at selected locations.

	Treatments		
Locations	UTC[†]	CruiserMaxx rice	NipsIt SUITE
	--------------------------bu/ac--------------------------		
Lonoke County	177.22 a[‡]	183.04 a	187.98 a
Jefferson County	136.33 b	161.67 a	167.00 a
PTRS 1	120.35 a	112.56 a	108.83 a
PTRS 2	143.31 a	144.28 a	143.93 a

[†] UTC = untreated check. PTRS = University of Arkansas System Division of Agriculture's Pine Tree Research Station

[‡] Means followed by the same lowercase letter in a column do not significantly differ, least significant difference $P = 0.10$.

Evaluation of Insecticide Seed Treatment Combinations for Control of Rice Water Weevil, *Lissorhoptrus oryzophilus*

N.M. Taillon[1], G.M. Lorenz[1], W.A. Plummer[1], K. McCullars[1], A.J. Cato[2], and J.L. Black[2]

Abstract

Combinations of insecticide seed treatments were evaluated on conventional and hybrid cultivars to determine efficacy against rice water weevils, grape colaspis, and potentially other insects that feed on rice. Results indicated that insecticide seed treatment combinations of neonicotinoids and diamides can reduce grape colaspis and rice water weevils, and increase yield.

Introduction

Controlling rice insect pests is an integral part of rice production today and can often mean the difference in maintaining profitability for growers in Arkansas. Rice water weevil (RWW) and grape colaspis (GC) are both major pests in Arkansas rice. Damage to the rooting system by these pests can cause the plant to yellow and become stunted and, in many cases, can cause significant stand reduction and subsequently reduce yield (Lorenz et al., 2006). Thin stands caused by GC often result in increased RWW infestations in areas of the field with a thin stand.

Growers are planting rice earlier each year and in years when the weather stays cool and wet, development of seedling rice is drastically slowed. This delay in growth also delays the timing of the permanent flood. Neonicotinoid insecticide seed treatments (ISTs) such as thiamethoxam (Cruiser) and clothianidin (NipSit) are very effective for early season control of GC while diamides such as rynaxapyr (Dermacor) or cyantraniliprole are not. However, neonicotinoids residual is only about 28-35 days. Diamides are very effective for control of RWW and have a residual of 60-70 days or more. The purpose of this study was to evaluate combinations of these ISTs for control of RRW, and to determine if one of these ISTs that would provide adequate control of RWW in Arkansas.

[1] Program Associate, Extension Entomologist, Program Associate, and Program Associate, respectively, Department of Entomology, Lonoke.

[2] Graduate Research Assistant, Graduate Research Assistant, respectively, Department of Entomology, Fayetteville.

Procedures

Two trials were located at the University of Arkansas System Division of Agriculture's Pine Tree Experiment Station, near Colt, Arkansas. Plot design was a randomized complete block with 4 replications. Plots were 5 ft × 16.5 ft using 7-inch drill spacing and standard agronomic practices were used to maintain these plots. A Clearfield conventional (CL 151) rice cultivar and a hybrid (XP 756) rice cultivar were used. Seed treatments in the conventional trial included an untreated check (UTC); CruiserMaxx® Rice 0.034 mg ai/seed (thiamethoxam + fungicides premix) + Vibrance 0.0002 mg ai/seed; CruiserMaxx 0.034 mg ai/seed + Vibrance 0.0002 mg ai/seed + experimental A Cyantraniliprol (CYNT) 0.03 mg ai/seed; experimental B at 0.043 mg ai/seed CruisierMaxx Rice + Sedaxane (CMR + SDX); experimental A (CYNT) 0.03 mg ai/seed + experimental B (CMR + SDX) 0.043 mg ai/seed; Dermacor® X-100 0.017 mg ai/seed (chlorantraniliprole); and NipsIt 0.0162 mg ai/seed (clothianidin). Seed treatments in the hybrid trial included: an UTC; NipsIt Inside 1.9 oz/cwt alone and in combination with CYNT 0.025 mg ai/seed, 0.03 mg ai/seed, and 0.05 mg ai/seed, and with Dermacor 0.017 mg ai/seed; Dermacor 0.017 mg ai/seed alone and in combination with CYNT 0.05 mg ai/seed; CruiserMaxx 0.034 mg ai/seed alone and in combinations with CYNT 4 oz/cwt, and Dermacor 0.017 mg ai/seed; and CYNT 0.045 mg ai/seed alone. All seed treatments, as well as the UTC, included a basic fungicide package of Apron XL (Mefenoxam), Maxim 4 FS (Fludioxonil), and Dynasty 83 FS (Azoxystrobin).

RWW larvae were evaluated by taking 3 core samples per plot with a 4-in. core sampler, 21 days after permanent flood. Due to cold temperatures and slow growing conditions, this was 64 and 65 days after planting, respectively. Each core was washed with water to loosen soil and remove larvae from the roots into a 40-mesh sieve. The sieve was then immersed in a saturated salt solution to float the larvae for counting. All samples were evaluated at the University of Arkansas System, Division of Agriculture's Lonoke Agricultural Extension and Research Center Lonoke, Ark. Yield was taken and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 2017 (Gylling Data Management, Inc., Brookings, S.D.), Analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$).

Results and Discussion

Results in the conventional cultivar indicated that all treatments reduced the number of RWW compared to the UTC (Table 1). CruiserMaxx + Vibrance + experimental A, and experimental A + experimental B reduced RWW compared to all other treatments except Dermacor. All treatments had higher yield than the UTC; CruiserMaxx + Vibrance + experimental A had higher yield than all other treatments.

In the Hybrid cultivar, all treatments except for the CruiserMaxx, NipsIt Inside, Nipsit Inside + Dermacor, and Nipsit Inside + Cyantraniliprole 4 oz/cwt reduced RWW compared to the UTC (Table 2). All treatments had higher yield than the UTC; CruiserMaxx + Dermacor had higher yield than all other treatments.

Significance of Findings

Due to the extended period of time from planting to establishment of permanent flood, these trials had pressure from both GC and RWW. The treatments that had both a neonicotinoid and a diamide in combination had lower RWW and higher yields. Due to these findings, further studies will be conducted to evaluate the added benefit of IST combinations.

Acknowledgments

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Literature Cited

Lorenz, G.M. III. 2006. Agriculture. Rice. "Insect Management" www.aragriculture.org/insects/rice weevil.htm

Lorenz, G., and J. Hardke. 2015. Insect management in rice. *In:* J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas Division of Agriculture Cooperative Extension Service. MP192. Available at: www.uaex.edu/publications/pdf/mp192/chapter-12.pdf

Table 1. Insecticide seed treatment combinations for control of rice water weevil (RWW) in Clearfield Conventional Rice–CL151.

Treatments	Number of RWW	Yield
UTC†	26.7 a‡	161.2 c
CruiserMaxx + Vibrance	14.7 b	179.5 b
CruiserMaxx + Vibrance + Experimental A	6.3 d	194.7 a
Experimental B	10.8 c	184.8 b
Experimental A + Experimental B	6.4 d	185.3 b
Dermacor	8.9 cd	177.4 b
NipsIt Inside	12.5 bc	186.2 b

† UTC = untreated control.

‡ Means followed by the same lowercase letter in a column do not significantly differ, least significant difference $P = 0.10$.

Table 2. Insecticide seed treatment combinations for control of rice water weevil (RWW) in Hybrid Rice–XP 756.

Treatments	Number of RWW	Yield
UTC†	31.8 ab‡	170.0 c
NipsIt Inside	27.9 abc	182.3 bc
NipsIt Inside + Cyantraniliprole 2 oz	23.3 cd	188.6 b
NipsIt Inside + Cyantraniliprole 3 oz	17.9 def	177.6 bc
NipsIt Inside + Cyantraniliprole 4 oz	24.9 bcd	178.7 bc
NipsIt Inside + Dermacor	26.4 bc	191.0 b
Dermacor + Cyantraniliprole 4 oz	13.5 f	183.6 bc
Cyantraniliprole 5 oz	14.9 ef	178.5 bc
CruiserMaxx	34.8 a	177.6 bc
CruiserMaxx + Cyantraniliprole 4 oz	17.58 def	182.1 bc
CruiserMaxx + Dermacor	21 c-f	208.1 a
Dermacor	23.1 cde	179.4 bc

† UTC = untreated control.

‡ Means followed by the same lowercase letter in a column do not significantly differ, least significant difference *P* = 0.10.

The Effect of Spray Droplet Deposition and Adjuvants on the Efficacy of Benzobicyclon

C. Brabham[1], J.K. Norsworthy[1], V. K. Varanasi[1], and R.C. Scott[2]

Abstract

Benzobicyclon is a new pro-herbicide currently being evaluated for use in the Midsouth as a post-flood weed control option in rice. The efficacy of benzobicyclon is improved when applied to flooded rice, but this phenomenon is not fully understood. Two greenhouse experiments were conducted at the Altheimer Laboratory at the University of Arkansas to determine the importance of spray droplet placement with or without adjuvants on benzobicyclon efficacy. Applications were made to 4- to 5-leaf sprangletop and 2- to 3-leaf barnyardgrass in a 2-inch flood. In the first experiment, benzobicyclon was applied only to foliage, flood water-only, and to both foliage and flood water. Additionally, a non-ionic surfactant, crop oil concentration (COC), or a methylated seed oil (MSO) were included with the foliage-only treatment. Analysis of the results indicated the majority of benzobicyclon phytotoxicity came from applications to the flood water while little to no activity was observed with benzobicyclon applied to foliage-only with or with adjuvants. In the second experiment, benzobicyclon was applied to both foliage and flood water with or without adjuvants. The results showed benzobicyclon requires an adjuvant; the addition of MSO provided near complete control of barnyardgrass and Amazon sprangletop at 28 days after treatment. To optimize the efficacy of benzobicyclon, applications should be made to flooded rice and should include an oil-based adjuvant.

Introduction

Benzobicyclon is a new rice herbicide currently being evaluated for use in the midsouthern United States as a post-flood weed control option. Benzobicyclon is a pro-herbicide and in a non-enzymatic chemical reaction with water is converted into the potent 4-hydroxyphenylpyruvate dioxygenase inhibitor (HPPD) benzobicyclon hydrolysate (Sekino et al., 2008). This will be the first HPPD-inhibiting herbicide (Group 27) registered in the United States for use in rice and will provide rice growers with a new site of action to control problematic grasses, broadleaves, sedges and aquatic weeds (McKnight, 2017; Young, 2017).

[1] Post-doctoral Research Associate, Professor, and Post-doctoral Research Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville..

[2] Professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.

Benzobicyclon to achieve acceptable levels of weed control requires the establishment of a flood prior to or immediately following an application (Norsworthy et al., 2014; McKnight, 2017; Young, 2017). This indicates the flood helps facilitate the conversion to and uptake of benzobicyclon hydrolysate. However, in Arkansas, benzobicyclon is expected to be applied latter in the growing season to flooded, 5-leaf rice and thus increasing the probability benzobicyclon will be applied to taller weeds. In this situation, benzobicyclon containing spray droplets can be taken up directly via leaf deposition, indirectly after dispersion in flood water, or the combination. The purpose of this research was to determine the importance of spray droplet deposition type and the role of adjuvants on benzobicyclon efficacy.

Procedures

Two greenhouse experiments were conducted at the University of Arkansas System Division of Agriculture Altheimer Laboratory, Fayetteville, Ark. in the fall and spring of 2017. In both experiments, plant growth conditions and experimental setups were similar. The test weed species were 4- to 5-leaf Amazon sprangletop (*Leptochloa panicoides* (J. Presl) Hitchc.) and 2- to 3-leaf barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.). Seeds were germinated in commercial potting mix and 4 to 5 plants at the 1-leaf growth stage were transplanted into 2-gallon buckets containing field soil. A 2-inch flood was established one day prior to treatments and held for 28 days after treatment (DAT). Benzobicyclon was applied at 12.6 fl oz/acre using a research track sprayer calibrated to deliver 20 gallons/acre.

In the first experiment, the main interest was in determining the importance of spray deposition type on benzobicyclon efficacy. The treatments were: foliage-only, where benzobicyclon was applied directly to the foliage and activated carbon was dispersed in the flood water to bind and inactivate any benzobicyclon; flood water-only, where benzobicyclon was applied only to the flood water and plant foliage was covered with tin foil during application and subsequently removed; and the combination (foliage + flood water). Additionally, adjuvants were tested with only the foliage-only treatment. The adjuvants were a non-ionic surfactant (NIS), crop oil concentration (COC), and methylated seed oil (MSO) with all applied at 1% v/v. In the second experiment, we tested the effects of adjuvants on benzobicyclon efficacy when applied to both foliage and flood water. Methylated seed oil and COC were included at 1% v/v while NIS was at 0.25% v/v. In all experiments, visual control ratings were taken at 14 and 28 DAT and plant material was harvest at 28 DAT and subsequently dried to obtain dry weights. Dry weight data were converted to percent control from the untreated control. All experiments were setup as a randomized complete block design. The first experiment had three replications per run and was repeated once in time. The second experiment had four replications per run and had three total runs. All data were subjected to analysis of variation and means were separated using Fisher's protected least significant difference.

Results and Disscussion

At 28 DAT, the visual control ratings of sprangletop to benzobicyclon at 12.6 fl oz/acre applied to the foliage-only with or without adjuvants, flood water-only, and to both the foliage + flood water was 8%, 59%, and 69%, respectively (Table 1). Similarly, sprangletop dry weights were reduced on average by 19%, 64%, and 77% for foliage-only, flood water-only, and the combination treatments, respectively. The visual control and reduction in percent dry weight data for barnyardgrass mirrored that of sprangletop. These results indicate for benzobicyclon to be efficacious, spray droplets need to come in contact with the flood water. Interestingly, little to no phytotoxicity was detected on either species with foliage-only treatments when no adjuvant was included, but the addition of an oil based adjuvant, especially MSO, significantly reduced weed species dry weight on average by 37%. These results could be attributed to benzobicyclon being an extremely lipophilic compound and a pro-herbicide that requires water to be converted to the active compound.

In the second experiment, the addition of adjuvants to benzobicyclon at 12.6 fl oz/acre when applied to both foliage and flood water significantly improved control of 4 to 5-leaf sprangletop and 2 to 3-leaf barnyardgrass (Table 2). The addition of COC or MSO provided near complete control of sprangletop at 28 DAT while near complete control of barnyardgrass was only obtained with the addition of MSO.

Significance of Findings

Benzobicyclon is a new site of action for Arkansas rice growers but requires proper flood management and the addition of an oil based adjuvant to be an effective weed control option. Future research is needed to determine the crop safety of rice cultivars to benzobicyclon plus MSO.

Acknowledgments

We would like to thank the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for support.

Literature Cited

McKnight, B. 2017. Activity of benzobicyclon herbicide in common Louisiana rice production practices. Ph.D. Dissertation. Louisiana State University.

Norsworthy. J. K., C. A. Sandoski, and R. C. Scott. 2014. A review of benobicyclon trials in Arkansas rice. Page 99-100 in Proceeding of the 35th Rice Technical Working Group. New Orleans, Louisiana: Louisiana State University Agricultural Center.

Sekino, K., H. Joyanagi, E. Ikuta, and Y. Yamada. 2008. Herbicidial activity of a new paddy bleaching herbicide, benzobicyclon. J. Pest Sci. 33:36-370.

Young, M. 2017. Evaluation of benzobicyclon for use in midsouthern rice (*Oryza sativa*) systems. M.S. Thesis. University of Arkansas, Fayetteville.

Table 1. The visual control ratings and dry weights of sprangletop and barnyardgrass at 28 days after treatment with benzobicyclon applied at 12.6 fl oz/acre to foliage-only, flood water-only, or both.

		Visual Control		Dry Weight	
Spray Deposition [a]	Adjuvant	Sprangletop	Barnyardgrass	Sprangletop	Barnyardgrass
		%		% of Untreated	
Untreated	…	-	-	100	100
Foliage-Only	None	1	1	98	106
	NIS	7	1	85	96
	COC	8	3	80	74
	MSO	17	8	60	67
Flood Water-Only	None	59	53	36	33
Foliage + Flood Water	None	69	54	23	32
$LSD_{0.05}$		9	9	15	22

[a] Nonionic surfactant (NIS), crop oil concentration (COC), methylated seed oil (MSO) were all applied at 1% v/v.

Table 2. The visual control ratings and dry weights of sprangletop and barnyardgrass at 28 days after treatment with benzobicyclon applied at 12.6 fl oz/acre to foliage and flood water with or without adjuvants.

		Visual Control		Dry Weight	
Treatment	Adjuvant[a]	Sprangletop	Barnyardgrass	Sprangletop	Barnyardgrass
		%		% of Untreated	
Untreated	…	-	-	100	100
Benzobicyclon +	None	67	29	31	73
	NIS	91	44	17	39
	COC	99	82	9	14
	MSO	99	96	7	8
$LSD_{0.05}$		7	10	10	9

[a] Crop oil concentration (COC) and methylated seed oil (MSO) were all applied at 1% v/v and the nonionic surfactant (NIS) was applied at 0.25% v/v. Benzobicyclon was applied at 12.6 fl oz/acre.

Effects of Low Rates of Engenia at Various Growth Stages in Rice

B.M. Davis[1], R.C. Scott [1] and J.K. Norsworthy[2]

Abstract

A study was conducted in the summer of 2017 to evaluate the effects of lower than labeled rates of dicamba on rice. Rice cultivars CL172 and XP760 were planted and maintained weed free. Dicamba applications of one-tenth and one-half the labeled rate of Engenia herbicide had no effect on rice when applied pre-emerge though the boot stages. The higher rate did impact rice heading and development when applied at flowering. This timing and rate also negatively impacted rice yield of both cultivars and a yield reduction of around 50% was observed.

Introduction

It has been established that when applied properly to rice certain auxin herbicides such as 2, 4-D and Grandstand (triclopyr) are safe (Hardke, 2016). However, when applied at certain timings these products can do damage to rice. Since the introduction of dicamba tolerant cotton and soybean there has been increased concerns about drift of dicamba to sensitive crops. Currently rice is listed or considered a sensitive crop on certain dicamba labels. However, given the nature of this chemistry it is doubtful that low rates of dicamba will injure rice in the vegetative stages. Less is known about dicamba applied to various stages of rice than with other auxin chemistries. The objective of this research was to evaluate the potential of dicamba to injure rice when exposed at various growth stages throughout the season.

Procedures

A field experiment was conducted at the University of Arkansas Pine Bluff Small Farm Outreach Center in Lonoke, Ark. in the summer of 2017 to evaluate the potential adverse effects of dicamba on two cultivars of rice. Rice was planted on 19 May 2017 at a seeding rate of 45 lbs/acre of CL172 and XP760. The field plot area was field cultivated and land planed prior to planting. The soil series was a Calhoun silt loam soil with a pH of 5.6. Plots were maintained weed free with a pre emergence application of

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Command at 10 oz/acre and with post-emergent applications of Permit plus at 0.67 oz/acre plus Facet L at 32 oz/acre followed by Ricebeaux at 3 qt/acre followed by Clincher at 15 oz/acre. Plot size was 2.5 ft wide by 25 ft long with 10-ft wide alleys between plots. Plots were set up in a randomized block design with 4 replications. Treatments consisted of dicamba (Engenia) herbicide applied at 0, 1.28, and 6.4 oz/acre. Dicamba was applied at pre-emergence, 3-4 leaf rice, post flood, panicle initiation, 14 days after panicle initiation, boot, and at flowering using a self-propelled sprayer calibrated to deliver 10 gal/acre at 3 mph using a 6 nozzle 10 ft boom with DGAI 110015 spray tips. A treated check was included for both rice cultivars for injury and yield comparisons.

Data collected consisted of visual injury, that was defined as percent chlorosis and necrosis. Treatments were rated based on treated checks with 0% being no injury and 100% being plant death. Ratings were taken at 40 and 120 days after planting. Flag leaf injury was documented at 120 days after planting and was recorded as percent of flag leaf turned down compared to the treated check. Plots were harvested for yield on 11 October 2017 using a modified commercial combine. Data was analyzed and subjected to analysis of variance and means were separated by Fisher's least significance difference test at a *P* value of 0.05.

Results and Disscussion

Dicamba applications of one-tenth and one-half of the labeled rate of Engenia herbicide had no effect on rice when applied pre-emerge though the boot stages (Table 1). The higher rate (6.4 oz/acre) did impact rice heading and development when applied at flowering. This was noted in the percentage of the flag leaves that were wilted or "turned down" at the 120 day rating. Figure 1 illustrates this symptomology, even though the negatively affected plots appear to have more rice. This timing and rate in-fact negatively impacted rice yield of both cultivars and a yield reduction of 102 bu/acre for CL172 and 136 bu/acre for XP760 was documented at harvest. The lower rate of dicamba (1.28 oz/acre) also reduced rice yield of CL172 by 53 bu/acre at the flowering, even though no leaf turn-down was observed. No other significant yield reductions were measured.

Significance of Findings

The results of this research indicate that moderate levels of dicamba can be tolerated by rice in the earlier developmental stages. This suggests that rice should not be considered a sensitive crop on the Engenia and other dicamba labels; however, a warning about drift to rice in the reproductive stages should be clearly stated.

Acknowledgments

We would like to thank the Arkansas Rice Promotion Board and the University of Arkansas System Division of Agriculture for the funding of this project.

Literature Cited

Hardke, J.T. editor. Rice Production Handbook. 2016. University of Arkansas System Division of Agriculture Cooperative Extension Service publication. MP192; p. 60-61.

Table 1. Response of rice to dicamba at reduced rates.

			Days After Planting							
			40		120					
			Injury		Injury		Flag leaf turndown		Yield	
Treatment[a]	Timing[b]	Rate	CL172	XP760	CL172	XP760	CL172	XP760	CL172	XP760
		oz/acre	---------------	------	------	%	------	---------------	bu/acre	
Untreated Check			0	0	0	0	0	0	216	304
Engenia	Pre	1.28	0	0	0	0	0	0	208	296
Engenia	Pre	6.4	0	0	0	0	0	0	218	300
Engenia	3-4 lf	1.28	0	0	0	0	0	0	225	318
Engenia	3-4 lf	6.4	0	0	0	0	0	0	209	288
Engenia	Post fld	1.28	0	0	0	0	0	0	228	289
Engenia	Post fld	6.4	0	0	0	0	0	0	197	279
Engenia	PI	1.28	0	0	0	0	0	0	226	269
Engenia	PI	6.4	0	0	0	0	0	0	214	282
Engenia	PI + 14 days	1.28	0	0	0	0	0	0	201	280
Engenia	PI + 14days	6.4	0	0	0	0	0	0	205	293
Engenia	Boot	1.28	0	0	0	0	0	0	182	286
Engenia	Boot	6.4	0	0	0	0	0	0	191	280
Engenia	Flowering	1.28	0	0	0	0	0	0	163	286
Engenia	Flowering	6.4	0	0	0	0	95	88	114	168
$LSD_{0.05}$							2	2	37	40

[a]All treatments contained 0.025% Non-Ionic surfactant and plots were maintained weed free.
[b] lf=leaf, fld=flood, and PI=panicle initiation.

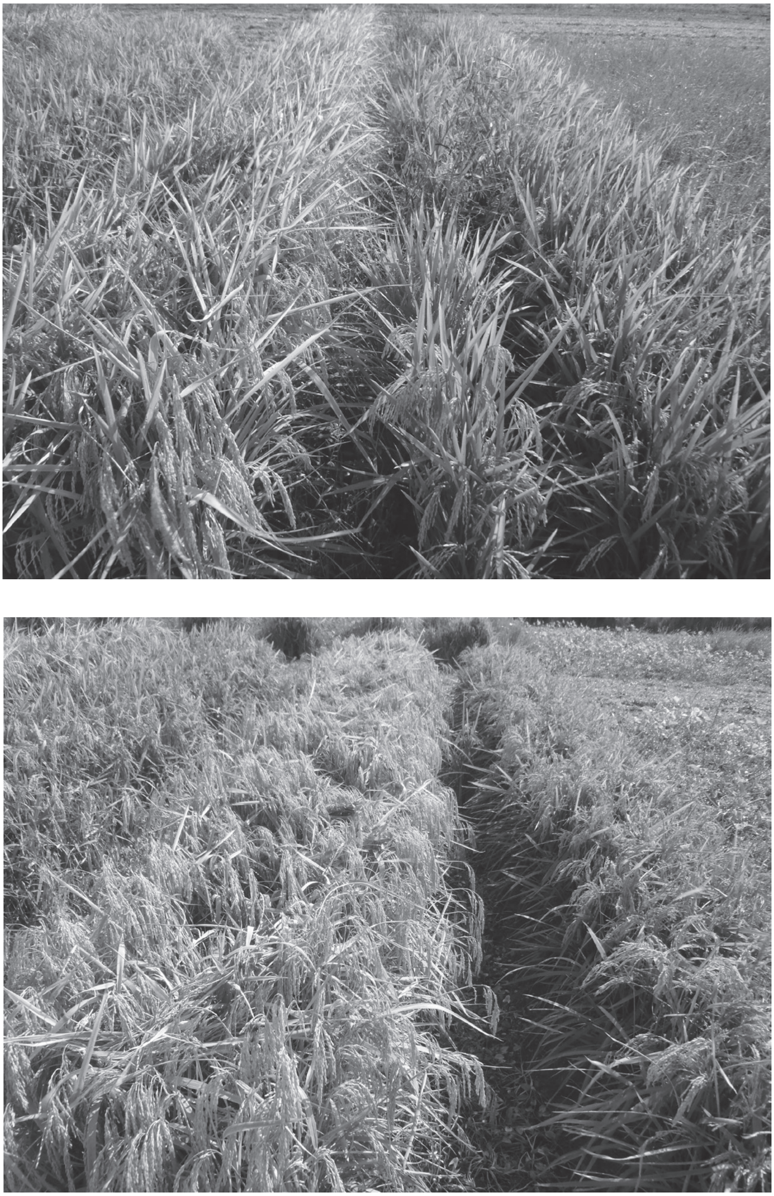

Fig. 1. Visual observation of "flag leaf turn-down" from flowering application of 6.4 oz/acre of Engenia (dicamba-TOP) to CL 172 (left-side each photo) and XP760 (right-side each photo) vs. the untreated check (BOTTOM).

Loyant Applied in Combination with Other Herbicides for Pre-Flood Weed Control in Rice

B. M. Davis[1], R.C. Scott[2], J.K. Norsworthy[3], and M.M. Perkins[1]

Abstract

A study was conducted in the summer of 2017 to evaluate preflood applications of Loyant either alone or in combination with other grass control herbicides for rice. Although larger than ideal weeds were present at the time of application, Loyant alone preflood at 1 pt/acre, controlled barnyardgrass greater than 88% for the remainder of the season, tank mixtures with Facet, Newpath, Grasp and other herbicides did not improved this level of control. In addition, hemp sesbania was controlled 99% or more by a single application of Loyant. Due to severe weed pressure the untreated check yielded only 20 bu/acre in this trial, although yields were low in this trial due to the lack of early weed control (only Command at a reduced rate was applied), Loyant preflood increased yields by over 100 bu/acre, as did Facet + Stam, and Loyant + Facet or Grasp. Although this test was essentially a preflood salvage scenario it did display the tremendous promise offered by Loyant herbicide for both grass and broadleaf weed control in rice at this timing.

Introduction

Since the initial discovery of propanil resistant barnyardgrass biotypes in the early 1990s (Carey et al., 1994) resistance in barnyardgrass to rice herbicides has been on the increase (Norsworthy et al., 2007, 2008). Herbicides with new effective modes of action against barnyardgrass are always needed. Loyant herbicide (DowDuPont Co.) is in the group 4 or auxin family of chemistry, the common name is florpyauxifen-benzyl. When applied properly this herbicide has the potential to provide broad spectrum weed control in rice, including resistant biotypes of barnyardgrass, hemp sesbania, aquatics and annual sedges. The objective of this trial was to evaluate Loyant herbicide applied preflood for the control of barnyardgrass and hemp sesbania.

Procedures

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[3] Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Bluff Small Farm Outreach Center in Lonoke, Arkansas in the summer of 2017 to evaluate weed control with the use of Loyant herbicide applied preflood in rice. Rice (CL 172) was planted on the 19 May 2017 at a seeding rate of 90 lb/acre. The field plot area was field cultivated and land planed prior to planting. The soil series was a Calhoun silt loam with a pH of 5.5. Plot size was 7.5 ft wide by 25 ft long with 10-ft wide alleys between plots. Plots were set up in a randomized block design with 4 replications. A pre-emergent blanket application of Command at 10 fl oz/acre was applied to all treatments with the exception of the untreated check. Treatments consisted of Loyant (16 oz/acre) alone or in combination with: Facet L (32 oz/acre), Newpath (6 oz/acre), Propanil (96 oz/acre), Ricestar HT (28 oz/acre), Clincher (15 oz/acre), Permit (1 oz/acre), Grasp SC (2.28 oz/acre), and Grasp Xtra (18 oz/acre). Pre-flood treatments were applied 4 days prior to establishment of a permanent flood (3-4 tiller rice) using a self- propelled sprayer calibrated to deliver 10 gal/acre at 3 mph using a 6 nozzle 10-ft boom with DGAI 110015 spray tips. Weed size at the time of application was 8 in. tall and tillering for barnyardgrass and 4-6 in. tall for hemp sesbania. An untreated check was included for injury, weed control, and yield comparisons.

Data collected consisted of visual weed control that was defined as a percent control, where 0% was no control and 100% was complete control based off the untreated check. Ratings were taken at 35, and 93 days after flooding. Plots were harvested for yield on 11 October 2017 using a modified commercial combine. All yields were adjusted to 12.5% grain moisture. Data was analyzed and subjected to analysis of variance and means were separated by Fisher's least significance difference test at a *P* value of 0.05.

Results and Discussion

Loyant applied alone or in combination with Facet or Newpath controlled barnyardgrass 88% or more at 93 days after treatment (Table 1). The addition of the tank mixtures evaluated in this test did not increase control of either barnyardgrass or hemp sesbania when evaluated at 35 or 93 days after treatment. Although not the best treatment for resistance management this indicates that Loyant alone can control tillering barnyardgrass when applied alone preflood, as long as the label is followed and a permanent flood is established in a timely manner (Hill et al. 2017). Rice yields were low due to early season competition. CL 172 yields ranged from 20 bushels per acre in the untreated check to 120 bu/acre with the more effective treatments. For example, a single application of Loyant preflood following a reduced rate of Command in this salvage scenario resulted in a 100 bu/acre yield increase over the untreated check.

Significance of Findings

This data confirms that Loyant herbicide can control both barnyardgrass and hemp sesbania when applied preflood in rice. The closest treatment with comparative weed control was Facet + Stam at full labeled rates, a treatment that would be significantly more expensive. Loyant herbicides represents a new herbicide option for preflood weed control, a timing often difficult to make as fields are being dried up for fertilization. Loyant herbicide is also effective at controlling resistant biotypes of barnyardgrass making this option a new tool in the fight to manage herbicide resistance in barnyardgrass.

Acknowledgments

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Literature Cited

Carey, V.F., III. 1994. Propanil-resistant barnyardgrass in Arkansas: Competitive Ability, Distribution, and Mechanism of Resistance. Ph.D. dissertation. Fayetteville, Ark.: Univ. of Arkansas. p. 113.

Hill, Z.T., L.T. Barber, R.C. Doherty, and A. Ross. 2017. Evaluation of Loyant herbicide for the control of common rice weeds as a single application and as a programs approach. Pest Management: Weeds, B.R. Wells Rice Research Studies 2016. pp. 204-212.

Norsworthy, J.K., N.R. Burgos, R.C. Scott, and K.L. Smith. 2007. Consultant perspectives on weed management needs in Arkansas rice. Weed Technol. 21:832-839.

Norsworthy, J.K., R.C. Scott, S. Bangarwa, G.M. Griffith, M.J. Wilson and J.A. Still. 2008. Control of clomazone-resistant barnyardgrass in rice with preemergence herbicides. Pest Management: Weeds. B.R. Wells Rice Research Studies 2008. pp. 190-193.

Table 1. Barnyardgrass and hemp sesbania control at 35 and 93 days after treatment and rice yield with Loyant and tank mixtures applied preflood in rice.

Pre flood Treatments[a]	Rate	Barnyardgrass		Hemp Sesbania		Rice Yield
	oz/A	Days after treatment --------------%Control-------------				bu/A
		35	93	35	93	
Untreated check		0	0	0	0	20
Loyant	16	88	90	99	100	122
Facet L	32	68	70	91	98	96
Newpath	6	53	63	23	0	79
Facet L Stam	32 96	73	75	95	100	117
Ricestar HT	28	58	63	0	0	100
Clincher	15	40	45	0	0	74
Permit	1	18	45	94	100	46
Grasp SC	2.28	50	60	94	100	80
Command Grasp Xtra	10 18	40	55	96	100	81
Command Loyant Facet L	10 32 32	85	90	98	100	136
Command Loyant Clincher	10 32 15	63	65	95	100	97
Command Loyant Newpath	10 32 6	80	88	99	100	126
Command Loyant Grasp SC	10 32 2.28	78	70	98	100	120
$LSD_{0.05}$		20	13	20	2	30

[a] All treatments had Command applied pre-emergence at 10 oz/acre, except the untreated check.

Off-Target Drift on Late-Season Rice (*Oryza sativa*)

R.C. Doherty[1], T. Barber[2], Z.T. Hill[1], J.K. Norsworthy[3], and A. Ross[2]

Abstract

Rice is often grown in close proximity to other row-crops such as corn, soybean, grain sorghum, and cotton. These production systems increase the risk of off-target herbicide drift on late-season rice. Research was conducted on the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer Ark. in 2016 and 2017. Glyphosate at 0.113 lb ai/acre, glufosinate at 0.053 lb ai/acre, paraquat at 0.0625 lb ai/acre, and sodium chlorate at 0.6 lb ai/acre were all evaluated for rice injury and yield reduction. In 2016 glyphosate caused up to 22% stunting and less than 4% necrosis, while glufosinate caused less than 5% stunting and up to 12% necrosis. In 2017 glyphosate caused less than 5% visual injury, while glufosinate caused up to 25% stunting and 72% necrosis. In both years, glyphosate and glufosinate delayed headed from 30 to 99% and decreased rice yield from 20 to 99%, when applied at boot and 50% heading timings. Paraquat and sodium chlorate applications caused up to 20% stunting and 90% necrosis. Paraquat and sodium chlorate reduced rice yield numerically, but no statistical reduction was noted in late-season rice.

Introduction

Arkansas is known for being number one in rice production in the United States, with production exceeding 1.25 million acres yearly. Rice crop establishment begins in the month of March and continues through June (Hardke et al., 2013). This establishment window is used to maximize rice yield and reduce inputs. The management of multiple cropping systems including corn, cotton and soybean across wide acreage geography increases the potential for off-target herbicide drift from these crops on to neighboring rice fields. Earlier rice planting dates have been noted to increase the likelihood of glyphosate and glufosinate drift from adjacent non-rice crops (Kurtz and Street, 2003). The battle with herbicide-resistant weeds has also increased the total herbicide load on a given acre, which increases potential for drift. In addition, harvest aid applications

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have become more common in soybean, leading to potentially increased off-target movement late in the season. The purpose of this research was to determine the effects of simulated drift rates of glyphosate, glufosinate, paraquat, and sodium chlorate, on rice growth and yield.

Procedures

Field research was conducted at one location in Arkansas, in 2016 and 2017, to evaluate the effects of rice growth habit and yields following simulated drift rates of glyphosate, glufosinate, paraquat, and sodium chlorate at varying crop growth stages. The trial was conducted in Rohwer, Arkansas at the RRS on a Sharkey clay soil. In 2016, CL111 rice cultivar was planted on 18 April. In 2017, CL172 was planted on 10 June. Trials were arranged in a randomized complete block design with four replications utilizing 6.33 ft. by 20 ft. plots. Treatments were applied using a compressed air Mudmaster™ sprayer at 12 GPA. Rates of glyphosate at 0.113 lb ai/acre and glufosinate at 0.053 lb ai/acre were applied to rice at boot, 50% heading, soft dough, hard dough, and draining crop stages. Paraquat at 0.0625 lb ai/acre and sodium chlorate at 0.6 lb ai/acre were applied at soft dough, hard dough, and draining crop stages. Evaluations were taken on the extent of necrosis, stunting, and reduced heading. Yields were collected with a Massey 10 combine outfitted with a HarvestMaster System utilizing Mirus software.

Results and Discussion

In 2016, drift simulations of glyphosate caused 21% stunting of rice at the boot stage and 13% at the 50% heading stage, with necrosis being 3% and 4%, respectively (Fig. 1). Heading was reduced by greater than 98% when glyphosate was applied at the boot stage and by 66% at the 50% heading stage (Fig. 3). Boot and 50% heading stages also suffered yield losses from low doses of glyphosate, 100% and 56%, respectively (Fig. 4). Comparatively less than 10% necrosis was observed at the boot and 50% heading stages and 12% at soft dough following glufosinate applications (Fig. 1). Heading was reduced by glufosinate 61% and 50% at the boot and 50% heading stages (Fig. 3). Glufosinate reduced yield by 21% when applied at boot and 19% at 50% heading stage (Fig. 4). Paraquat applications resulted in less than 5% stunting across timings, 28% necrosis when applied at soft dough, and 4% at hard dough stages (Fig. 5). A 45% yield reduction was recorded at the soft dough stage, while less than 20% was recorded at the hard dough and draining stages. Sodium chlorate caused less than 20% stunting or necrosis and a 10-24% yield reduction was noted (Figs. 5 and 7).

In 2017, drift simulations of glyphosate caused 5% stunting of the rice at the boot stage and 3% at the 50% heading stage, while causing no necrosis (Fig. 2). Heading was reduced by greater than 98% at the boot stage and by 34% at the 50% heading stage (Fig 3). The boot and 50% heading stages also suffered yield losses of 100 and 26%, respectively (Fig. 4). Glufosinate caused necrosis levels of 51% at boot, 66% at 50% heading and 72% and 67% at soft and hard dough, while causing 34 % at draining

(Fig. 2). Heading was reduced by 27% and 21% at the boot and 50% heading stages, while causing less than 5% reduction at remaining stages (Fig. 3). Yield was reduced by 47% at boot and 27% at 50% heading stage (Fig. 4). Paraquat caused no stunting at any stage. Necrosis levels ranged from 65-73% (Fig. 6). An 18% yield reduction was recorded at the soft dough stage, while less than 4% was recorded at the hard dough and draining stages (Fig. 7). Sodium chlorate caused no stunting and 36-56% necrosis, while an 8-23% yield reduction was noted (Figs. 6 and 7).

Significance of Findings

In 2016 and 2017, glyphosate and glufosinate caused significant yield lose, as high as 99%, when drift rates of glyphosate were applied to rice at boot and 50% heading. Paraquat and sodium chlorate reduced rice yield numerically, but no significance was noted. In conclusion, boot applications of glyphosate and glufosinate caused the highest injury and yield loss, while the soft dough stage was most susceptible to injury when paraquat and sodium chlorate were applied.

Acknowledgments

The authors would like to extend thanks to the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for supporting and funding this project.

Literature Cited

Hardke, J.T., L.T. Barber, R.D. Cartwright, P. Counce, B.C. Griggs, C. Henry, F.N. Lee, G. Lorenz, R. Mazzanti, K. Moldenhauer, R.J. Norman, J.K. Norsworthy, T.L. Roberts, S. Sadaka, L. Schmidt, B. Scott, T. Siebenmorgen, T. Slaton, Y. Wamishe, B. Watkins, and C.E. Wilson. 2013. MP 192 Arkansas Rice Production Handbook. University of Arkansas System Division of Agriculture, Cooperative Extension Service, Little Rock.

Kurtz, M.E. and Street, J.E. 2003. Response of rice (*Oryza sativa*) to glyphosate applied to simulate drift. Weed Technol. 17:234-238.

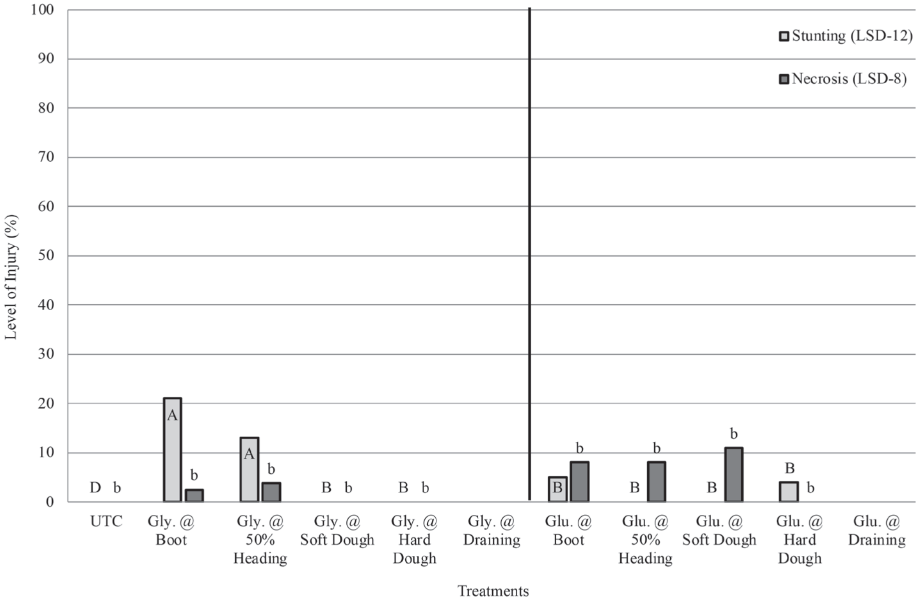

Fig. 1. Injury after treatments of glyphosate and glufosinate 3 days after draining application 2016. Abbreviations: UTC, untreated check; Gly, glyphosate; Glu, glufosinate. Values without the same letter are significantly different.

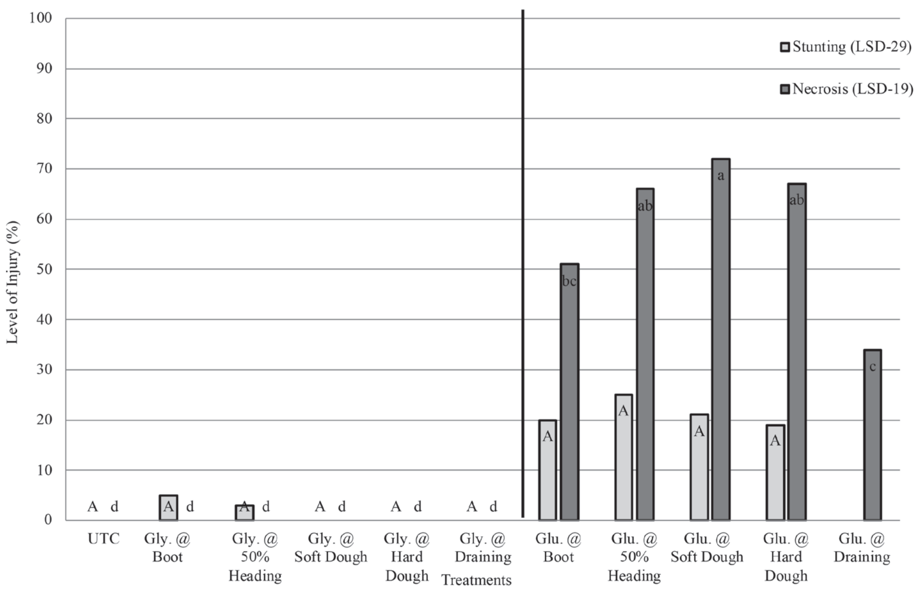

Fig. 2. Injury after treatments of glyphosate and glufosinate 8 days after draining application 2017. Abbreviations: UTC, untreated check; Gly, glyphosate; Glu, glufosinate. Values without the same letter are significantly different.

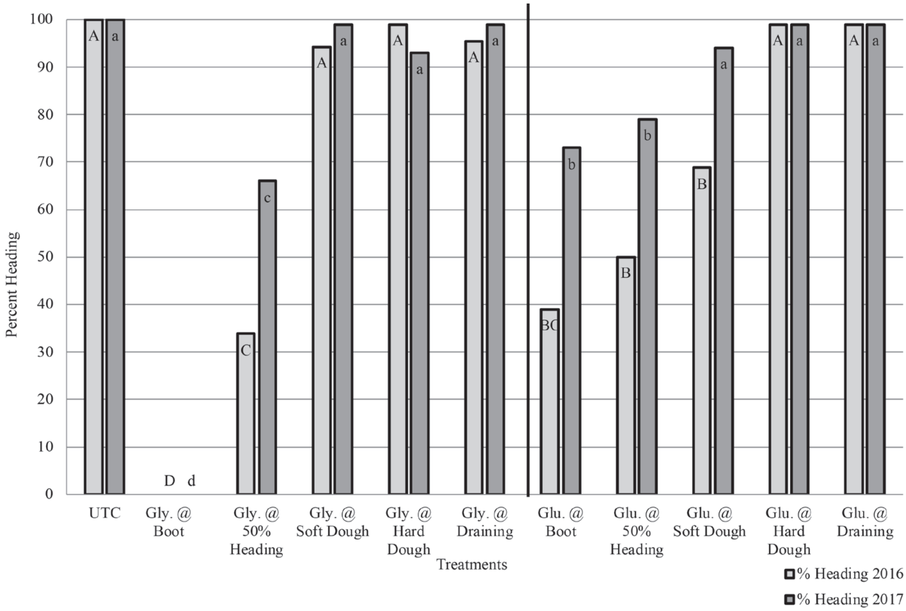

Fig. 3. Heading after treatments of glyphosate and glufosinate 3 days after draining application. Abbreviations: UTC, untreated check; Gly, glyphosate; Glu, glufosinate. Values without the same letter are significantly different.

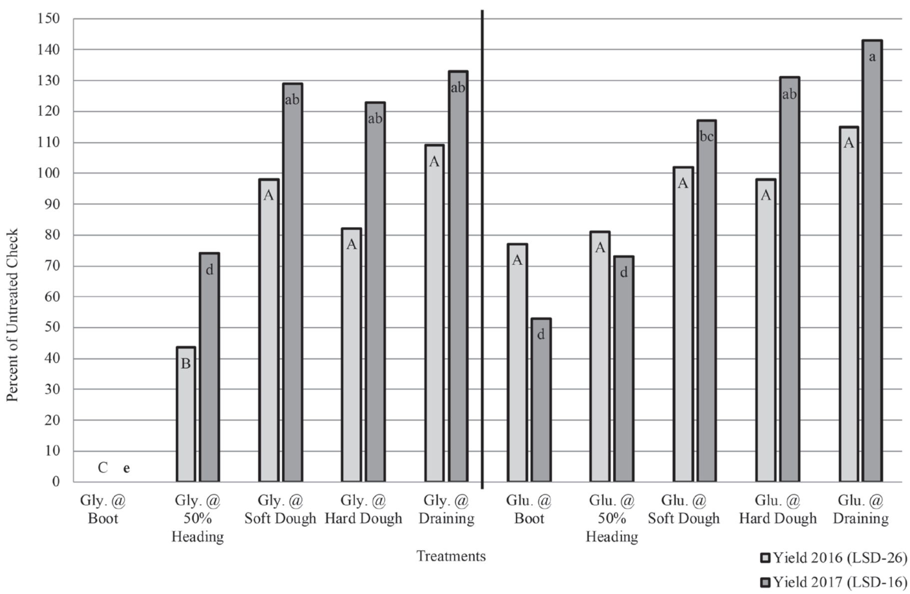

Fig. 4. Yield data after treatments of glyphosate and glufosinate. Abbreviations: Gly, glyphosate: Glu, glufosinate. Values without the same letter are significantly different.

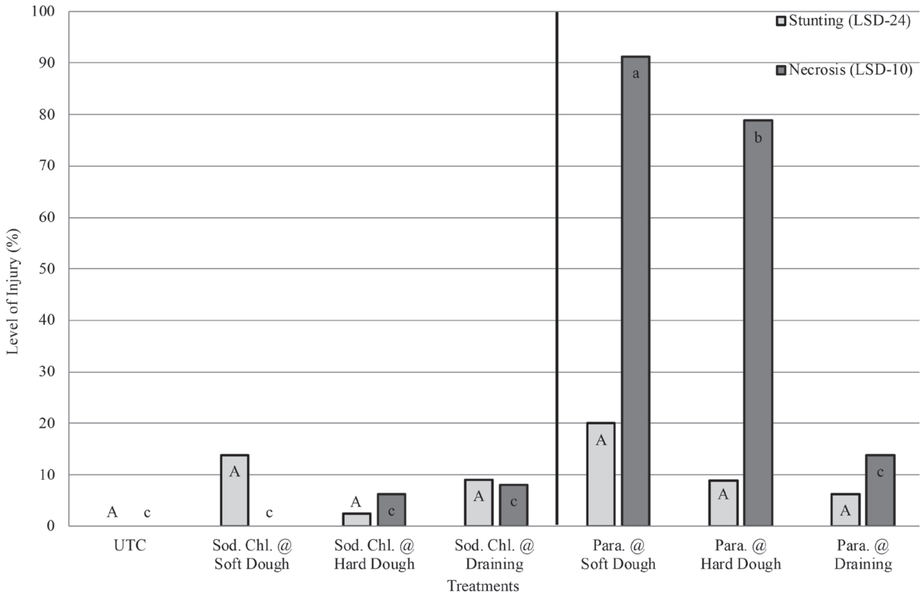

Fig. 5. Injury after treatments of sodium chlorate and paraquat 3 days after draining application 2016. Abbreviations: UTC, untreated check; Sod. Chl, sodium chlorate; Para, paraquat. Values without the same letter are significantly different.

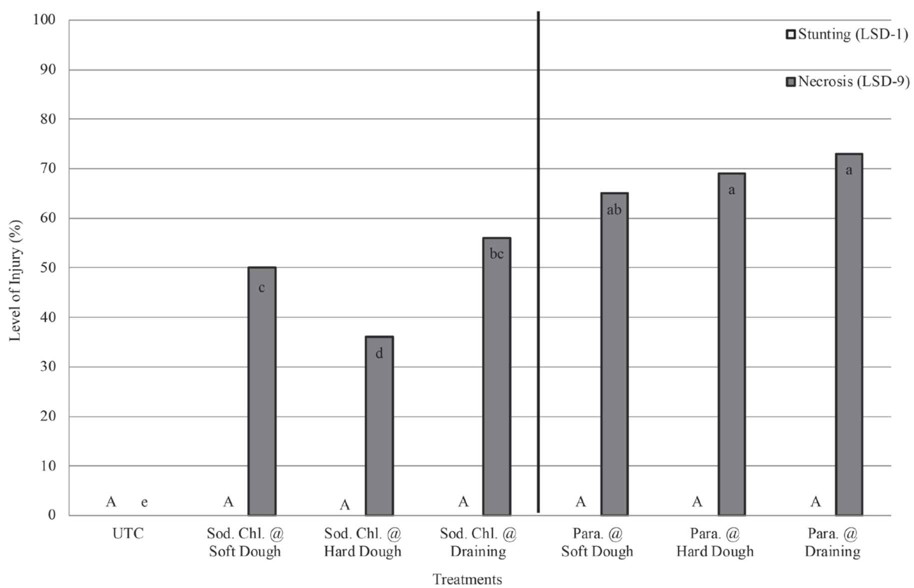

Fig. 6. Injury after treatments of sodium chlorate and paraquat 10 days after draining application 2017. Abbreviations: UTC, untreated check; Sod Chl, sodium chlorate; para, paraquat. Values without the same letter are significantly different.

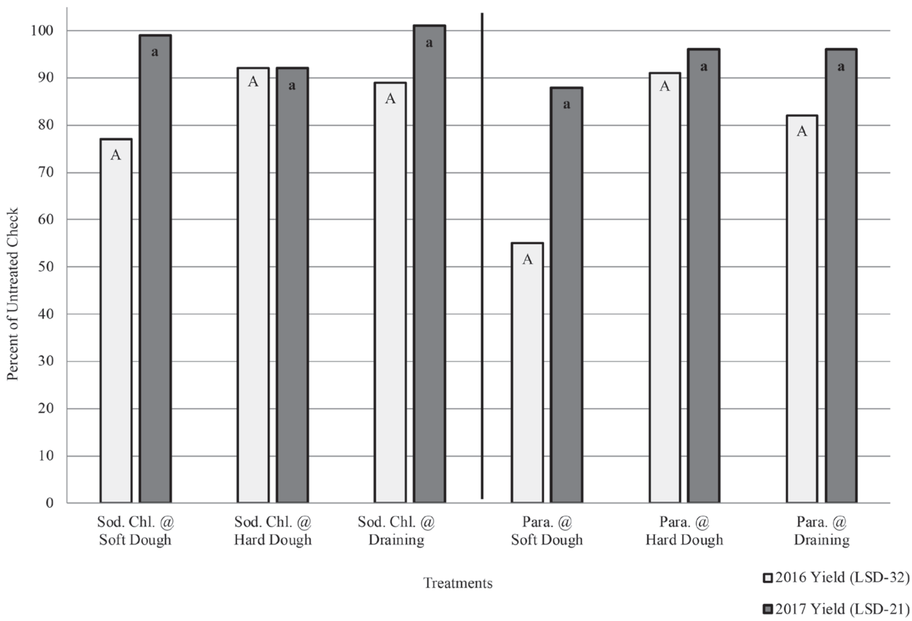

Fig. 7. Yield data after treatments of sodium chlorate and paraquat. Abbreviations: Sod Chl, sodium chlorate; Para, paraquat. Values without the same letter are significantly different.

Barnyardgrass Control Using Acetochlor in Arkansas Rice Herbicide Programs

M.E. Fogleman[1], J.K. Norsworthy[1], Z.D. Lancaster[1], and R.C. Scott[2]

Abstract

Herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) continues to be the focus of weed control programs for Arkansas rice growers. Heavy reliance on select herbicide sites of action (SOA) has led to increased resistance in the state, and limited effective management strategies. Very-long-chain fatty acid (VLCFA)-inhibiting herbicides such as acetochlor target an alternative SOA, and could provide control of such species. Field experiments were conducted in 2016 and 2017 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, to evaluate efficacy of acetochlor-containing rice herbicide programs. Experiments were designed as a randomized complete block with herbicide treatments consisting of acetochlor (Warrant) at 0.94 lb ai/acre or clomazone (Command) at 0.4 lb ai/acre applied alone, or as part of a season-long program. Differences in rainfall between locations and years caused variation in herbicide activation and affected crop damage and weed control. When evaluated early-season, clomazone alone controlled (98-100%) barnyardgrass better than acetochlor alone (69-98%). However, both clomazone- and acetochlor-based programs provided >96% barnyardgrass control when evaluated late-season and rice yielded >190 bu/acre. This suggests that acetochlor-based rice herbicide programs are comparable to that of standard programs.

Introduction

Arkansas rice producers face many challenges throughout the growing season. One of the most important and perhaps most difficult challenges is achieving control of barnyardgrass (*Echinochloa crus-galli*). Barnyardgrass is the most problematic weed in Arkansas rice production today, due to its competitive nature and evolved resistance to propanil, clomazone, quinclorac, and acetolactate synthase (ALS)-inhibiting herbicides (Lovelace et al., 2003; Norsworthy et al., 2009; Norsworthy et al., 2013).

Acetochlor (Warrant™) is a very-long-chain fatty acid (VLCFA)-inhibiting herbicide, currently labeled for use in soybean (*Glycine max*), corn (*Zea mays*), cotton

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(*Gossypium hirsutum*), and grain sorghum (*Sorghum bicolor*). Annual grasses such as barnyardgrass, goosegrass (*Eleusine indica*),and large crabgrass (*Digitaria sanguinalis*) have been effectively controlled by acetochlor in labeled crops (Krausz, 2000; Cahoon et al., 2015), which indicates that the same may be true in rice. At relatively low risk for resistance, acetochlor applied early in the season could be used to control resistant weeds such as barnyardgrass, which may be more difficult to control post-emergence (POST). The objective of this study was to evaluate barnyardgrass control using acetochlor in a season-long herbicide program.

Procedures

Field experiments were conducted in 2016 and 2017 on a Calloway silt loam at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, to evaluate weed control following standard rice herbicide programs, with and without the addition of acetochlor, in imidazolinone-resistant (Clearfield) rice systems. Cultivar CL111 was drill-seeded at 22 seed/ft of row into plots measuring 6 ft by 17 ft. The experimental design was a randomized complete block with four replications and a non-treated control plot for comparison. Acetochlor (Warrant) at 0.94 lb ai/acre, or clomazone (Command) at 0.4 lb ai/acre, was applied delayed preemergence (DPRE) 1) alone, 2) followed by imazethapyr (Newpath) at 0.06 lb ai/acre early post-emergence (EPOST), or 3) followed by imazethapyr EPOST followed by imazethapyr pre-flood (PREFLD).

All applications were made using a CO_2-pressurized backpack calibrated to deliver 15 gal/acre using AIXR 100015 nozzles. Visual estimates of crop injury and weed control were rated on a scale from 0 to 100, with 0 being no injury or control and 100 being crop death or complete weed control. At maturity, rice grain was harvested using a small-plot combine, and yield data were recorded. Data were subjected to analysis of variance (ANOVA) in JMP Pro 13 (SAS Institute, Inc., Cary, N.C.) with site year considered as a random effect. Data that met assumptions of ANOVA were separated using Fisher’s protected least significant difference test ($P = 0.05$).

Results and Discussion

In either year, clomazone or acetochlor applied DPRE resulted in minimal injury (≤ 8%) (Table 1). In 2016, clomazone provided better early season control of barnyardgrass than acetochlor at ≥98% and ≥65%, respectively. However, in 2017, early season barnyardgrass control was comparable, at ≥97% and ≥93% for clomazone and acetochlor, respectively. There were no differences between clomazone or acetochlor-containing programs at 6 weeks after flooding (WAF) in either year. Additionally, either herbicide followed by imazethapyr EPOST and imazethapyr PREFLD provided 100% control of barnyardgrass at 6 WAF. Yields were higher in 2016 than 2017, however the same general trend was observed overall. Within a program, there were no differences in yield between clomazone and acetochlor-based programs. In 2017, improved control from acetochlor 2 weeks after treatment (WAT) may be attributed to timely herbicide activation due to rainfall near the time of application (Fig. 1). In contrast, clomazone provided consistent control in both years, indicating that less rainfall may be required for activation. A high-input, two-pass program, clomazone DPRE followed by acetochlor + imazethapyr EPOST, provided ≥98% control throughout the growing season and yielded >190 bu/acre, suggesting that the addition of acetochlor prolonged residual control and eliminated the need for a third application.

Significance of Findings

If acetochlor were registered for use in U.S. rice, it could be used as a resistance management tool by targeting an alternative site of action, while providing weed control comparable to residual herbicides used today. Future research should determine the efficacy of acetochlor on weedy rice, as well as other problematic species for which clomazone provides little or marginal control.

Acknowledgments

We would like to thank the staff at the Pine Tree Research Station for their help in conducting this research. Funding for this research was provided by the University of Arkansas System Division of Agriculture and the Arkansas Rice Promotion Board.

Literature Cited

Cahoon C.W., A.C. York, D.L. Jordan, W.J. Everman, R.W. Seagroves, L.R. Braswell and K.M. Jennings. (2015). Weed control in cotton by combinations of micro-encapsulated acetochlor and various residual herbicides applied preemergence. Weed Technol 29:740-750.

Krausz R.F., B.G. Young, G. Kapusta, and J.L. Matthews (2000). Application timing determines giant foxtail (*Setaria faberi*) and barnyardgrass (*Echinochloa crus-galli*) control in no-till corn (*Zea mays*). Weed Technol 14:161-166.

Norsworthy J.K., J. Bond, and R.C. Scott. (2013). Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol 27:623-630.

Norsworthy J.K., R.C. Scott, K.L. Smith, J. Still, L.E. Estorninos Jr., and S. Bagarwa. (2009). Confirmation and management of clomazone-resistant barnyardgrass in rice. Proc South Weed Sci Soc 62:210.

Lovelace M. (2003). Implications of quinclorac use in Arkansas: Impacts of quinclorac drift on tomato physiology and development of quinclorac resistance in barnyardgrass. Ph.D. Dissertation, University of Arkansas.

Table 1. Rice injury, barnyardgrass control, and rough rice yield in 2016 and 2017 at the Pine Tree Research Station.

			Injury		Barnyardgrass					
			2 WAT†		2 WAT		6 WAF		Yield	
Program	Rate	Application timing‡	2016	2017	2016	2017	2016	2017	2016	2017
	(lb ai/A)		%						(bu/A)	
Nontreated control			0§	0	0	0	0	0	89 d	84 e
Acetochlor	0.94	DPRE	0	0	69 b	98 a	68 c	64 c	124 c	93 d
Clomazone	0.4	DPRE	0	1 a	98 a	100	78 b	76 b	166 b	105 d
Acetochlor + imazethapyr	0.94 + 0.06	EPOST	0	0	100	93 b	98 a	96 a	195 a	170 b
Clomazone + imazethapyr	0.4 + 0.06	EPOST	0	0	99 a	97 ab	96 a	96 a	187 a	164 bc
Acetochlor fb imazethapyr	0.94 fb 0.06	DPRE fb PREFLD	0	0	65 b	99 a	97 a	97 a	189 a	151 c
Clomazone fb imazethapyr	0.4 fb 0.06	DPRE fb PREFLD	2 a¶	0	99 a	98 a	100	97 a	184 a	162 bc
Acetochlor fb imazethapyr fb imazethapyr	0.94 fb 0.06 fb 0.06	DPRE fb EPOST fb PREFLD	0	0	68 b	100	100	100	188 a	175 b
Clomazone fb imazethapyr fb imazethapyr	0.4 fb 0.06 fb 0.06	DPRE fb EPOST fb PREFLD	1 a	0	98 a	99 a	100	100	191 a	167 b
Clomazone fb acetochlor + imazethapyr	0.4 fb 0.94 + 0.06	DPRE fb EPOST	5 a	8 a	99 a	98 a	100	98 a	195 a	193 a

† Abbreviations: WAT, weeks after treatment; WAF, weeks after flooding.

‡ Abbreviations: DPRE, delayed pre-emergence; EPOST, early post-emergence; PREFLD, preflood; fb, followed by.

§ Means of 0 or 100 were not included in statistical analysis.

¶ Means within a column followed by the same lowercase letter are not different according to Fisher's protected least significant difference ($\alpha = 0.05$).

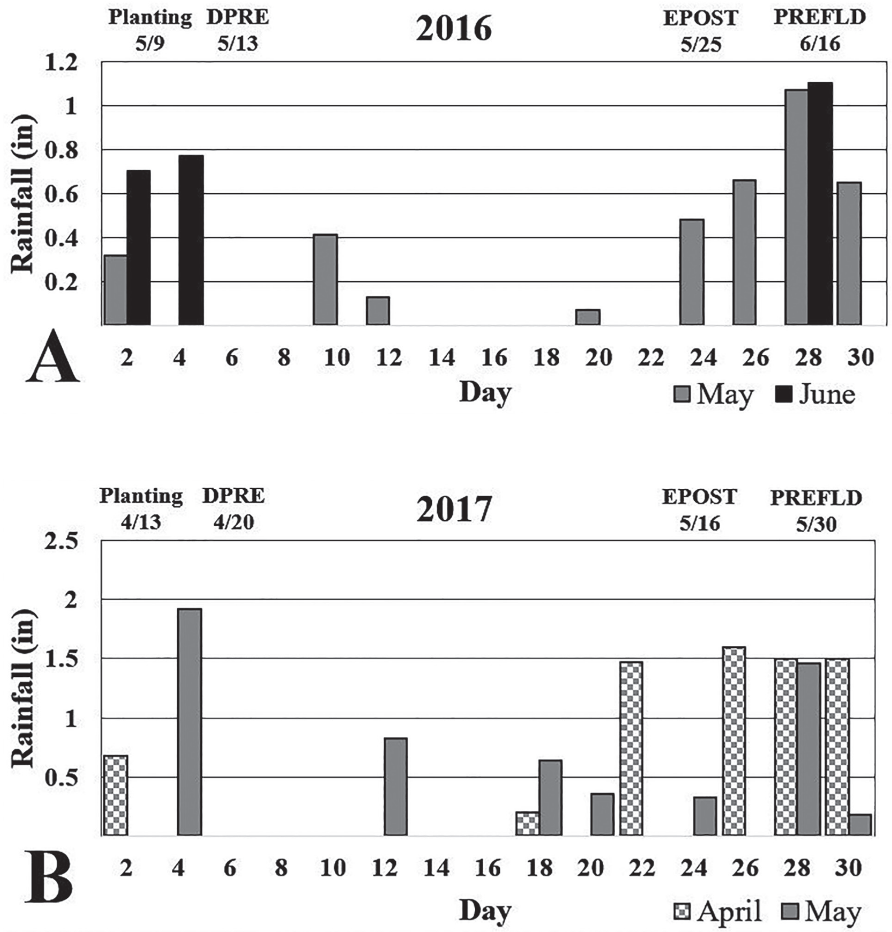

Fig. 1. Rainfall data for May and June of 2016 (A) and 2017 (B) at the University of Arkansas System DIvision of Agriculture's Pine Tree Research Station. DPRE, delayed pre-emergence; EPOST, early post-emergence; PREFLD, preflood.

Tolerance of Rice Cultivars to 4-Hydroxyphenolpyruvate Dioxygenase (HPPD)-Inhibiting Herbicides

M.H. Moore[1], R.C. Scott[2], and J.K. Norsworthy[3]

Abstract

A field trial was conducted in the summer of 2017 to evaluate the tolerance of 10 commonly planted rice cultivars when applied with 4-hydroxyphenolpyruvate dioxygenase (HPPD) inhibiting herbicides. Plots were planted with the cultivars Roy J, Diamond, LaKast, Jupiter, Titan, Rondo, CL151, CL172, CLXL745, or XP753. At the 2- to 3-leaf stage, each cultivar was applied with topramezone, mesotrione, or tembotrione at labeled corn rates. Nontreated checks were also included for comparison. After application, visual injury was assessed 2 and 4 weeks after treatment (WAT) and rough grain yield was taken at physiological maturity. Herbicide treatments applied to the cultivar Rondo displayed the most injury of over 90% observed at 4 WAT. Grain yields were also significantly reduced by 60-100% when compared to the nontreated check. Jupiter was least affected by the HPPD-inhibiting herbicides with mesotrione exhibiting the most injury (20%) 4 WAT and less than 10% yield reduction. These observations suggest that HPPD-inhibiting herbicides present a high risk for severe rice injury that would be undesirable in commercial rice cropping systems.

Introduction

Due to the rising instances of herbicide-resistant weeds in rice cropping systems, it is imperative for research to be conducted utilizing different herbicide sites of action (SOA) not used in current rice weed control programs. In recent years, studies have been conducted on 4-hydroxyphenolpyruvate dioxygenase (HPPD)-inhibiting herbicides, most notably the post-flood applied herbicide, benzobicyclon, in rice. The success of benzobicyclon has spurred research using other HPPD-inhibitors currently used in corn including topramezone, mesotrione, and tembotrione. All three HPPD-inhibitors may be applied preflood and have greater control of barnyardgrass—the most concerning weed in rice production based on responses from a survey of crop consultants in Arkansas and Mississippi—than benzobicyclon (Damalas et al., 2017; Norsworthy et al., 2013; Soltani et al., 2012). Although benzobiciclon has shown great promise for

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use with most rice cultivars, when applied to cultivars with *indica* backgrounds severe crop injury has been observed (Young et al., 2017). Due to topramezone, mesotrione, and tembotrione, belonging to the same SOA as benzobicyclon and the great range of rice cultivars being planted in rice cropping systems each year, it is important to know how differing cultivars react when applied with these herbicides.

The objective of this research was to assess rice injury and grain yield of ten cultivars when applied with topramezone, tembotrione, or mesotrione at the 2- to 3-leaf stage as compared to the nontreated checks for each rice cultivar.

Procedures

A field experiment was conducted in 2017 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. The soil series was a DeWitt silt loam. Rice was cone planted with either Roy J, Diamond, LaKast, Jupiter, Titan, Rondo, CL151, CL172, CLXL745, or XP753 rice cultivars on 17 May 2017 in a randomized complete block design. Conventional cultivars were planted at 22 seeds/row ft and hybrid cultivars at 7 seeds/row ft at a depth of 0.75 inches with 7.5-inch row spacings as recommended by the University of Arkansas System Division of Agriculture. Plots were consistent in size at 7 ft wide by 15 ft in length and maintained weed free via pre-emergence applications of clomazone + quinclorac at 0.234 + 0.374 lb ai/acre.

Herbicide treatments consisted of topramezone at 0.021 lb ae/acre tembotrione at 0.165 lb ai/acre, or mesotrione at 0.187 lb ai/acre applied when the rice reached the 2- to 3-leaf stage using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gallons/acre. All treatments included 1% v/v of crop oil concentrate. In addition to herbicide treatments, nontreated checks were also included for comparison.

Data collected comprised of percent visible injury 14 and 28 days after treatment (DAT) and rough rice yield taken at maturity. Visible injury from each week were analyzed utilizing two-way analysis of variance (ANOVA) with means separated using Fisher's protected least significant difference ($\alpha = 0.05$). Yield data were analyzed using one-way ANOVA comparing herbicide treatment and the nontreated check for each corresponding cultivar. For cultivars with no statistical yield reduction, standard error was reported.

Results and Discussion

Herbicide treatments resulted in significant variation across rice cultivars. The greatest amount of injury was seen with all herbicide applications when applied to the only *indica* cultivar, Rondo, with over 80% injury at 14 DAT and over 90% at 28 DAT (Table 1). For rice cultivars other than Rondo, topramezone exhibited the most injury 14 DAT when applied to Roy J (71%), Diamond (43%), LaKast (39%), Titan (45%), CLXL745 (86%), or XP753 (64%). At the same evaluation timing, mesotrione or tembotrione were least injurious; however by 28 DAT, mesotrione was most injurious when applied to CL151 (35%). Crop injury exhibited in this trial contradicts studies conducted by Young et al. (2017) where no crop injury was observed when benzobicyclon was applied to CL151, CLXL745, Jupiter, LaKast, Roy J, or XP753. Although visual crop injury was seen across all cultivars when applied with any HPPD-inhibiting herbicide, a reduction in grain yield did not always occur. No yield loss was observed when any herbicide was applied to Roy J, Jupiter, Titan, or CL172. However when topramezone, tembotrione, or mesotrione was applied to LaKast, Rondo, CL151, CLXL745, or XP753, yield was significantly reduced with Rondo showing the most reduction ranging from 64% to 100% yield loss when compared to the nontreated check.

Significance of Findings

This research is useful in determining rice cultivar tolerance to several HPPD-inhibiting herbicides. Data collected from this study indicate that the application of topramezone, tembotrione, and mesotrione may potentially result in rice injury undesirable by most commercial growers. Further research is needed to determine the cause of this injury seen in cultivars unaffected by benzobicyclon, another HPPD-inhibiting herbicide (Young et al., 2017).

Acknowledgments

Special thanks to the Arkansas Research and Promotion Board, and the University of Arkansas System Division of Agriculture for providing funding for this project.

Literature Cited

Damalas C.A., T.K. Gitsopoulos, S.D. Koutroubas, C. Alexoudis, I. Georgoulas. (2017). Weed control and selectivity in maize (*Zea mays* L.) with tembotrione mixtures. Intnl. J. Pest Manag. 64:11-18.

Norsworthy J.K., J. Bond, and R.C. Scott. (2013). Weed Management Practices and Needs in Arkansas and Mississippi Rice. Weed Technol. 27:623-630.

Soltani N., A.C. Kaastra, C.J. Swanton, and P.H. Sikkema. (2011). Efficacy of mesotrione and topramezone for the control of annual grasses. Int. Res. J. Agric. Sci. Soil Sci. 2:46-50.

Young M.L., J.K. Norsworthy, R.C. Scott, and L.T. Barber. (2017). Tolerance of Southern US Cultivars to Benzobicyclon. Weed Technol. 31:658-665.

Table 1. Visible rice injury at 2 and 4 weeks after treatment (WAT) and grain yield response as influenced by cultivar and 4-hydroxypheno-lpyruvate dioxygenase (HPPD)-inhibiting herbicide at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center in 2017.

Cultivar	Herbicide	Visual injury % 2 WAT	4 WAT	Grain yield
				lbs/acre
Roy J	None	-	-	8610 a‡
	Topramezone	71 cd†	51 d†	8720 a
	Tembotrione	23 lm	15 ijk	8780 a
	Mesotrione	27 klm	18 hij	8700 a
Diamond	None	-	-	8690 a
	Topramezone	43 e-h	28 fg	7660 b
	Tembotrione	29 jkl	16 h-k	8620 a
	Mesotrione	30 i-l	21 ghi	8630 a
LaKast	None	-	-	8240 a
	Topramezone	39 f-i	25 gh	7640 bc
	Tembotrione	24 lm	14 ijk	7230 c
	Mesotrione	24 lm	22 ghi	7850 b
Jupiter	None	-	-	8520 a
	Topramezone	31 i-l	15 ijk	8370 a
	Tembotrione	26 klm	18 hij	8610 a
	Mesotrione	36 g-j	20 g-j	8070 a
Titan	None	-	-	8760 a
	Topramezone	45 efg	28 fg	8470 a
	Tembotrione	34 h-k	23 ghi	8650 a
	Mesotrione	26 klm	23 ghi	8980 a
Rondo	None	-	-	7340 a
	Topramezone	88 a	95 ab	1720 c
	Tembotrione	83 ab	92 abc	2640 b
	Mesotrione	91 a	98 a	0 d
CL151	None	-	-	8020 a
	Topramezone	24 lm	11 jk	7300 b
	Tembotrione	18 mn	8 k	7020 b
	Mesotrione	31 i-l	35 ef	7180 b
CL172	None	-	-	8450 a
	Topramezone	25 klm	16 h-k	8240 a
	Tembotrione	29 jkl	19 g-j	8570 a
	Mesotrione	9 n	14 ijk	8340 a
CLXL745	None	-	-	7940 a
	Topramezone	86 a	88 bc	3130 b
	Tembotrione	83 ab	83 c	3200 b
	Mesotrione	75 bc	90 abc	2820 b
XP753	None	-	-	9030 a
	Topramezone	64 d	41 e	8450 bc
	Tembotrione	46 ef	28 fg	8450 ab
	Mesotrione	49 ef	38 e	8040 c

† Means within a column followed by the same letter are not significantly different at $\alpha = 0.05$ according to Fisher's protected least significant difference (LSD).
‡ Means followed by the same letter are not significantly different within the same cultivar at $\alpha = 0.05$ according to Fisher's protected LSD.

Program Approaches to Weed Control with Provisia Herbicide in Early-Season Arkansas Rice

M.M. Perkins[1], R.C. Scott[1], and B.M. Davis[1]

Abstract

Provisia herbicide controlled barnyardgrass when applied alone or in combination with several tank mixtures. The use of Permit, Facet, Ricebeaux, and Loyant herbicides in combination with Provisia also provided control of hemp sesbania. Slight antagonism on barnyardgrass control was observed when Provisia herbicide was tank-mixed with Basagran and Prowl; however this antagonism was overcome in a program approach involving a follow up application of Provisia. In this research, a program approach of Command plus Sharpen herbicides applied pre-emergence followed by a sequential application of Provisia plus a broadleaf product followed by a later post-emergence application of Provisia alone proved to be a viable treatment for a typical Arkansas weed spectrum. In the absence of the pre-emergence treatment, tank mixtures with products containing some residual activity and broadleaf control in the first of two Provisia applications were also effective. Provisia rice yields reflected the effectiveness of the weed control programs and ranged from 99 to 165 bu/acre.

Introduction

In 2017 a study was conducted at the University of Arkansas System Division of Agriculture's Pine Bluff Research Farm near Lonoke Arkansas to evaluate Provisia herbicide in program approaches for the control of barnyardgrass and hemp sesbania in rice. Provisia™ herbicide, common name quizalofop p-ethyl, is a member of the group 1 or graminicide family of herbicides. This group of herbicides inhibits acetyl CoA carboxylase in susceptible plants (Shaner et al., 2014). Provisia is a trademark of BASF Corporation and is used to designate both the herbicide and the herbicide-tolerant rice cultivars being sold as Provisia rice. This is the second non-GMO herbicide-tolerant rice released by BASF, the former being Clearfield™ rice which was first released in 2002.

Like Clearfield rice, a major use for Provisia rice will be for the control of "weedy" rice or red rice; however in addition, Provisia herbicide should also control other prob-

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lematic grass rice weeds, including resistant biotypes of barnyardgrass. Provisia will need to be used in combination with other products in a program approach for a complete weed control program and for the Provisia system to be effective. The graminicide family of chemistry includes other products such as, Select, RiceStar and Clincher, which are known to be susceptible sometimes to antagonism when tank-mixed with broadleaf products and Provisia is no exception (Scherder et al., 2005; Buehring et al., 2006).

The objective of this research was to evaluate various herbicide programs and tank mixtures for the control of barnyardgrass and hemp sesbania in a Provisia herbicide based weed control system.

Procedures

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Bluff Small Farm Outreach Center near Lonoke, Ark. in the summer of 2017 to evaluate the weed control with the use of Provisia herbicide in flooded rice. The HPI Provisia rice was planted on 19 May 2017 at a seeding rate of 80 lb/acre. The test plot area was field cultivated and land planed prior to planting. The soil series was a Calhoun silt loam soil with a pH of 5.4. Plot size was 7.5 ft wide by 25 ft long with 10-ft wide alleys between plots. Plots were set up in a randomized block design with 4 replications. Treatments consisted of Provisia (15.5 oz/acre) alone and in combination with Permit (1 oz/acre), Basagran 5L (20 oz/acre) + Prowl 3.3 (38.8 oz/acre), Facet L (32 oz/acre) alone and with Prowl, Prowl + Sharpen (1 oz/acre), Ricebeaux (96 oz/acre), and Loyant (16 oz/acre). All treatments except the check, Ricebeaux and Prowl + Sharpen included a pre-emergence application of Command (16 oz/acre) plus Sharpen (1.0 oz/acre). Treatment application timings consisted of 2- to 3- leaf and 1- to 2- tillers applied using a self-propelled sprayer calibrated to deliver 10 gal/acre at 3 mph. The untreated check was included for injury, weed control, and yield comparisons.

Data collected consisted of visual weed control that was defined as a percent control where 0% was no control and 100% was complete control based off the untreated check. Ratings were taken at 28 and 44 days after emergence (DAE). Plots were harvested for yield on 9 October 2017 using a modified commercial combine. All yields were adjusted to 12.5% grain moisture. Data was analyzed and subjected to analysis of variance and means were separated by Fisher's least significance difference test at a *P* value of 0.05.

Results and Discussion

Command plus Sharpen applied pre-emergence followed by two applications of Provisia controlled barnyardgrass 100% at 44 DAE (Table 1). However, this treatment alone was not adequate for the control of hemp sesbania. Many of the program approaches evaluated did control both barnyardgrass and hemp sesbania at 44 DAE. The addition of Basagran to Provisia herbicide reduced barnyardgrass control by 7% compared to the application of Provisia alone at 22 DAE. This was also the only tank-mix partner that did not adequately control hemp sesbania when used in the overall program. This is to be expected as Basagran alone is known to be less effective on hemp sesbania than many of the other products evaluated (Scott et al., 2018).

Rice yields did reflect the level of weed control obtained by the various weed control treatments (Table 1). However, the only difference observed was between those plots that received a herbicide versus the untreated check where yield was improved by 53-65 bu/acre. The average rice yield for the treated plots in this study was about 160 bu/acre. Many rice cultivars on the market today are capable of much higher yields (Hardke, 2017). However in cases of severe herbicide resistant barnyardgrass and red or weedy rice infestations, this system may provide growers with a much needed and more profitable option.

Significance of Findings

Provisia herbicide can be an effective grass control product in addition to its value as a red rice herbicide program. Tank mixtures, especially when applied first in a sequential program, can result in both effective grass and broadleaf weed control. While rice yields were less than those which can be achieved with higher yielding cultivars, further development of these cultivars could lead to more widespread adoption of this technology as growers seek out new weed control options to battle herbicide resistance.

Acknowledgments

We would like to thank the Arkansas Rice Promotion Board, BASF Corporation, Dow AgroScience, and the University of Arkansas System Division of Agriculture for the funding of this project.

Literature Cited

Buehring, N.W., R.E. Talbert, and F.L. Baldwin. 2006. Interactions of graminicides with other herbicides applied to rice (*Oryza sativa*). Weed Technol. 20:215-220.

Hardke, J.T. 2017. Trends in Arkansas Rice Production. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 643:11-21. Fayetteville.

Scherder, E. F., R. E. Talbert, and M. L. Lovelace. 2005. Antagonism of cyhalofop grass activity halosulfuron, triclopyr, and propanil. Weed Technol. 19:934-941.

Scott, R.C., L.T. Barber, J.K. Norsworthy, J.W. Boyd, N. Burgos and G. Seldon. 2018. Recommended chemicals for weed and Brush Control. MP44. University of Arkansas. www.uaex.edu.

Shaner, D.L. (ed.). Herbicide Handbook 10th Edition. 2014. Herbicide Handbook Committee, Weed Science Society of America, Lawrence, Kan.

Table 1. Barnyardgrass and hemp sesbania control and rice yield following Provisia herbicide programs.

Tank mix partners[a]	Rate	Timing[b]	Barnyardgrass 28	Barnyardgrass 44	Hemp sesbania 28	Hemp sesbania 44	Rice yield
			Days after emergence				
	oz/acre		----------------% Control----------------				bu/acre
Untreated Check			0	0	0	0	99
None			96	100	70	45	153
Permit	1.0	2-3 LF	99	100	99	100	159
Basagran 5L Prowl 3.3 EC	20.0 38.8	2-3 LF 2-3 LF	89	100	75	63	165
Prowl 3.3 EC Facet L	38.8 32.0	2-3 LF 2-3 LF	96	100	95	100	164
Prowl 3.3 EC Sharpen	38.8 1.0	2-3 LF 2-3 LF	98	100	94	93	156
Ricebeaux	96.0	2-3 LF	95	100	95	95	165
Facet L	32.0	2-3 LF	95	100	98	100	164
Loyant	16.0	2-3 LF	95	100	99	90	158
$LSD_{0.05}$			6	---	15	18	20

[a] All treatments except the untreated check, Ricebeaux, and Prowl + Sharpen contained a pre-emergence treatment of 16 fl oz/acre Command plus 1.0 fl oz/acre Sharpen. All treatments consisted of Provisia at 15.5 fl oz/acre applied at 2- to 3- leaf and 1- to 2- tiller rice. All post-emergence treatments contained Agri-dex at 1.0% v/v.

[b] LF=leaf.

Target-Site Mutations in Pennsylvania Smartweed (*Polygonum pensylvanicum*) Confer High Level of Resistance to Acetolactate Synthase Inhibitors

V.K. Varanasi[1], J.K. Norsworthy[1], C. Brabham[1], and R.C. Scott[2]

Abstract

Pennsylvania smartweed, a member of the knotweed family (*Polygonaceae*), is a summer annual broadleaf weed of horticultural and agronomic crops distributed throughout the United States. Pennsylvania smartweed is a common weed of rice in the mid-South. Acetolactate synthase (ALS) inhibitors have been extensively used for controlling smartweeds in Clearfield® rice. In the present study, we confirmed resistance to different ALS-inhibiting herbicides and characterized the underlying resistance mechanism in a Pennsylvania smartweed population. Resistant (R) plants were collected in 2016 from a field in southeast Missouri near Arkansas. A dose-response experiment was conducted in the greenhouse with the following rates of the herbicides applied to R plants: Londax (bensulfuron-methyl) at 1, 16, 32, 64, 128, and 256x (x = 0.96 oz/acre); Newpath (imazethapyr) at 0.5, 1, 4, 8, 16, and 32x (x = 1.51 oz/acre); Regiment (bispyribac-sodium) at 0.5, 1, 4, 8, 16, and 32x (x = 0.45 oz/acre), respectively. Susceptible (S) plants were treated with 0.125, 0.25, 0.5, 1, and 2x rates of the above herbicides. Dry biomass data collected 3 weeks after treatment were analyzed and a resistance index (R/S) was calculated based on the GR_{50} ratios. The target-site *ALS* gene was amplified from R and S plants and sequences analyzed for mutations known to confer ALS-inhibitor resistance. The Pennsylvania smartweed population in question was found to be resistant to Londax (R/S = 2440), Newpath (R/S = 12.7), and Regiment (R/S = 7), respectively. Sequencing of the *ALS* gene from R plants revealed two previously known mutations ($Pro_{197}Ser$, $Ala_{122}Ser$) conferring resistance to sulfonylureas and imidazolinones. This is the first worldwide report of ALS-inhibitor resistance in Pennsylvania smartweed.

Introduction

Pennsylvania smartweed, a member of the knotweed family (*Polygonaceae*), is a summer annual broadleaf weed of horticultural and agronomic crops distributed

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throughout the United States. Pennsylvania smartweed is a common weed of Arkansas rice production, especially in systems where preplant or fall tillage is limited. Pennsylvania smartweed can produce up to 19,000 seed/plant and require wet soil conditions to germinate. Depending on the plant density, Pennsylvania smartweed can cause yield reductions of 13% to 62% in soybean, 20% in corn, and 85% in cotton, respectively (Coble and Ritter, 1978; Sankula and Gianessi, 2003). Acetolactate synthase (ALS)-inhibiting herbicides (WSSA group 2) have been used alone or tank-mixed with other herbicides for controlling smartweeds in Clearfield® rice. The ALS-inhibitors are one of the most common herbicide sites of action used in many cropping systems. These herbicides inhibit ALS, a key enzyme in the biosynthesis of the branched-chain amino acids such as valine, leucine, and isoleucine (Umbarger, 1978). Weeds have a tendency to rapidly evolve resistance to ALS-inhibitors, limiting their utility as an effective weed control (Tranel and Wright, 2002). Extensive use of ALS-inhibiting herbicides has resulted in evolution of resistance to these herbicides and by 2017, resistance to ALS inhibitors was reported in 159 weed species around the world (Heap, 2017). Pennsylvania smartweed was previously reported to be resistant to atrazine (WSSA group 5) in 1990 in a corn cropping system (Heap, 2017). However, resistance to ALS inhibitors in this species has not previously been reported in the U.S. or elsewhere. In the present study, we confirmed resistance to different ALS inhibitors and characterized the underlying mechanism of resistance in a Pennsylvania smartweed population.

Procedures

The resistant (R) plants were collected in 2016 from a field in southeast Missouri near Arkansas. Scarified seed from the susceptible (S) plants was obtained from River Refuge Seed Company (Brownsville, Ore.). Based on the preliminary studies, the following herbicide rates were selected for conducting a dose-response on R plants: bensulfuron-methyl at 0.96 oz/acre (Londax®, RiceCo, Memphis, Tenn.) (1, 16, 32, 64, 128, and 256x); imazethapyr at 1.51 oz/acre (Newpath®, BASF, Research Triangle Park, N.C.) (0.5, 1, 4, 8, 16, and 32x), bispyribac-sodium at 0.45 oz/acre (Regiment®, Valent USA Corp., Walnut Creek, Calif.) (0.5, 1, 4, 8, 16, and 32x). Susceptible seedlings were treated with following rates of the three ALS-inhibitors: 0.125, 0.25, 0.5, 1, and 2x, respectively. Bensulfuron-methyl, imazethapyr, and bispyribac-sodium belong to sulfonylurea (SU), imidazolinone (IMI), and pyrimidinylthiobenzoic acid chemical families of ALS inhibitors. Once seedlings reached the 3- to 4-leaf stage, they were sprayed with above herbicides using a research track sprayer equipped with two flat-fan spray nozzles (TeeJet spray nozzles; Spraying Systems Co., Wheaton, Ill.) calibrated to deliver 20 gal/acre of herbicide solution at 39 psi, moving 1 m/h. All herbicide treatments included recommended adjuvants: crop oil concentrate (COC) at 1% v/v for bensulfuron-methyl, non-ionic surfactant (NIS) at 0.25% v/v for imazethapyr, and Dyna-a-Pak® at 2.5% v/v for bispyribac-sodium, respectively. The experiment was conducted twice with three replications (10 seedlings/replication). Aboveground dry biomass was determined 3 weeks after treatment and data analyzed using the *drc* package in R 3.1.2

(R Development Core Team, 2017). The resistance index (R/S) was calculated as GR_{50} ratio between the 'R' and the 'S' Pennsylvania smartweed populations.

Genomic DNA (gDNA) was isolated from 8 resistant and 2 susceptible plants using a modified CTAB (cetyl trimethylammonium bromide) protocol (Doyle and Doyle, 1987). Primers were designed using OligoAnalyzer 3.1 (IDT SciTools, 2014; Integrated DNA Technologies, Inc., Coralville, Iowa) for *ALS* gene sequencing (Table 1).

Results and Discussion

Based on the whole-plant dose-response studies, the Pennsylvania smartweed population collected from the southeast Missouri region was found to be resistant to the three ALS-inhibitors (bensulfuron-methyl, imazethapyr, and bispyribac-sodium) (Fig. 1A, B, and C). The effective dose that causes 50% inhibition (GR_{50}) of growth (biomass reduction) was determined for the three herbicides and resistance index (R/S) was calculated (Table 2). The R/S values for bensulfuron-methyl, imazethapyr, and bispyribac-sodium were 2330, 12, and 6, respectively. The results show that the Pennsylvania smartweed population under study is highly resistant to bensulfuron-methyl, followed by imazethapyr and bispyribac-sodium.

Sequencing of the target-site *ALS* gene from two R plants revealed two previously known mutations, proline to serine ($Pro_{197}Ser$) and alanine to serine ($Ala_{122}Ser$) (Fig. 2). Point mutations at Pro_{197} in the *ALS* gene are known to confer resistance to sulfonylureas (such as bensulfuron-methyl) and not to IMIs. Many of the point mutations at Pro_{197} in the ALS can also lead to cross-resistance to other ALS inhibitors (Wright and Penner, 1998). The low-level resistance to Regiment observed in Pennsylvania smartweed is most likely due to cross-resistance because of $Pro_{197}Ser$ mutation. The mutation $Ala_{122}Ser$ in the *ALS* gene is an IMI-specific mutation conferring resistance to imazethapyr (Yu and Powles, 2014).

Significance of Findings

In summary, this study reports the first documented case, to our knowledge, of field-evolved resistance in Pennsylvania smartweed to ALS inhibitors. Resistance to ALS-inhibitors will reduce control options for Pennsylvania smartweed in rice cropping systems.

Acknowledgments

We appreciate the support from the University of Arkansas System Division of Agriculture as well as the Arkansas Rice Promotion Board for funding this research.

Literature Cited

Coble, H.D. and R.L. Ritter. 1978. Pennsylvania smartweed (*Polygonum pensylvanicum*) interference in soybeans (*Glycine max*). Weed Sci. 26:556-559.

Doyle, J.J. and Doyle, J.L.1987. A rapid DNA isolation procedure for small quantities of fresh leaf tissue. Phytochem. Bull. 19:11-15.
Heap, I. 2017. The International Survey of Herbicide Resistant Weeds. Accessed 20 Nov 2017. http://www.weedscience.org
IDT SciTools. 2017. A suite for analysis and design of nucleic acid oligomers. Accessed 20 November 2017. https://www.idtdna.com/calc/analyzer
R Core Team. 2018. R: A language and environment for statistical computing. Vienna, Austria: R foundation for statistical computing. Accessed 6 January 2018. http://www.R-project.org
Sankula, S. and L.P. Gianessi. 2003. The value of herbicides in US crop production. National Center for Food and Agricultural Policy. http://www.ncfap.org/documents/FullText.pdf
Tranel, P.J. and T.R. Wright TR. 2002. Resistance of weeds to ALS-inhibiting herbicides: what have we learned? Weed Sci. 50:700-712.
Umbarger, H.E. 1978. Amino acid biosynthesis and its regulation. Annu. Rev. Biochem. 47:533-606.
Wright, T.W. and D. Penner. 1998. In vitro and whole-plant magnitude and cross-resistance characterization of two imidazolinone-resistant sugarbeet (*Beta vulgaris*) somatic cell selections. Weed Sci. 46:24-29.
Yu, Q. and S.B. Powles. 2014. Resistance to AHAS inhibitor herbicides: current understanding. Pest Manag. Sci. 70:1340-1350.

Table 1. Primers used for amplifying the acetolactate synthase (ALS) gene in Pennsylvania smartweed.

Gene	Primer Sequences	Tm (C)
ALS 5’ region	5'- ACC TCC TTC CGC TAC TAT AAC TC -3' 5'- AGT CCC TCT TCA TTA GCA GAA TAA GTG -3'	54
ALS 3’ region	5'- CAC TTA TTC TGC TAA TGA AGA GGG ACT -3‘ 5'- GCT TCA GCG AAT TTG AGC ATA TC -3'	

Table 2. The effective dose that causes 50% inhibition (GR_{50}) of growth (biomass reduction) for Londax, Newpath, and Regiment.

	GR_{50} values		
Pennsylvania smartweed populations	**Londax**	**Newpath**	**Regiment**
	---------------------------oz/acre -----------------------		
Resistant	73.2	1.27	0.07
Susceptible	0.03	0.10	0.01

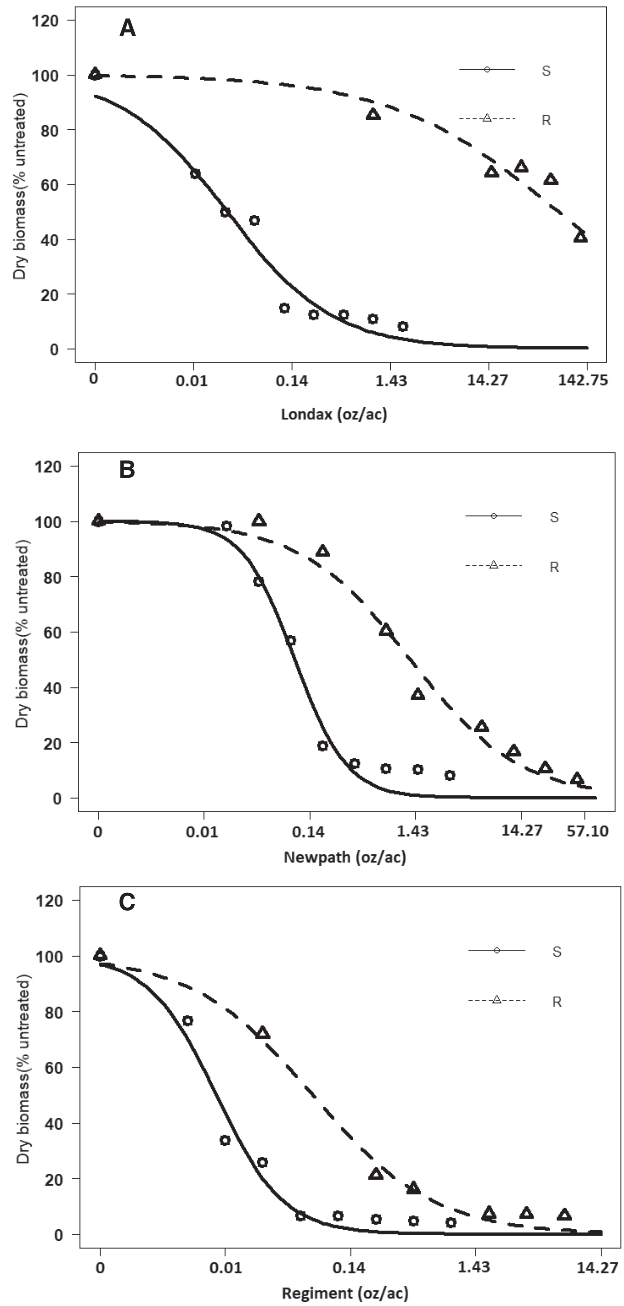

Fig. 1. (A) Acetolactate synthase (ALS) dose-response using four parameter log logistic model for Londax. (B) ALS dose-response using four parameter log logistic model for Newpath. (C) ALS dose-response using four parameter log logistic model for Regiment.

R1 GAAGGTGTTACCGATGTTTTTGCTTACCCTGGTGGA**<u>TCA</u>**TCCATGGAAATCCATCAAGCT
R2 GAAGGTGTTACCGATGTTTTTGCTTACCCTGGTGGA**GCA**TCCATGGAAATCCATCAAGCT
SUS GAAGGTGTTACCGATGTTTTTGCTTACCCTGGTGGA**GCA**TCCATGGAAATCCATCAAGCT
$Ala_{122}Ser$

R1 TTCTTGACTCACTCCCGCTTGTCGCCATTACTGGGCAACTT**CCC**CGGCGTATGATTGGTA
R2 TTCTTGACTCACTCCCGCTTGTCGCCATTACTGGGCAACTT**<u>TCC</u>**CGGCGTATGATTGGTA
SUS TTCTTGACTCACTCCCGCTTGTCGCCATTACTGGGCAACTT**CCC**CGGCGTATGATTGGTA
$Pro_{197}Ser$

Fig. 2. Two acetolactate synthase (*ALS*) gene mutations conferring ALS-inhibitor resistance in Pennsylvania smartweed.

Preliminary Study of Soil-Herbicide Interactions of Rogue Herbicide

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Abstract

With the pending approval of Rogue herbicide, information regarding herbicide-soil interactions is needed to optimize its efficacy for Arkansas rice farmers. Batch equilibration experiments were carried out with a silt loam and a clay soil with benzobicyclon hydrolysate (BH; active metabolite in Rogue herbicide), to determine optimal equilibration time and ratio of soil to solution for soil sorption experiments. Results indicate a soil:solution of 1:1 and equilibration time of 16 hours are optimal for determining the soil sorption of BH in silt loam, and a soil:solution of 1:1 or 1:5 and 16 hours equilibration time is appropriate for clay soil. Using the parameters established in this study, batch equilibration studies will be carried out on a broader range of soils from across Arkansas rice producing regions. Understanding the dynamics between soil and Rogue will inform scientifically sound recommendations to Arkansas farmers for effective weed control and environmental stewardship.

Introduction

The evolution of weed resistance has prompted the U.S. release of benzobicyclon (BZB), a post-flood rice herbicide that has been used for decades in Asia (Williams and Tjeerdema, 2016). In California, BZB is already available to rice producers as a granular product, called Butte, for aerial applications. Rogue, a liquid formulation for ground application, is intended for the Arkansas market and is currently under regulatory review (EPA, 2017). Benzobicyclon is a pro-herbicide that degrades rapidly into the active metabolite benzobicyclon hydrolysate (BH; Williams and Tjeerdema, 2016).

Little is known about the environmental fate and transport of BZB and BH in Arkansas agricultural systems. Processes, such as soil sorption of BH, could affect the efficacy of Rogue, with soils that tightly sorb BH requiring higher application rates for effective weed control. This study used batch equilibration experiments to determine

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optimal equilibration time, ratio of soil to solution, and reaction vessel material for subsequent experiments that will estimate BH soil adsorption rates for 10 Arkansas agricultural soils.

Procedures

Soil Processing. Two soil series, Henry silt loam and Sharkey clay, representative of the most common soil textures used for rice production in Arkansas, were selected for this study. Soil was collected from the top 10 cm from the University of Arkansas System Division of Agriculture Pine Tree Research Station (silt loam) and Northeast Research and Extension Center (clay) and was characterized for pH, organic matter content, and electrical conductivity (Table 1) (Sikora and Moore, 2014). Soil samples were pre-processed by air-drying in the greenhouse, grinding, and homogenizing by passing through a 2-mm sieve. Oven-dry gravimetric soil moisture content was calculated by drying 25-g air-dried soil in triplicate for each soil at 105 ºC overnight.

Batch Equilibration Study. Adsorption is estimated as the change in BH concentration in the solution of a soil-solution matrix following a reaction period. The BH portion no longer in solution following the reaction period is assumed be sorbed to soil particles. Three soil:solution ratios and four equilibration time intervals were tested to identify optimal conditions for future adsorption experiments, as described by the Organization of Economic Cooperation and Development (OECD, 2000). Air dried soil (25, 5, or 1 g) was suspended in 25 mL of 0.01 M $CaCl_2$, representing ratios of 1:1, 1:5, or 1:25, respectively. Reaction vessels containing only 25 mL of 0.01 M $CaCl_2$ served as controls (OECD, 2000) and allowed testing of reaction vessel material, high density polyethylene (HDPE), for reactivity with BH. All vessels were spiked with 0.13 mg BH dissolved in acetonitrile to bring the initial BH concentration to 5 mg/L. Soil mass and total solution volume were corrected for air-dry soil moisture content using the oven-dry gravimetric soil moisture content.

Four equilibration times were tested, with reaction vessels shaken for 4, 16, 24, or 28 hrs on an end-over-end rotary shaker. Duplicate vessels for each soil:solution ratio and time interval combination were included to capture potential variability. Following shaking, samples were centrifuged at 4000 rpm for 5 min to separate solid and liquid phases. An aliquot of the liquid phase was removed and filtered through a 0.45 µm PTFE membrane into glass HPLC vials. Samples were capped and stored in the refrigerator until subsequent analysis within 24 hrs.

Benzobicylon Hydrolysate Analysis. The BH concentration in each reaction vessel was quantified using high performance liquid chromatograph with diode array detection (HPLC-DAD; Shimadzu LC 20-AD with Columbus C18 250 × 4.6 mm, 100 Å, 5 µL). Separation was achieved with an aqueous 0.1% H3PO4 and acetonitrile gradient mobile phase at 1 mL/min flow rate with 40 ºC oven. The mobile phase gradient was 10-100% acetonitrile over 15 min, followed by 100% acetonitrile for 5 min and 10% acetonitrile for 10 min. Injection volume was 25 µL. Detection was at 287 nm with a retention time of 12.97 min.

Data Analysis. Results from the HPLC analysis were used to calculate adsorption % and the soil-water partitioning coefficient (K_D) for each soil. K_D (mL/g) was calculated by the equation:

$$K_D = \frac{(x/m)}{C_e} \qquad \text{(Eq. 1)}$$

Where *x/m* is the herbicide sorbed to the soil (mg/g) and C_e is the herbicide in solution at equilibrium (mg/mL; Weber et al., 2000).

Results and Discussion

Equilibration time is identified as the interval at which rates of sorption/desorption of BH result in no further change in concentration in solution. Results of this study indicated that equilibration occurred for BH by 16 hours for both soil types. For the silt loam (Fig. 1A) and the clay (Fig. 1B), BH adsorption increased up to 16 h, but remained constant thereafter across all soil:solution ratios. Fluctuations in adsorption to the silt loam in the 1:25 soil:solution ratio at 24 h and to the clay for the 1:1 soil:solution at 28 hrs were small in magnitude relative to changes observed up to 16 h and were therefore accredited to inherent sampling variability.

The OECD (2000) recommends selecting soil:solution ratios to target adsorption percentage >20% and preferably >50%. For the silt loam, the %BH adsorbed at 16 hrs was 35% for 1:1, 9.8% for 1:5, and 3.1% for the 1:25 soil:solution ratios (Fig. 1A). Therefore, the 1:1 ratio was identified as preferred for further equilibration studies using Arkansas silt loam soils. For the clay, the %BH adsorbed at 16 h was 74% for 1:1, 38% for 1:5, and 12% for 1:25 soil:solution ratios (Fig. 1B). The %BH adsorbed for the 1:25 ratio was outside the acceptable range, but both 1:1 and 1:5 ratios were acceptable for further testing on Arkansas clay soils.

Overall, the clay soil sorbed more BH than the silt loam (Fig. 1A and 1B). The maximum percent adsorption was in the 1:1 soil solution for both soils, but was 74.2% for the clay and just 34.6% for the silt loam, which was more comparable to the percent adsorption in the clay 1:5 soil solution ratio. The calculated K_D at equilibrium in the 1:1 soil:solution ratio for the Henry silt loam was 0.59 mL/g and was 3.8 mL/g for the Sharkey clay. The higher K_D value of the clay indicates that a greater proportion of applied Rogue (as BH) will bind to the soil particles than will remain in the soil water. The lower K_D value for the silt loam indicates that relatively more BH will remain in the soil water than will sorb to soil particles. Sorption of organic compounds like BH is controlled by several soil properties, including pH, texture, minerology, organic matter content and composition, among others (Weber et al., 2000). While these results show greater sorption to clay than to silt loams, indicating a strong textural effect, these experiments should be repeated on a wider range of soil series to elucidate the potential effects of soil texture and other soil properties, in order to use this information for developing soil-specific Rogue application rates.

Adsorption of BH to the test vessel in controls was <1%. This finding indicates the test vessels used in this preliminary study were non-reactive with BH and suitable to use in future studies (OECD, 2000). Additionally, the lack of degradation in the controls indicates that dissipation pathways, such as photodegradation or hydrolysis, did not contribute substantially to changes in BH concentration in solution in the test vessels containing soil.

Significance of Findings

Establishing appropriate parameters for batch equilibration studies is the first step in studying soil-herbicide interactions of Rogue in Arkansas rice production systems. Using the optimized equilibration time, soil:solution ratios, and reaction vessel materials identified in this study, batch equilibration studies will be carried out to estimate adsorption rates on a broader range of soils from across Arkansas rice producing regions. Understanding the dynamics between regional soils and Rogue will inform scientifically sound recommendations to Arkansas farmers for effective weed control and environmental stewardship.

Acknowledgments

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Literature Cited

EPA. 2017. Environmental fate and ecological risk assessment for use of the new herbicide, benzobicyclon, for weed control in water seeded rice. Office of Pesticide Programs, Environmental Fate and Effects Division.

OECD. 2000. Organization of Economic Cooperation and Development. Test No. 106: Adsorption -- Desorption Using a Batch Equilibrium Method. OECD Guidelines for the Testing of Chemicals, Section 1.

Sikora, F.J. and K.P. Moore. 2014. Soil test methods from the Southeastern United States. Southern Cooperative Series Bulletin No. 419.

Williams, K.L. and R.S. Tieerdema. 2016. Hydrolytic Activation Kinetics of the Herbicide Benzobicyclon in Simulated Aquatic Systems. Journal of Agricultural and Food Chemistry 64(24): 4838-4844.

Weber, J., G.G. Wilkerson, H.M. Linker, J.W. Wilcut, R.B. Leidy, S. Senseman, W.W. Witt, M. Barrett, W.K. Vencill, D.R. Shaw, T.C. Mueller, D.K. Miller, B.J. Brecke, R.E. Talbert, and T.F. Peeper. 2000. A proposal to standardize soil/solution herbicide distribution coefficients. Weed Science 48(1), 75-88.

Table 1. Select soil chemical properties of two soils used for sorption experiments with benzobicyclon hydrolysate (active metabolite in Rogue).

Soil Series	Location	pH	EC[a]	LOI[b]
			μmhos cm^{-1}	%
Henry silt loam	PTRS[c]	7.34	272	2.62
Sharkey clay	NREC[d]	6.55	289	3.78

[a] EC = electrical conductivity.
[b] LOI = loss on ignition.
[c] PTRS = Pine Tree Research Station, Colt, Ark.
[d] NREC = Northeast Research and Extension Center, Keiser, Ark.

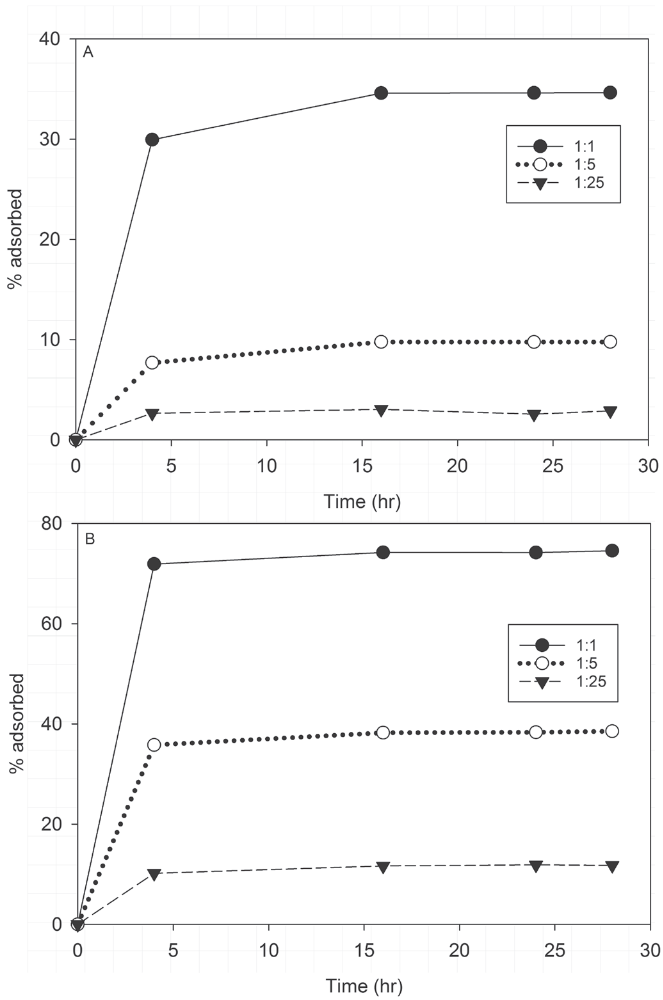

Fig. 1. Sorption of benzobicyclon hydrolysate (active metabolite in Rogue) to (A) Henry silt loam and (B) Sharkey clay at various soil:solution ratios of 1:1, 1:5, and 1:25 over time.

Loyant™ Herbicide Use in Furrow-Irrigated Rice

H.E. Wright[1], J.K. Norsworthy[1], Z.D., Lancaster[1], G.L. Priess[1], R.C. Scott[2], and J.M. Ellis[3]

Abstract

Loyant™ is a new post-emergence (POST) synthetic auxin (WSSA group 4) herbicide from DowDuPont recently labeled for use in rice. It provides broad-spectrum weed control, with strong activity on both Palmer amaranth (*Amaranthus palmeri*) and barnyardgrass (*Echinochloa crus-galli*). The weed control spectrum of Loyant indicates it will be a good fit in a herbicide program for furrow-irrigated rice. Field experiments were conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. and the Lon Mann Cotton Research Station (LMCRS) near Marianna, Ark. in summer 2017 to evaluate Loyant-containing weed control programs in furrow-irrigated rice. This experiment was arranged as a randomized complete block design with a 3-factor factorial. Command® plus Facet® L or Command plus League® was applied pre-emergence (PRE) followed by Ricestar®HT as an early-post-emergence (EPOST) application. Loyant was applied as a mid-post-emergence application (MPOST) alone and as a tank mix with Prowl® or with Clincher®plus Prowl and compared to the standard treatment of Prowl plus Riceshot®. An as-needed application of Grasp® Xtra was made late-post-emergence (LPOST) vs. no application. In both locations, Loyant-containing MPOST treatments provided better Palmer amaranth control 4 weeks after treatment (WAT) when compared to the standard treatment that did not contain Loyant. Contrasts were conducted for LMCRS to compare Loyant and Grasp Xtra-containing treatments to those that did not contain Loyant and Grasp Xtra. At this location, treatments that contained both Loyant MPOST and Grasp Xtra LPOST controlled Palmer amaranth better 4 WAT than the treatments that did not contain Loyant and Grasp Xtra. Additionally, Loyant-containing treatments at LMCRS yielded higher than treatments that did not contain Loyant. Results from these experiments, coupled with knowledge from previous research, indicates Loyant will be a good fit in furrow-irrigated rice and will provide a much-needed option for Palmer amaranth control.

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Introduction

In 2016, nearly 3% of Arkansas rice acres were furrow-irrigated with that number expected to be even higher in 2018 (Hardke, 2017). Flooding has historically been used as a means of weed control in rice (Scott et al., 2013), with weed control maintained through herbicides until flooding, when troublesome terrestrial weeds such as Palmer amaranth (*Amaranthus palmeri*) are no longer problematic (Norsworthy et al., 2011). Current recommendations for rice weed control include the use of a residual pre-emergence (PRE) herbicide mixed with a contact herbicide for grass and broadleaf weed control, followed by a residual post-emergence (POST) herbicide to maintain control until a permanent flood is established. However, the lack of flood coupled with constantly wet soil in furrow-irrigated rice creates a favorable environment for weed emergence (Norsworthy et al., 2008).

Florpyrauxifen-benzyl, the active ingredient in Loyant™ herbicide, is a new broad-spectrum herbicide from DowDuPont. It is a synthetic auxin (WSSA group 4) that controls both Palmer amaranth and barnyardgrass (*Echinochloa crus-galli*), another problematic weed in rice production (Miller, 2017a; Norsworthy et al., 2013). Loyant has a unique mode of action, which allows it to control quinclorac (WSSA group 4)-resistant barnyardgrass, meaning resistance to quinclorac does not confer resistance to Loyant (Miller et al., 2017). Prior research has been conducted with Loyant in flooded rice production; however, no previous research has been conducted with Loyant in furrow-irrigated rice production. Thus, the objective of this research was to evaluate Loyant as part of a herbicide program for furrow-irrigated rice

Procedures

Field experiments were conducted in 2017 to evaluate Loyant-containing weed control programs at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) near Marianna, Ark. and Pine Tree Research Station (PTRS) near Colt, Ark. on silt loam soils. Rice cultivar CL172 was drill-seeded into raised beds at a rate of 22 seeds/row ft at PTRS and 18 seeds/row ft at LMCRS. Row and drill spacing at LMCRS was 38 inches and 7 inches, respectively, and 30 inches and 7.5 inches, respectively, at PTRS. Plots were 4 bedded rows × 20 ft in length. This experiment was designed as a randomized complete block with a 3-factor factorial for a total of 16 herbicide programs and 4 replications. Factor A consisted of Command® at 0.8 pt/acre mixed with Facet® L at 32 fl oz/acre or League®at 6.4 oz/acre applied PRE followed by an early-postemergence (EPOST) application of Ricestar® HT at 24 fl oz/acre 2 weeks after PRE. Factor B was four mid-postemergence (MPOST) herbicide combinations applied 2 weeks after EPOST. The MPOST combinations were Prowl® at 2.1 pt/acre plus Riceshot® at 4 qt/acre, Loyant™ at 1 pt/acre plus Prowl, Loyant premixed with Clincher® at 1.78 pt/acre plus Prowl, and Loyant alone. Methylated seed oil (MSO) at 0.5 pt/acre was added to all Loyant-containing treatments. Factor C was a late post-emergence (LPOST) application of Grasp® Xtra at 20 fl oz/acre (as-needed). The as-needed LPOST application was made if control ratings for any weed species in a treatment fell below 80% for two replications. Control ratings for multiple weed species, including Palmer amaranth, were taken 2, 3, and 4 weeks after MPOST and LPOST applications, with 0% being no control and 100% being complete control. Yield data were also collected at crop maturity. Data were analyzed using JMP Pro 13.2 (SAS Institute Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference test ($P = 0.05$). Preplanned contrasts were included to compare treatments that contained Loyant to treatments that did not and to compare treatments containing the LPOST to treatments that did not.

Results and Discussion

Weed pressure was variable and the Palmer amaranth population was higher at LMCRS than at PTRS. Thus, the LPOST application of Grasp Xtra was not needed at PTRS. Considering these differences, both locations were analyzed separately. At PTRS, Palmer amaranth control for Loyant-containing treatments 4 weeks after MPOST (WAMPOST) was >90% (Fig. 1). Orthogonal contrasts of Loyant-containing treatments also showed treatments with Loyant-controlled Palmer amaranth better than treatments that did not contain Loyant ($P < 0.0024$). Barnyardgrass control 4 WAMPOST for Loyant-containing treatments was also nearly 100%. Rough rice yields from treatments with Loyant were not very different than treatments without Loyant (Fig. 2), which may be attributed to the lack of weed pressure.

At LMCRS, treatments containing Loyant followed by an LPOST application of Grasp Xtra provided the best control of Palmer amaranth (94%) 4 weeks after LPOST (WALPOST) (Fig. 3). Additionally, orthogonal contrasts showed Palmer amaranth control was increased by treatments with Loyant, compared to treatments without Loyant ($P < 0.0001$), and treatments that contained Grasp Xtra LPOST compared to treatments without Grasp Xtra ($P < 0.0001$). Barnyardgrass control was also nearly 100% 4 WALPOST for Loyant-containing treatments. Rough rice yields showed Loyant- and Grasp Xtra- containing treatments yielded 135 to 145 bu/acre, which is 15 bu/acre higher than the next best treatment that contained Loyant but did not contain Grasp Xtra (Fig. 4).

Significance of Findings

The results of this experiment coincide with previous research which evaluated the efficacy of Loyant on Palmer amaranth and barnyardgrass (Miller, 2017a and b). Effective control of barnyardgrass and Palmer amaranth suggests that Loyant will provide a much-needed tool to control these troublesome weeds in rice. Data from this experiment also suggests Loyant will provide a good rotational herbicide option in furrow-irrigated rice. Loyant, when used as part of a herbicide program, will be a good fit in both flood- and furrow-irrigated rice in Arkansas.

Acknowledgements

We appreciate the staff at LMCRS and PTRS for their assistance with this research. We would also like to thank the Arkansas Rice Research and Promotion Board, DowDuPont, and the University of Arkansas System Division of Agriculture for their support.

Literature Cited

Hardke, J.T. Trends in Arkansas Rice Production, 2017. B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 643:11-14.

Miller, M.R. 2017a. Evaluation of florpyrauxifen-benzyl control spectrum and tank-mix compatibility with other commonly applied herbicides in rice. Ph.D. Dissertation. Fayetteville, Ark.: University of Arkansas. pp. 31-49.

Miller, M.R. 2017b. Influence of formulation, herbicide rate, adjuvant rate, spray volume, and timing of flood establishment on florpyrauxifen-benzyl efficacy. Ph.D. Dissertation. Fayetteville, Ark.: University of Arkansas. pp. 50-71.

Miller, M.R, J.K. Norsworthy, and R.C. Scott. 2017. Evaluation of florpyrauxifen-benzyl on herbicide-resistant and herbicide-susceptible barnyardgrass accessions. Weed Technol. https://doi.org/10.1017/wet.2017.100

Norsworthy, J.K, J. Bond, R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Technol. 27:623-630.

Norsworthy, J.K, G.M. Griffith, and R.C. Scott. 2008. Imazethapyr use with and without clomazone for weed control in furrow-irrigated, imidazolinone-tolerant rice. Weed Technol. 22:217-221.

Norsworthy, J.K., R.C. Scott, S.K. Bangarwa, G.M. Griffith, M.J. Wilson, M. McCelland. 2011. Weed management in a furrow-irrigated imidazolinone-resistant hybrid rice production system. Weed Technol. 25:25-29.

Scott, R.C., J.K. Norsworthy, L.T. Barber, and J.T. Hardke. 2013. Arkansas rice production handbook. Misc. Pub. 192. Arkansas Cooperative Extension Service. Little Rock, Ark.: University of Arkansas. pp. 53-62.

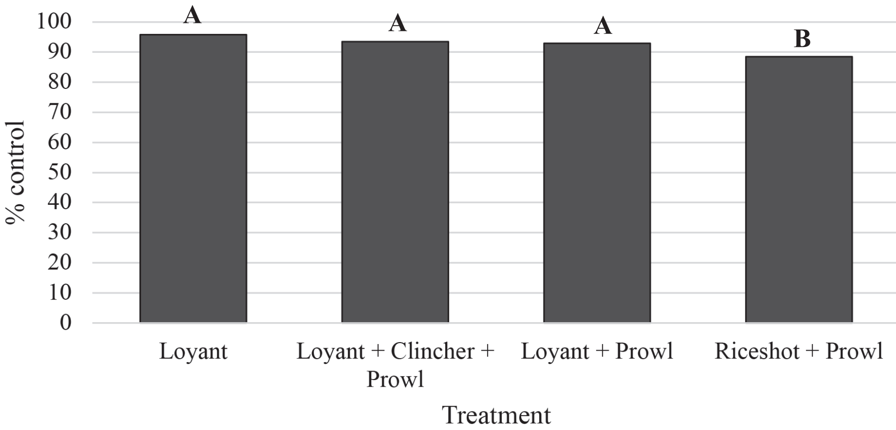

Fig. 1. Palmer amaranth control 4 weeks after treatment (WAT) of the mid-post-emergence application, averaged across pre-emergence-treatments at the University of Arkansas System Division of Agriculture's Pine Tree Research Station. Means with the same letter are not significantly different (α = 0.05).

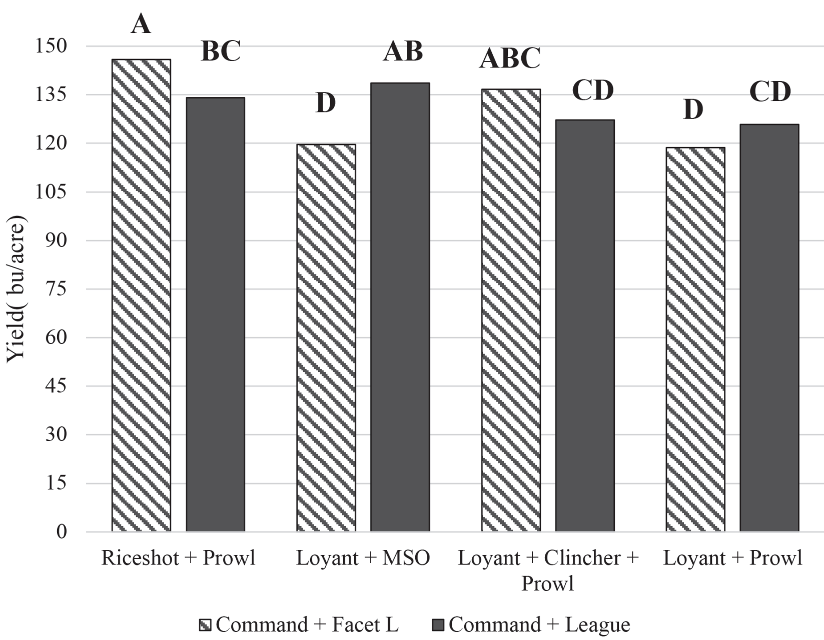

Fig. 2. Rough rice yield at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS). Solid bars are treatments with Command + League applied pre-emergence and striped bars are treatments with Command + Facet L applied pre-emergence. Letters are used to separate means using Fisher's protected least significant difference. Means with the same letter are not significantly different (α = 0.05).

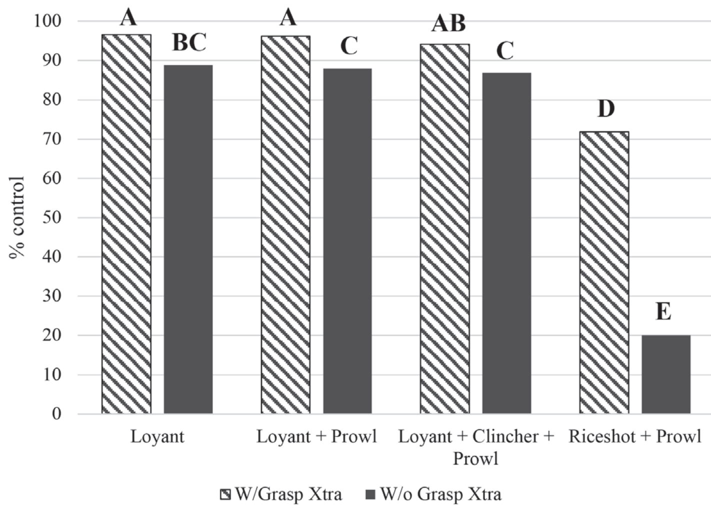

Fig. 3. Palmer amaranth control 4 weeks after treatment (WAT) of the late-post-emergence application, averaged across pre-emergence-treatments at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS). Striped bars are treatments containing the late-post-emergence application of Grasp Xtra and solid bars are treatments that do not contain the late-post-emergence application. Letters are used to separate means using Fisher's protected least significant difference. Means with the same letter are not significantly different (α = 0.05).

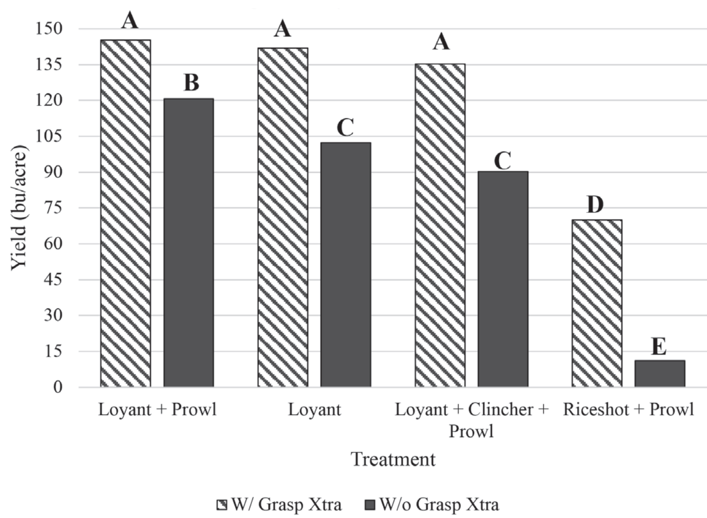

Fig. 4. Rough rice yield at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), averaged across pre-emergence-treatments. Striped bars are treatments containing the late-post-emergence application of Grasp Xtra and solid bars are treatments that do not contain the late-post-emergence application. Letters are used to separate means using Fisher's protected least significant difference. Means with the same letter are not significantly different (α = 0.05).

2017 Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars and Planting Date Studies

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Abstract

The computer program termed Degree-Day 50 (DD50) has become one of the most successful management tools developed by the University of Arkansas System Division of Agriculture. The program predicts critical growth stages that assist in increasing the effectiveness of crop management operations. In order to maintain its relevance, the computer program must be updated continually as new rice cultivars become available to the grower. In pursuit of this goal, studies are conducted in a controlled research environment where developmental data and DD50 thermal unit thresholds for current and new cultivars are determined. Throughout the 2017 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential data for 20 cultivars were evaluated over 6 SDs under a dry-seeded, delayed-flood management system commonly used in southern U.S. rice production.

Introduction

The Degree-Day 50 (DD50) Rice Management Program is a modification of the growing degree-day concept, daily high and low air temperatures are used to measure a day's thermal quality for plant growth. Developed in the 1970s to help farmers time midseason nitrogen (N) applications with precision, the DD50 Rice Management Program currently provides predicted dates for timing 26 key management decisions including fertilization, pesticide applications, permanent flood establishment, scouting insect and disease, predicting draining date and suggested harvest time.

Beginning with emergence, the DD50 generates a predicted, cultivar-specific, rice plant development file that is based on the accumulation of DD50 units. The initial file is created by calculating thermal unit accumulation using 30-year average weather data collected by the National Weather Service weather station closest to a rice producer's

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location in Arkansas. As the season progresses the program is updated with the current year's weather data on a daily basis for enhanced accuracy.

The data used to forecast plant development for a specific cultivar, is collected in yearly studies where promising experimental lines and newly released conventional and hybrid rice cultivars are evaluated in four to six seeding dates (SD) per season within the recommended range of rice SDs for Arkansas. Once a new cultivar is released, the information obtained in these studies is employed to provide threshold DD50 thermal units to the DD50 Rice Management Program that facilitates the prediction of dates of plant developmental stage occurrences and prediction of dates for when particular management practices should be implemented. Therefore, the objectives of this study were to develop a DD50 thermal accumulation database for promising new cultivars, verification and refinement of the existing database of current cultivars, assessment of the effect of SD on DD50 thermal unit accumulation, and also effects of SD on grain and milling yields of a particular cultivar which determined optimal SDs.

Procedures

During 2017, the DD50 study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Fourteen conventional cultivars (CL111, CL151, CL153, CL163, CL172, CL272, Diamond, Jupiter, LaKast, PVL01, Roy J, Thad, Titan, and Wells) were dry-seeded at a rate of 30 seed/ft^2 in plots 8 rows wide (7.5-inch spacing) and 16.5 ft long. Six hybrids (RT 7311 CL, RT 7812 CL, RT XL745 CL, RT Gemini 214 CL, RT XP760, and RT XP753) were seeded into plots of the same dimensions using the reduced seeding rate for hybrids (10.3 seeds/ft^2). The SDs for 2017 were 21 March, 5 April, 18 April, 2 May, 19 May, and 15 June. General agronomic information is shown in Table 1. Cultural practices established for dry-seeded, delayed-flood rice production were followed. A single preflood application of 120 lb N/acre as urea was applied to all plots at the 4- to 5-leaf growth stage and flooded within 2 days of preflood N-fertilization. The flood was maintained until maturity. The collected data for all SDs included: maximum and minimum daily temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) was also collected for the 21 March, 18 April, and 19 May SDs. At maturity, the four center rows in each plot were harvested, weight of grain and moisture content were recorded, and a subsample of harvested grain was taken for milling purposes on all SDs. The grain yield was adjusted to 12% moisture and reported on a bushel/acre (bu/acre) basis. The dry rice was milled obtaining percent of head rice (%HR; whole kernels) and percent of total white rice (%TR) to provide milling yield expressed as %HR/%TR. The arrangement of each seeding rate corresponded to a randomized complete block design with four replications. Statistical analyses were conducted using PROC GLM v. 9.4 (SAS Institute, Inc. Cary, N.C.) and mean separation was conducted using Fisher's protected least significant difference test ($P = 0.05$) where appropriate.

Results and Discussion

Times between seeding and emergence ranged from 11 to 15 days (Table 1) directly affecting the required days from seeding to flooding. In general, SD studies report a decrease in days between seeding and emergence as the SD is delayed. The 2017 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from late March to late May and mid-June. It is likely that cooler temperatures during mid-April delayed emergence of the 18 April SD. The time from seeding to establishment of permanent flood followed the same trend as the SD was delayed, ranging from 51 days for the 21 March to 34 days for the 15 June SDs. The times from emergence to flooding in 2017 followed the same trend as SD was delayed. The 21 March SD required a much longer time interval than the other SDs with 39 days from emergence to permanent flood. The second through fifth SDs required similar spans of time from emergence to flooding (29-30 days). The 15 June SD required a further shortened time interval (22 days) between emergence to flooding. These results alone underscore the importance of the effect of seasonal variation of weather conditions on the overall growth and development of the rice crop as well as the need to continually update the DD50 thermal unit thresholds.

The days required from emergence to 0.5-inch IE averaged 58 days across three SDs (Table 2). Averaged across cultivars, the number of days to reach 0.5-inch IE ranged from 70 days when seeded 21 March to 46 days when seeded 19 May. A decreasing trend in time required to reach 0.5-inch IE as SD was delayed. The DD50 thermal unit accumulation needed to reach 0.5-inch IE ranged from a low of 1229 for RT 7311 CL, to a high of 1381 for CL272 when averaged across SD.

The time needed to reach the developmental stage known as 50% heading from the time of seeding averaged across SD and cultivars was 87 days (Table 3). The 9 May SD is excluded from this discussion due to the lack of a complete dataset. The average time for cultivars to reach 50% heading ranged from 98 days when seeded 21 March to 78 days when seeded in mid-June. For individual cultivars, the average time required to reach 50% heading ranged from 105 days for Jupiter and PVL01 seeded 21 March to 71 days for CL 111 when seeded in mid-June. For 2017, the thermal unit accumulation from emergence to 50% heading averaged 2139 DD50 units across SD and cultivars. The average individual cultivar DD50 thermal unit accumulation, from emergence to 50% heading, ranged from a low of 1940 for RT XL745 CL seeded 18 April to a high of 2420 for Jupiter seeded 21 March.

Average grain yield for the 2017 study was 191 bu/acre (Table 4). When averaged across cultivars, grain yield was highest when seeded 21 March (211 bu/acre), and lowest when seeded 15 June (143 bu/acre). In general, grain yield was highest for each cultivar in the earlier SDs and was noticeably lower for the 15 June SD. Similar yields for the 21 March, 5 April, and 18 April, and the 2 May and 19 May SD were measured during 2017. The most consistent conventional cultivars across SD were Diamond, Jupiter, and Titan. The hybrids RT 7311 CL, RT 7812 CL, and RT XP753 performed well across SD during this study year.

During 2017, the milling yield averaged across all SDs and cultivars was 63% head rice and 70% total milled rice (Table 5). The average percent head rice increased between the 18 April and 2 May SDs, then again between the 19 May and 15 June SD. The average percent total rice also increased as SD was delayed. Interestingly, the 15 June SD exhibited the highest milling yields during 2017. With some exceptions, all cultivars averaged 63% head rice and 70% total milled rice or better during this study year regardless of SD.

Significance of Findings

The data obtained during 2017 will be used to determine the DD50 thermal unit thresholds for new conventional and hybrid cultivars and strengthen the DD50 thermal unit threshold of currently grown cultivars. The grain and milling yield data contributes to the database of information used by University personnel to help producers make decisions in regard to rice cultivar selection, in particular for early and late seeding situations.

Acknowledgments

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Table 1. General seeding, seedling emergence, and flooding date information for the Degree-Day 50 seeding date study in 2017 at the University of Arkansas System Division of Agriculture’s Rice Research and Extension Center near Stuttgart, Ark.

	Seeding date					
	21 March	**5 April**	**18 April**	**2 May**	**19 May**	**15 June**
Emergence date	2 April	16 April	3 May	15 May	31 May	27 June
Flood date	11 May	16 May	2 June	13 June	29 June	19 July
Days from seeding to emergence	12	11	15	13	12	12
Days from seeding to flooding	51	41	45	42	41	34
Days from emergence to flooding	39	30	30	29	29	22

Table 2. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2017.

	Seeding date							
	21 March		18 April		19 May		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units
CL153	67	1313	50	1197	-	-	58	1255
CL172	72	1449	55	1327	46	1262	57	1346
CL272	73	1464	55	1333	48	1347	59	1381
Diamond	71	1414	55	1320	46	1285	57	1340
PVL01	68	1342	49	1169	-	-	58	1255
RT 7311 CL	65	1277	49	1176	45	1247	56	1229
RT 7812 CL	69	1366	52	1244	45	1247	55	1286
RT Gemini 214 CL	69	1372	51	1217	45	1247	58	1289
RT XP760	68	1338	51	1232	-	-	59	1285
Thad	71	1427	56	1361	47	1316	58	1368
Titan	71	1420	54	1315	47	1301	57	1345
Wells	72	1449	54	1302	47	1309	59	1357
Mean	70	1386	52	1272	46	1285	58	1318
$LSD_{0.05}$[b]	1.5	37.9	1.2	31.8	1.7	51.5	NS	61.4

[a] DD50 units calculated daily by equation [(daily max temperature + daily min temperature)/2]-50.

[b] LSD = least significant difference.

Table 3. Influence of seeding date on Degree-Day 50 (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2017.

	Seeding date											
	21 March		5 April		18 April		2 May		15 June		Average	
Cultivar	days	DD50[a] units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
CL111	95	2090	87	2039	77	1979	76	2097	71	2051	84	2051
CL151	96	2126	88	2061	78	2011	77	2105	79	2185	85	2076
CL153	97	2140	90	2137	80	2075	82	2263	78	2164	87	2154
CL163	97	2148	88	2069	79	2051	83	2296	79	2182	87	2141
CL172	99	2207	91	2168	79	2051	80	2204	78	2177	87	2157
CL272	101	2260	93	2222	82	2131	83	2289	80	2205	90	2225
Diamond	97	2147	89	2107	80	2059	80	2200	79	2191	86	2128
Jupiter	105	2420	95	2277	85	2216	83	2283	80	2223	92	2299
LaKast	94	2054	87	2032	78	2003	77	2109	75	2113	84	2049
PVL01	105	2405	97	2341	85	2239	82	2247	82	2259	92	2308
Roy J	102	2283	93	2230	83	2154	84	2324	81	2244	90	2248
RT 7311 CL	93	2040	86	2001	77	1963	74	2034	72	2064	82	2009
RT 7812 CL	102	2282	93	2230	83	2162	83	2296	83	2296	90	2242
RT XL745 CL	94	2047	84	1956	76	1940	73	2003	73	2085	82	1986
RT Gemini214 CL	96	2126	89	2107	80	2067	79	2185	82	2266	86	2121
RT XP760	98	2185	90	2122	80	2083	80	2199	82	2266	87	2147
RT XP753	94	2054	86	2009	77	1979	75	2042	72	2063	83	2021
Thad	97	2154	91	2160	82	2123	83	2296	78	2166	88	2183
Titan	96	2111	87	2047	78	1995	78	2149	74	2090	85	2075
Wells	99	2199	91	2152	79	2051	82	2248	81	2238	88	2163
Mean	98	2174	90	2123	80	2066	80	2194	78	2176	87	2139
$LSD_{0.05}$[b]	1.6	48.1	1.5	46.7	1.2	39.0	2.5	71.4	1.5	33.2	4.7	55.8

[a] DD50 units calculated daily by equation [(daily max temperature + daily min temperature)/2]-50.

[b] LSD = least significant difference.

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2017.

	Grain yield by seeding date						
Cultivar	**21 March**	**5 April**	**18 April**	**2 May**	**19 May**	**15 June**	**Average**
	(bu/acre)						
CL111	183	184	183	169	152	127	166
CL151	202	201	200	174	185	142	184
CL153	181	188	202	177	161	127	173
CL163	187	194	189	189	176	140	179
CL172	185	176	198	177	170	111	170
CL272	213	195	219	175	169	128	183
Diamond	222	222	213	199	218	155	205
Jupiter	209	205	220	190	218	161	201
LaKast	207	202	195	180	188	143	186
PVL01	165	163	181	146	152	92	150
Roy J	216	195	206	173	197	120	190
RT 7311 CL	252	244	226	225	229	174	225
RT 7812 CL	250	235	228	204	244	163	221
RT XL745 CL	209	212	209	153	203	146	189
RT Gemini 214 CL	237	221	237	200	225	132	209
RT XP760	223	212	239	207	202	140	204
RT XP753	257	252	239	223	240	187	233
Thad	198	194	199	172	186	134	181
Titan	237	237	219	186	186	171	203
Wells	186	169	187	177	178	134	172
Mean	211	204	210	185	194	143	191
$LSD_{0.05}$[a]	15.8	16.9	16.5	20.2	16.4	13.4	15.4

[a] LSD = least significant difference.

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center during 2017.

	Milling yield by seeding date						
Cultivar	**21 March**	**5 April**	**18 April**	**2 May**	**19 May**	**15 June**	**Average**
	---(%HR/%TR)[a]---						
CL111	66/70	67/71	65/72	67/73	66/72	71/74	67/72
CL151	65/69	64/69	66/71	66/71	66/72	70/73	66/71
CL153	66/70	65/69	67/72	68/73	67/72	70/73	67/72
CL163	62/69	63/69	65/72	65/71	67/71	69/73	65/71
CL172	66/70	66/70	66/71	65/71	68/72	70/73	67/71
CL272	64/67	63/66	63/69	66/69	56/68	63/70	63/68
Diamond	59/68	62/69	62/71	62/69	65/70	68/72	63/70
Jupiter	59/63	61/64	65/68	64/67	62/67	69/71	63/67
LaKast	57/69	58/69	60/71	63/72	66/72	69/73	62/71
PVL01	64/71	65/70	64/72	63/72	65/72	68/72	65/71
Roy J	62/69	64/70	63/71	62/70	66/71	66/71	64/71
RT 7311 CL	58/69	58/68	57/70	62/71	62/71	65/72	60/70
RT 7812 CL	59/68	60/68	62/70	65/71	67/72	63/69	63/70
RT XL745 CL	60/70	61/69	55/70	60/71	64/72	68/73	61/71
RT Gemini 214 CL	60/68	60/68	60/70	63/71	65/71	63/69	62/69
RT XP760	58/67	58/68	60/70	63/70	65/70	63/70	61/69
RT XP753	61/70	59/69	57/70	62/71	63/72	68/73	62/71
Thad	61/69	62/69	62/71	65/71	66/71	65/71	63/70
Titan	64/67	63/67	54/68	65/70	57/68	66/69	61/68
Wells	62/71	64/71	64/72	63/72	65/72	69/73	64/72
Mean	62/69	62/69	62/71	64/71	64/71	67/72	63/70
$LSD_{0.05}$ %HR[b]	1.9	2.4	3.3	2.1	2.1	3.1	1.8
$LSD_{0.05}$ %TR	1.0	1.3	0.8	1.2	0.9	2.5	0.9

[a] %HR/%TR = percent head rice and percent total milled rice.

[b] LSD = least significant difference.

Low-Use-Rate Zinc Fertilization Strategies for Rice

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Abstract

New fertilization methods using low zinc (Zn) rates have been developed and marketed for rice (*Oryza sativa* L.) fertilization. Limited research is available to validate the efficacy of these methods. Our research objectives were to evaluate the effect of Zn seed treatment rate combined with six Zn fertilization methods on: 1) early-season canopy coverage, 2) rice seedling Zn concentration, and 3) grain yield. Two field experiments were conducted in 2017 on soils mapped as Calloway and Calhoun silt loams. 'Roy J' (Calloway) or 'Diamond' (Calhoun) rice was treated with 0 or 0.33 lb Zn/cwt (hundredweight) as ZnO and was combined with: i) no Zn (UTC), ii) granular $ZnSO_4$ applied at 10 lb Zn/acre (GRAN), iii) 1.5 lb Zn/acre as McroEssentials (MESZ), iv) 1.0 lb Zn/acre as Zn-EDTA a (EDTA), and v/vi) 0.5 and 1.0 lb Zn/acre of WolfTrax Zn-DDP (DDP). On the Calhoun soil, canopy coverage was not affected by Zn seed treatment rate or fertilization method. When Zn fertilization methods were averaged, application of 0.33 lb Zn/cwt to seed increased seedling Zn concentration ($P = 0.0044$) by 3.3 ppm (mg Zn/kg) compared with rice seed that had no Zn seed treatment. A significant interaction between Zn seed treatment rate by fertilization method tended to have greater canopy coverage on the Calloway soil for rice fertilized with MESZ. Grain yield was not affected by Zn seed treatment rate, fertilization methods, or their interaction. Results suggest that low-use-rate Zn fertilizers provide only minimal Zn for rice seedlings, and should be avoided on fields where Zn deficiencies are probable.

Introduction

Zinc deficiency is the most common yield-limiting micronutrient of rice grown on silt loam soils in Arkansas. The potential yield loss from Zn deficiency can approach 100%, when it is severe and left uncorrected, but yield losses of 10% to 60% are more typical. Zinc fertilization is recommended when rice is grown on: i) sandy or silt loam textured soil, ii) soil with pH > 6.0, and iii) soil-test Zn concentrations below the critical value [Mehlich-3 Zn ≤ 4.0 ppm (mg/kg)] (Norman el al., 2013). Supplying Zn to

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rice can be achieved by one or more methods that may include broadcasting granular Zn preplant, spraying rice foliage during early vegetative growth, or treating seed with Zn before planting.

The standard method of Zn fertilization in Arkansas, has been the application of Zn sulfate ($ZnSO_4$) at 10 lb Zn/acre. In addition, spraying preplant or post-emergence Zn solutions at 1.0 lb Zn/acre or seed treated with 0.25 to 0.50 lb Zn/cwt (hundredweight) have increased in popularity within the last two decades. Fertilizer manufactures have developed new Zn-containing fertilizers that are being sold to growers with limited university research verifying their efficacy. Our research objectives were to evaluate the effect of Zn seed treatment rate combined with six Zn fertilization methods on: 1) rice seedling Zn concentration, 2) early-season canopy coverage, and 3) grain yield.

Procedures

Two sites evaluating different low-use-rate Zn fertilizer methods were established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark., on soils mapped as Calloway or Calhoun silt loams. At each site, composite soil samples (0-4 inches deep) were taken from plots that did not receive Zn fertilizer. Soil samples were analyzed for soil pH (1:2 soil:water mixture), Mehlich-3 extractable soil nutrients, and soil organic matter (Table 1). Individual plots were 6.5-ft wide and 20-ft long. 'Roy J' and 'Diamond' rice were treated with Zinche ST (32.5% Zn, Drexel Chemical Company) with the treated seed containing 0.33 lb Zn/cwt. 'Diamond' rice was also treated with AV-1011 bird repellent at a rate of 18.3 fl. oz./cwt. Treated rough rice was combined with no Zn (UTC), granular $ZnSO_4$ applied at 10 lb Zn/acre (GRAN), 1.5 lb Zn/acre as MicroEssentials (MESZ, 12-40-0-10S-1Zn, The Mosaic Company), 1.0 lb Zn/acre as Zn-EDTA (Ultra-Che Zinc 9% EDTA, Winfield Solutions, LLC,) applied at the 2-leaf stage (EDTA), and 0.50 and 1.0 lb Zn/acre as WolfTrax Zn-DDP (DDP, Compass Minerals) coated to triple superphosphate and muriate of potash (DDP1 and DDP2). Granular muriate of potash and triple superphosphate were broadcast to the soil surface to provide equal P (60 lb P_2O_5/acre) and K (90 lb K_2O/acre) rates for all treatments. At each site, preplant treatments were applied to a tilled soil before planting either 'Roy J' (Calloway soil) on 18 April or 'Diamond' (Calhoun soil) on 3 May. Fertilizer treatments, on the Calhoun soil, were incorporated by tillage. At the 5-leaf stage, urea was applied at 150 lb N/acre. A flood was established within 2 days after N application, and standard disease, insect, and weed management practices were used throughout the season to ensure pests did not limit yield.

Canopy coverage was measured 3 (Calloway) or 4 (Calhoun) times during early vegetative growth using a smart phone application called Canopeo (http://www.canopeo-app.com). An iPad was attached to a tripod with a bracket for stability. For each sample date, the iPad was set to a consistent 3-ft height above the soil surface, and the tripod arm was extended so that a photograph of the middle 5 rows (13.25 sq ft) in each plot was captured to determine canopy coverage.

A 6-ft section of seedlings from an inside row at the midtillering growth stage was cut 1 inch above the soil surface to measure whole plant dry matter accumulation and tissue Zn concentration. The samples were bagged, oven-dried at 131 ºF (55 ºC) to a constant weight, weighed, and ground to pass through a 1-mm sieve. A subsample was taken and digested with 30% H_2O_2 and concentrated HNO_3 for determination of nutrient analysis on an inductively coupled plasma atomic emission spectrophotometer. A small plot combine was used to harvest the middle 5 rows of each plot, and yield was calculated at 12% moisture before statistical analysis was performed.

Each field trial was a randomized complete block design with a 2 (Zn Seed rate) by 6 (Zn fertilization method) factorial treatment structure. Canopy coverage data were analyzed as a split-plot design with sample time expressed as cumulative Degree-Day 50 (DD50) growing degree units (GDUs) as the main plot, and factorial arrangement of Zn treatments as the subplot. Only five of the Zn fertilization methods were included in Canopeo measurements. Analysis of variance (ANOVA) using the MIXED procedure in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.), for canopy measurements, was performed separately for each field trial with measurement time, seed treatment rate, and fertilization method included as fixed effects. Analysis of variance on seedling Zn concentration and grain yield data was performed using the MIXED procedure where Zn seed treatment rate and Zn fertilization methods were fixed effects, and replicate and field trial were random effects. When appropriate, means were separated using Fisher's protected least significant difference at a significance level of 0.10.

Results and Discussion

Canopy coverage, on the Calhoun soil, was not affected by Zn seed treatment rate ($P = 0.3221$), fertilization method ($P = 0.8826$), or their interaction (0.9373), but was affected by GDUs as measurements ($P < 0.0001$) significantly increased with each measurement time. Canopy coverage by Diamond rice averaged 5%, 21%, 62%, and 89% at 398, 580, 728 and 960 GDUs, respectively. On the Calloway soil (Table 2), Roy J canopy coverage also increased with increasing GDUs ($P < 0.0001$) averaging 15%, 37%, and 88% at 496, 668, and 850 GDUs, respectively. For Roy J rice on the Calloway soil, a significant interaction between seed Zn treatment rate and fertilization method ($P = 0.0473$; Table 2) showed that canopy coverage tended to be greater for rice fertilized with MESZ compared to all other Zn fertilization methods. Rice receiving MESZ was the only Zn treatment that included preplant N fertilizer, which was likely responsible for the extra early-season growth. Regardless of Zn seed treatment rate, the lowest canopy coverage was for rice that did not receive Zn fertilization, and intermediate canopy coverage for rice fertilized with EDTA or DDP. Canopy coverage when rice was fertilized with GRAN and a Zn seed treatment was among the lowest, but when planted without a Zn seed treatment was among the highest canopy coverage.

The interaction between Zn seed treatment rate and fertilization method had no significant effect on seedling Zn concentration ($P = 0.9513$), but was affected by each of the main effects (Table 3). When Zn fertilization methods were averaged, application of 0.33 lb Zn/cwt to seed increased seedling Zn concentration by 3.2 mg Zn kg^{-1} compared with rice seed that had no Zn seed treatment. Fertilization method also affected seedling Zn concentration with rice fertilized with GRAN having the greatest Zn concentration. Rice fertilized with EDTA or MESZ performed better than the UTC, but similar to DDP1 and DDP2. Grain yield was not affected by Zn seed treatment rate, fertilization method or the interaction (P = 0.9599) between main effects.

Significance of Findings

Rice canopy covers <5.0% of the soil surface before the 2-3 leaf stage indicating that a majority of the solution intended for foliar application is actually applied to the soil surface. Although no Zn deficiency symptoms were observed at either site, the results suggest that the Zn availability from low-use-rate Zn fertilization methods provided minimal Zn to seedling rice compared to granular $ZnSO_4$ at 10 lb Zn/acre. Thus, low-use-rate Zn fertilization methods should be avoided either in favor of applying 10 lb Zn/acre or use of two or more of the most effective low-use-rate methods in combination with each other in fields where there is a high probability of Zn deficiency.

Acknowledgments

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Literature Cited

Norman, R., N. Slaton., and T. Roberts. 2013. Soil fertility. pp. 69-101. *In*: J.T. Hardke, editor. Rice Production Handbook. Publication MP192. University of Arkansas Coop. Ext. Ser., Little Rock, Ark.

Table 1. Selected soil chemical property means (0-4 inch depth, n = 4-6) from two sites used to evaluate rice response to different fertilization methods at the University of Arkansas System Division of Agriculture's Pine Tree Research Station, Colt, Ark., in 2017.

Location	Soil pH	Soil OM†	Mehlich-3 extractable soil nutrients										
			P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		------%------	ppm (mg/kg)										
Calloway	6.6	2.2	28	79	1335	204	14	48	345	444	3.1	0.8	0.5
Calhoun	7.6	2.1	22	77	2002	311	7	33	314	303	2.5	1.0	0.6

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

Table 2. Percent canopy coverage for Roy J rice as affected by the interaction between Zn fertilization method and Zn seed treatment rate, averaged across sampling times, for a trial conducted on a Calloway silt loam in 2017.

Fertilizer†	Zn rate	0.0 lb Zn/cwt‡	0.33 lb Zn/cwt
	(lb/acre)	---------(% canopy coverage)---------	
UTC†	0	40.0 d§	43.0 cd
EDTA	1.0	45.8b cd	46.8 bc
DDP1	0.5	46.9 bc	46.3 bcd
GRAN	10.0	50.6 ab	41.7 cd
MESZ	1.5	52.5 ab	54.9 a
Interaction *P*-value		-------------------0.0473-------------------	

† UTC, untreated check; EDTA, Ultra-Che 1 lb Zn/acre foliar Zn applied at 2-3 leaf stage; DDP1, WolfTrax 0.5 lb Zn/acre coated to P and K; GRAN, 10 lb Zn/acre granular zinc sulfate; and MESZ, 1.5 lb Zn/acre Micro-Essentials.

‡ cwt = hundredweight.

§ Regardless of column, means followed by different lowercase letters are statistically different at the 0.10 level.

Table 3. Tissue Zn concentration at the midtillering stage and grain yield as affected by the main effects of Zn fertilization methods, averaged across Zn seed treatment rates, and Zn fertilization methods, for trials conducted in 2017.

Fertilizer	Zn rate	Tissue Zn	Grain yield
	(lb/acre)	(ppm; mg/kg)	(bu/acre)
UTC†	0	29.7 c‡	200 a
EDTA	1.0	34.2 b	201 a
DDP1	0.5	31.0 bc	198 a
DDP2	1.0	32.1 bc	202 a
GRAN	10.0	45.1 a	199 a
MESZ	1.5	33.3 b	200 a
P- value		<0.001	0.7633
Seed Trt			
0 lb Zn/cwt		32.6 b	201 a
0.33 lb Zn/cwt		35.8 a	199 a
P-value		0.0044	0.4675

† UTC, untreated check; EDTA, Ultra-Che 1 lb Zn/acre foliar Zn applied at 2-3 leaf stage; DDP1, WolfTrax 0.5 lb Zn/A coated to P and K; GRAN, 10 lb Zn/acre granular zinc sulfate; and MESZ, 1.5 lb Zn/acre Micro-Essentials.

‡ Means for tissue Zn and grain yield were averaged over two locations, and within each column, means followed by different lowercase letters are statistically different at the 0.10 level.

Grain Yield Response of Four New Rice Cultivars to Seeding Rate

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Abstract

The cultivar × seeding rate studies determine the proper seeding rates for new rice (*Oryza sativa*, L.) cultivars over a range of production/growing conditions in Arkansas. The four rice cultivars evaluated in 2017 were CL153, CL172, Diamond, and Titan. Each cultivar was seeded at 10, 20, 30, 40, and 50 seed/ft^2. In accordance with current recommendations and predominant grower practice, all seed received insecticide and fungicide seed treatments. Trials were seeded at three on-farm locations in eastern Arkansas. Stand density and grain yield results were consistent with current seeding rate recommendations of 30 seed/ft^2 (60 to 70 lb/acre) under optimum conditions and seeding dates on silt loam soils. Current recommendations for adverse conditions such as late seeding date or clay soils are a 20% seeding rate increase (36 seed/ft^2; ~80 lb/acre) compared to a loamy soil and optimum seeding date. Care should be taken that without the use of an insecticide seed treatment, stand density and grain yield may be reduced compared to results in this study. Grain yield response to seeding rate was clear at all locations in 2017. Reduced grain yield was observed at the two lowest (10 to 20 seed/ft^2) seeding rates. While grain yields at the currently recommended seeding rate of 30 seed/ft^2 were significantly lower than those at 50 seed/ft^2, the 30 seed/ft^2 rate still achieved greater than 95% of optimum grain yield at all three locations.

Introduction

The cultivar × seeding rate studies measure the grain yield performance of new rice (*Oryza sativa*, L.) cultivars over a range of seeding rates on representative silt loam and clay soils and determine the proper seeding rate to maximize yield on these soils under climatic conditions that exist in Arkansas. Optimal stand density for pure-line cultivars is considered to be 10 to 20 plants/ft^2 (Wilson et al., 2013). Seeding rate is then adjusted as needed to meet field specific conditions. In general, rice is seeded at

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30 seed/ft^2 on silt loam soils and 36 seed/ft^2 on clay soils. Use of an insecticide seed treatment has increased in recent years and is currently used on approximately 68% of the rice acres in Arkansas (Hardke, 2016). The use of an insecticide seed treatment, as in this trial, has been shown to increase stand density by over 10% and increase grain yield by an average of 8 bu/acre (Taillon et al., 2015). Lower stand densities and grain yields may be expected when planting without the use of insecticide seed treatments.

The release of new cultivars, combined with changes in production practices including the use of insecticide and fungicide seed treatments, requires the continued evaluation of seeding rates for new cultivars to ensure recommendations maximize profit potential for rice growers. The objective of this study was to determine the optimal seeding rate for four new rice cultivars in environments and growing conditions common to Arkansas rice production.

Procedures

The three on-farm locations for the 2017 cultivar × seeding rate studies included a grower field in Phillips Co. on a clay soil near Marvell, Ark.; a grower field in Poinsett Co. on a silt loam soil near Weiner, Ark.; and a grower field in White Co. on a silt loam soil near Bald Knob, Ark. The pure-line cultivars CL153, CL172, Diamond, and Titan were seeded at on-farm locations at Phillips Co. on 29 March, Poinsett Co. on 18 April, and White Co. on 12 April. All seed was treated with NipsIt SUITE® seed treatment containing an insecticide and fungicides. Seeding rates evaluated for each cultivar were 10, 20, 30, 40, and 50 seed/ft^2. The midpoint of 30 seed/ft^2 corresponds to 65-70 lbs seed/acre for most long-grain cultivars and is the base recommendation on well-prepared silt loam soils. Plots were 8 rows (7.5-in spacing) wide and 16.5 ft in length. Cultural practices otherwise followed recommended practices for maximum yield. The experimental design for all trials and cultivars was a randomized complete block design with 6 replications.

Stand density was determined 3-4 weeks after rice emergence by counting the number of seedlings emerged in a total of 10 row feet. Nitrogen (N) was applied to studies at the 4- to 6-leaf (lf) growth stage in accordance with the grower's standard practice. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of grain were determined, and a subsample of harvested grain removed for milling yield determinations. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. A bushel of rice weighs 45 lbs. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

At Phillips Co. on a clay soil, stand density increased as seeding rate increased from 10 to 50 seed/ft^2 (Table 1). Stand density within the recommended range of 10-20 plants/ft^2 was obtained using 20 to 30 seed/ft^2. Seeding rates of 40 to 50 seed/ft^2 actually exceeded 20 plants/ft^2. For the early planting date and clay soil, these stand densities exceeded typical response for clay soils.

At Poinsett Co. on a silt loam soil, stand density was not reported due to flooding from a large rainfall event around the 3-4 lf stage. This resulted in stand loss, but was difficult to measure as tillering had begun by the time plants emerged from the floodwaters.

At White Co. on a silt loam soil, stand density increased as seeding rate increased from 10 to 50 seed/ft^2 (Table 1). Stand density within the recommended range of 10 to 20 plants/ft^2 was obtained using 20 to 40 seed/ft^2. Seeding rates of 10 or 50 seed/ft^2 resulted in stand densities below or above, respectively, the recommended range. These results agree with current recommendations given the optimum planting window and loam soil type.

Grain yield was not influenced by a cultivar × seeding rate interaction during 2017. The main effect of seeding rate did have a significant influence on grain yield at all locations (Table 2). At all three locations, the 50 seed/ft^2 seeding rate resulted in grain yields significantly greater than the 10 to 30 seed/ft^2 seeding rates; however, it was not significantly greater than the 40 seed/ft^2 seeding rate.

Comparison of grain yields by converting to percent of optimal yield at each location is provided in Fig. 1. At all three locations, all seeding rates except 20 seed/ft^2 resulted in greater than 95% optimal grain yields. However, the 50 seed/ft^2 seeding rate was needed to achieve 100% optimal grain yield at all locations.

The reason for not achieving peak yields at lower seeding rates and stand densities could be influenced by several factors. As these were grower managed fields, the N rate may not have been maximized to achieve grain yield at lower stand densities. It is also possible that N fertilization did not occur early enough to maximize tillering in treatments with lower stands. Finally, it is possible that the mild environmental conditions resulted in reduced plant growth and yield potential at lower stand densities.

Significance of Findings

The cultivar × seeding rate studies in 2017 agree with previous research (Hardke et al., 2016) that an optimum seeding rate for new rice cultivars is approximately 30 seed/ft^2. This corresponds to a seeding rate of 65 to 80 lb seed/acre depending on seed size of individual cultivars. Seeding rates lower than the current recommendation risk insufficient stand densities that will be unable to maximize grain yield potential. Currently recommended seeding rate adjustments based on soil type, seeding date, and environmental conditions are in agreement with the findings of this study.

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Literature Cited

Hardke, J.T. 2016. Trends in Arkansas rice production, 2015. In: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 634:13-23. Fayetteville, Ark.

Hardke, J.T., D.L. Frizzell, E. Castaneda-Gonzalez, T.L. Clayton, G.J. Lee and R.J. Norman. 2016. Grain yield response of four new rice cultivars to seeding rate. In: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 634:13-23. Fayetteville, Ark.

Taillon, N.M., G.M. Lorenz, J. Black, W.A. Plummer, and H.M. Chaney. 2015. Insecticide seed treatments in rice: is there value to the grower? In: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 626:137-144. Fayetteville, Ark.

Wilson, C.E., Jr., Y. Wamishe, G. Lorenz, and J. Hardke. 2013. Rice stand establishment. In: J.T. Hardke (ed.). Arkansas Rice Production Handbook. University of Arkansas Division of Agriculture Cooperative Extension Service MP192:31-40. Little Rock, Ark.

Table 1. Influence of seeding rate on stand density at three locations during 2017.

	Stand density†		
Seeding rate	**Phillips‡**	**Poinsett**	**White**
(seed/ft^2)	(plants/ft^2)		
10	6.0 e§	----	5.5 e
20	11.1 d	----	10.5 d
30	16.0 c	----	13.0 c
40	20.7 b	----	17.4 b
50	25.3 a	----	20.8 a
$LSD_{0.05}$¶	1.2	----	1.9

† Averaged across CL153, CL172, Diamond, and Titan cultivars.

‡ Phillips = farmer field in Phillips Co. on a clay soil; Poinsett = farmer field in Poinsett Co. on a silt loam soil; and White = farmer field in White Co. on a silt loam soil.

§ Means within a column followed by the same letter are not significantly different ($P > 0.05$).

¶ LSD = least significant difference.

Table 2. Influence of seeding rate on rice grain yield at three locations during 2017.

Seeding rate	Grain yield†		
	Phillips‡	Poinsett	White
(seed/ft²)	----------(bu/acre)----------		
10	211.1 d§	180.3 c	199.9 d
20	225.6 c	192.9 b	209.8 c
30	229.0 bc	193.9 b	210.5 bc
40	232.1 ab	196.5 ab	215.9 ab
50	234.7 a	202.1 a	217.9 a
$LSD_{0.05}$¶	5.3	5.9	5.7

† Averaged across CL153, CL172, Diamond, and Titan cultivars.

‡ Phillips = farmer field in Phillips Co. on a clay soil; Poinsett = farmer field in Poinsett Co. on a silt loam soil; and White = farmer field in White Co. on a silt loam soil.

§ Means within a column followed by the same letter are not significantly different ($P > 0.05$).

¶ LSD = least significant difference.

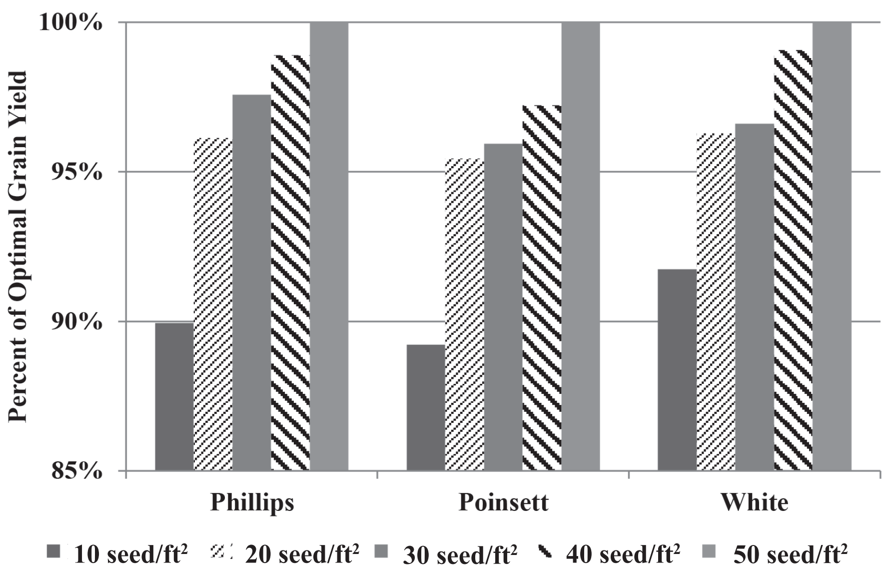

Fig. 1. Influence of seeding rate on rice grain yield in on-farm seeding rate trials in Phillips, Poinsett, and White Counties during 2017. Percent of optimal grain yield calculated based on the highest grain yield at each location equivalent to 100% optimal grain yield.

2017 Rice Grower Research and Demonstration Experiment Program

J.T. Hardke[1], G.J. Lee[1], and D.L. Frizzell[1]

Abstract

The 2017 Rice Grower Research and Demonstration Experiment (GRADE) Program was conducted at seven locations in commercial rice fields across Arkansas. Until the 2017 growing season, the University of Arkansas System Division of Agriculture relied primarily on two methods of testing research-based recommendations: small-plot research, with plots small but standardized; and the Rice Research Verification Program (RRVP) which is in place to verify that small-plot-based recommendations are effective on a commercial scale. One-thousandth of an acre is the typical size of a small plot, while the RRVP is an entire field, ranging anywhere from 20 acres to over 100. The Rice GRADE Program utilizes large-block, replicated strip trials designed to be a bridge between the RRVP and small-plot testing. Each plot in these trials ranges in size from 0.5 to 3 acres.

Introduction

In 2017, the University of Arkansas System Division of Agriculture's Cooperative Extension Service and the Arkansas Rice Research and Promotion Board established the Rice Grower Research and Demonstration Experiment (GRADE) Program. The purpose of the Rice GRADE Program was to coordinate and demonstrate large-scale plot performance of rice recommendations and cultivars in commercial production fields across the Arkansas production regions. The overall objective of the program is to increase confidence and visibility of research by bridging the gap between small-plot research trials and whole field verification program demonstrations.

The goals of the Rice GRADE Program are: 1) to conduct large-scale trials on commercial rice farms; 2) to accumulate large-plot research data on cultivar performance, seeding rate, nitrogen rate and timing, etc.; 3) to generate data to support development of rice budgets, computer-assisted management programs, agronomic practices, resource utilization, and statewide rice extension programs; and 4) to provide hands-on training of agents, consultants, and growers.

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The benefits of larger-scale demonstrations include allowing more growers opportunities to evaluate and provide input on practices at a larger scale than small-plot research, impact more counties, and provide supplemental information to the verification program. A demonstration of this type would also allow more hands-on participation by county agents, consultants, and others while providing many more sites for educational field events. Long term, the success of this program should result in adoption of lower-risk recommended practices and increase whole-farm profit.

Procedures

The Rice GRADE Program fields were selected prior to planting at the beginning of the growing season. Routine visits by the program coordinator are made to monitor growth and development of the crop and to record relevant data. Overall management of the test area is based on normal grower practices with necessary input from the program coordinator, county agent, and rice extension agronomist.

Trials in 2017 included: 1) Arkansas Co. row spacing demonstration; 2) Arkansas Co. furrow-irrigated rice insecticide seed treatment demonstration; 3) Cross Co. cultivar demonstration; 4) Monroe Co. cultivar demonstration; 5) Poinsett Co. seeding rate demonstration; 6) Poinsett Co. cultivar demonstration; and 7) St. Francis Co. cultivar demonstration. All demonstrations were set up with 3 to 4 replications per treatment in a randomized block design. Plots were seeded with a John Deere 6120e tractor used to pull an 8-ft Great Plains no-till box drill. Where appropriate, cooperator equipment was used. Plots ranged in size from 24 to 32 ft wide and 300 to 500 ft in length. Harvest was completed with a cooperator combine harvester and weights were collected with a weigh wagon. Grain yield was corrected to 12% moisture and reported in bushels (bu) per acre. Samples were collected to evaluate harvest moisture and test weight, then dried to 12% moisture to evaluate for milling yields as percent head rice (%HR) and total milled rice (%TR) reported as %HR / %TR. Data were analyzed using PROC GLM in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and means separated using Fisher's least significant difference (0.10).

Results and Discussion

The row spacing demonstration in Arkansas Co. compared a 10-inch row spacing (213 bu/acre) to a 7.5-inch row spacing (209 bu/acre) (Table 1). Previous small-plot research has suggested that a narrow row spacing is advantageous to a wider row spacing. While yields were close, the significant difference between the two row spacings suggests additional research is necessary.

The furrow-irrigated insecticide seed treatment (IST) demonstration in Arkansas Co. showed no difference in grain yield between currently recommended insecticide seed treatments and the untreated control (Table 2). Little data exists on ISTs in a furrow-irrigated system; however, reduced rice water weevil pressure may have contributed to a lack of a response to ISTs during 2017.

In all four cultivar demonstrations, Diamond was the highest yielding cultivar and significantly higher in three of the four demonstrations (Tables 3, 4, 5, and 6). The highest overall yields were observed at Cross Co. (Table 3), while the lowest overall yields were observed at St. Francis Co. (Table 6), which had red rice and blast disease issues. The Monroe Co. field (Table 4) was affected by herbicide drift which may have contributed to reduced yields. The overall performance of Diamond in large-block trials compared to other conventional cultivars is similar to that observed in small-plot cultivar trials. At Cross Co. (Table 3), Diamond had significantly higher grain yields than all other cultivars. Harvest moisture was significantly higher for Diamond and Taggart compared to LaKast and Roy J. At Monroe Co. (Table 4), Diamond had significantly higher grain yields compared to all other cultivars, while LaKast and Roy J also had significantly higher grain yields compared to Taggart. At Poinsett Co. (Table 5), grain yield was not significantly different among the four cultivars. However, LaKast and Taggart had significantly greater percent head rice compared to Diamond at this location during 2017. At St. Francis Co. (Table 6), all four cultivars had significantly different yields ranging from highest to lowest for Diamond, LaKast, Taggart, and Roy J, respectively.

The Poinsett Co. seeding rate demonstration evaluated Roy J seeded at 25, 40, 55, 70, and 85 lb seed/acre (Table 7). The 55, 70, and 85 lb/acre seeding rates resulted in significantly higher grain yields than the 25 and 40 lb/acre seeding rates. These results align with small-plot research data that shows seedling stand counts between 12 and 18 plants/ft^2 are necessary to maximize grain yields of cultivars.

Significance of Findings

Data collected from the 2017 Rice GRADE Program provides support for data generated from small-plot research in regard to cultivar performance and seeding rate recommendations. However, row-spacing data conflicts slightly with previous research and should be evaluated further.

Acknowledgments

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Table 1. Arkansas County row spacing demonstration near Stuttgart, Ark. in 2017.

Row spacing	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
7.5-inch	13.5	39.8	209 b†	58.5	71.8
10-inch	12.9	41.0	213 a	58.2	71.5
P-value	0.475	0.525	0.011	0.751	0.313
LSD $_{0.10}$‡	NS§	NS	1.7	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ LSD = least significant difference.
§ NS = not significant.

Table 2. Arkansas County furrow-irrigated rice insecticide seed treatment demonstration near Stuttgart, Ark. in 2017.

Insecticide seed treatment	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
Untreated	21.1	42.3	166	52.5	63.6
CruiserMaxx Rice	21.2	43.4	161	54.0	64.4
NipsIt INSIDE	21.2	42.4	163	54.4	64.6
Dermacor	20.4	42.0	167	54.9	65.6
P-value	0.771	0.278	0.644	0.154	0.256
LSD $_{0.10}$†	NS‡	NS	NS	NS	NS

† LSD = least significant difference.
‡ NS = not significant.

Table 3. Cross County cultivar demonstration near Wynne, Ark. in 2017.

Cultivar	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
Diamond	16.1 a†	42.5	218 a	64.8	71.2
LaKast	14.2 c	42.4	206 b	65.9	72.6
Roy J	15.4 b	41.9	203 b	65.5	71.3
Taggart	16.3 a	43.4	202 b	65.9	72.7
P-value	<0.001	0.216	0.007	0.491	0.191
LSD $_{0.10}$‡	0.5	NS§	6.8	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ LSD = least significant difference.
§ NS = not significant.

Table 4. Monroe County cultivar demonstration near Brinkley, Ark. in 2017.

Cultivar	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
Diamond	14.4	41.2	174 a†	54.8	68.4
LaKast	14.3	38.5	163 b	56.0	69.7
Roy J	14.4	40.7	164 b	56.0	68.4
Taggart	14.2	42.0	155 c	54.6	69.7
P-value	0.389	0.535	0.010	0.390	0.278
LSD $_{0.10}$‡	NS§	NS	7.6	NS	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ LSD = least significant difference.
§ NS = not significant.

Table 5. Poinsett County cultivar demonstration near Weiner, Ark. in 2017.

Cultivar	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
Diamond	11.8	42.5	184	53.4 b†	68.3
LaKast	12.5	41.4	171	56.2 a	68.9
Roy J	12.0	40.9	168	54.4 ab	67.9
Taggart	12.0	43.0	184	56.8 a	69.6
P-value	0.100	0.163	0.315	0.082	0.233
LSD $_{0.10}$‡	NS§	NS	NS	2.7	NS

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ LSD = least significant difference.
§ NS = not significant.

Table 6. St. Francis County cultivar demonstration near Hunter, Ark. in 2017.

Cultivar	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
	(%)	(lb/bu)	(bu/acre)	(%)	(%)
Diamond	13.5 b†	42.7 ab	158 a	48.9 b	67.9 bc
LaKast	13.6 b	42.0 b	150 b	57.5 a	69.5 ab
Roy J	13.5 b	39.6 c	130 d	49.7 b	65.8 c
Taggart	14.1 a	43.7 a	142 c	50.6 b	70.7 a
P-value	<0.001	0.002	<0.001	0.003	0.013
LSD $_{0.10}$‡	0.2	3.7	4.4	3.3	2.2

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).
‡ LSD = least significant difference.

Table 7. Poinsett County seeding rate demonstration (Roy J) near Weiner, Ark. in 2017.

Seeding rate	Plant stand	Harvest moisture	Test weight	Grain yield	Head rice	Total rice
(lb/acre)	(plant/ft^2)	(%)	(lb/bu)	(bu/acre)	(%)	(%)
25	7.5 e[†]	15.4 a	44.3	156 c	53.7 a	68.9
40	11.3 d	13.8 b	43.9	165 b	50.3 b	68.8
55	14.8 c	13.4 b	45.7	171 a	48.1 c	68.8
70	18.7 b	13.3 b	44.3	173 a	47.6 c	68.5
85	23.1 a	13.1 b	44.6	171 a	47.8 c	69.0
P-value	<0.001	0.089	0.250	0.001	<0.001	0.761
LSD (0.10)[‡]	1.9	1.4	NS[§]	4.7	1.2	NS

[†] Means within a column followed by the same letter are not significantly different ($P > 0.1$).
[‡] LSD = least significant difference.
[§] NS = not significant.

Arkansas Rice Performance Trials, 2015-2017

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Abstract

The Arkansas Rice Performance Trials (ARPTs) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program and commercially available cultivars from public and private breeding programs. The ARPTs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARPTs were conducted at five locations during 2017. Averaged across locations, grain yields were highest for the commercial cultivars XP753, XP760, RT7812CL, RTGemini214CL, RT7311CL, Diamond, and Jupiter. Two advanced experimental lines, AREX7-1084 and AREX7-1124 also outperformed many current commercial cultivars. Cultivars with the highest overall milling yields during 2017 included: CL153, CL163, CL172, and Roy J.

Introduction

Cultivar selection is likely the most important management decision made each year by rice producers. This choice is generally based upon past experience, seed availability, agronomic traits, and yield potential. When choosing a rice cultivar, grain yield, milling yield, lodging potential, maturity, disease susceptibility, seeding date, field characteristics, the potential for quality reductions due to pecky rice, and market

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strategy should all be considered. Data averaged over years and locations are more reliable than a single year of data for evaluating rice performance for such important factors as grain and milling yields, kernel size, maturity, lodging resistance, plant height, and disease susceptibility.

The ARPTs are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, Mississippi and Missouri with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices.

Procedures

The five locations for the 2017 ARPTs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; and the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; and two commercial farmer fields: the Trey Bowers farm in Clay County (CLAY); and Whitaker Farms in Chicot County (CHICOT). Seventy-five entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at RREC, PTRS, NEREC, CLAY, and CHICOT on 7 April, 10 May, 7 April, 6 April, and 14 April, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 30 seed/ft^2 (loam soil) or 36 seed/ft^2 (clay soil) in plots 8 rows (7.5-inch spacing) wide and 16.5 ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 10.3 seed/ft^2 (loam soil) or 12.4 seed/ft^2 (clay soil). Cultural practices varied somewhat among the ARPT locations but overall were grown under conditions for high yield. Phosphorus and potassium fertilizers were applied before seeding at the RREC and PTRS locations. Nitrogen (N) fertilizer was applied to ARPT studies located on experiment stations at the 4- to 5-leaf growth stage in a single pre-flood application of 130 lbs N/acre on silt loam soils and 160 lb N/acre on clay soils using urea as the N source. The permanent flood was applied within 2 days of preflood N application and maintained throughout the growing season. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain removed for grain quality and milling determinations. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. The dried rice was milled to obtain percent head rice (%HR; whole kernels) and percent total white rice (%TR) presented as %HR/%TR. Each location of the study was arranged in a randomized complete block design with four replications.

Results and Discussion

The 3-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2015-2017 are listed in Table 1. The top yielding entries, averaged across three study years, include: RiceTec (RT) XP753, RT Gemini 214 CL, RT 7311 CL, RT XP760, Diamond, and RT XL745 CL with grain yields of 221, 213, 211, 210, 194, and 194 bu/acre, respectively. In regard to percent head rice and percent total white rice (%HR / %TR), CL153, CL111, CL163, and Roy J had the highest overall average milling yields from 2015-2017.

Selected agronomic traits, grain yield, and milling yields from the 2017 ARPT are shown in Table 2. Grain yield averaged across all locations and cultivars was 178 bu/acre. RT XP753, RT XP760, RT 7311 CL, RT 7812 CL, and RT Gemini 214 CL were the only cultivars to maintain a grain yield above 200 bu/acre at all locations. Other notable cultivars in 2017 included Diamond, Jupiter, RT XL745 CL, and Titan. Milling yield, averaged across locations and cultivars, was 53/69 (%HR/%TR) during 2017. CL153, CL163, CL172, and Roy J had the highest milling yields of all commercial entries averaged across locations.

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

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

Significance of Findings

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

Acknowledgments

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Table 1. Results of the Arkansas Rice Performance

Cultivar	Grain length[a]	Straw strength rating[b]	50% Heading[c] (days)	Plant height (in.)	Test weight (lb/bu)	Milled kernel weight[d] (mg)	Chalky kernels[d] (%)
CL111	L	1.3	81	39	41.9	21.3	2.78
CL151	L	2.1	81	38	41.3	19.9	3.57
CL153	L	1.0	84	38	41.7	20.1	1.90
CL163	L	1.5	86	38	41.3	20.7	2.32
CL172	L	1.0	84	36	41.1	21.1	1.93
CL272	M	1.0	84	38	41.7	21.9	2.23
Diamond	L	1.4	84	40	41.3	21.4	1.61
Jupiter	M	1.8	85	36	40.3	20.9	2.35
LaKast	L	1.5	81	41	42.0	21.7	1.53
MM14	M	1.1	83	33	42.8	21.1	1.46
Roy J	L	1.0	88	41	40.8	20.7	1.70
RT 7311 CL	L	2.0	83	42	38.9	20.5	5.38
RT CLXL745	L	2.7	79	43	41.7	22.4	3.27
RT Gemini 214 CL	L	2.1	88	45	39.1	20.1	4.74
RT XP753	L	1.4	80	43	42.2	21.2	3.12
RT XP760	L	2.5	85	45	41.5	20.8	4.03
Taggart	L	1.1	87	43	41.2	22.7	1.54
Thad	L	1.0	87	37	41.5	20.6	1.05
Titan	M	1.6	80	38	41.3	22.5	1.95
Wells	L	1.1	85	40	41.4	21.9	1.75
AREX4-1105	LA	1.0	85	39	41.4	21.8	1.35
AREX6-1124	L	1.0	88	38	39.1	21.4	3.39
CLX6-1030	M	1.3	88	39	38.2	22.1	2.45
CLX6-1111	L	1.2	86	38	38.7	20.6	3.06
Mean		1.4	84	40	41.0	21.2	2.54

[a] Grain length: L = long-grain; M = medium-grain.
[b] Relative straw strength based on field tests using the scale: 1 = very strong straw, 5 = very weak straw; based on percent lodging (2014, 2016, and 2017 - no lodging in 2015).
[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.
[d] Data from Riceland Grain Quality Lab, 2014-2016. Based on weight of 1000 kernels.

Trials averaged across the 3-year period of 2015-2017.

Milling yield by year				Grain yield by year			
2015	2016	2017	Mean	2015	2016	2017	Mean
---------- (% head rice / % total rice) -----------				----------------------(bu/acre)----------------------			
62/70	58/67	58/70	59/69	144	149	167	153
61/70	53/70	58/70	57/70	166	164	191	174
62/69	57/69	61/71	60/70	154	169	185	169
61/70	54/70	60/70	58/70	151	150	190	164
58/69	50/69	60/70	56/70	142	161	180	161
62/70	53/69	52/68	56/69	162	176	193	177
60/69	55/68	56/69	57/69	186	188	206	194
61/68	57/69	59/67	59/68	176	167	203	182
56/68	55/69	56/70	56/69	162	182	188	177
61/69	--	55/68	58/68	155	--	186	171
61/70	55/69	60/70	58/70	169	167	196	177
--	54/69	50/69	52/69	--	208	214	211
58/69	46/69	52/70	52/69	187	192	202	194
--	53/69	56/69	54/69	--	211	215	213
54/69	45/67	49/70	49/68	212	231	220	221
59/69	52/68	55/69	55/69	207	205	218	210
58/70	47/69	59/71	55/70	167	179	183	176
58/69	52/70	57/70	56/69	137	147	185	156
56/68	54/69	51/68	53/68	165	192	200	186
57/70	52/69	55/70	55/70	161	171	182	171
62/70	59/69	52/71	61/70	142	162	176	160
--	59/68	63/71	61/70	--	162	186	174
--	55/67	58/68	56/67	--	169	202	186
--	56/68	58/70	57/69	--	176	190	183
59/69	53/69	57/70	56/69	165	177	194	180

Table 2. Results of the Arkansas Rice

Cultivar	Grain length[a]	Straw Strength rating[b]	50% heading[c]	Plant height	Test weight
			(days)	(in.)	(lb/bu)
CL111	L	1.4	88	36	39.0
CL151	L	1.8	88	36	39.0
CL153	L	1.0	91	35	39.2
CL163	L	1.4	91	36	38.8
CL172	L	1.0	91	33	38.6
CL272	M	1.0	89	36	39.2
Diamond	L	1.0	91	38	38.8
Jupiter	M	1.0	91	35	38.2
LaKast	L	1.8	89	39	39.4
MM14	M	1.0	90	34	39.1
PVL01	L	1.0	94	35	38.6
Roy J	L	1.0	94	40	38.3
RT CLXL745	L	2.2	85	39	39.2
RT 7311 CL	L	1.8	87	39	39.0
RT 7812 CL	L	2.8	94	41	37.9
RT Gemini 214 CL	L	1.6	90	41	39.2
RT XP753	L	1.4	87	38	39.4
RT XP760	L	1.8	90	41	39.4
Taggart	L	1.0	94	41	38.6
Thad	L	1.0	92	36	39.2
Titan	M	1.2	85	36	39.1
Wells	L	1.0	91	39	38.9
AREX4-1105	LA	1.0	92	38	39.1
AREX6-1124	L	1.0	90	36	39.0
AREX7-1084	L	1.0	93	37	39.0
AREX7-1124	M	1.6	87	35	38.5
CLX6-1030	M	1.0	90	37	38.3
CLX6-1111	L	1.0	89	35	38.9
CLX6-1133	L	1.8	90	39	38.6
Mean		1.6	84	43	38.8

[a] Grain length: L = long-grain; M = medium-grain.
[b] Relative straw strength based on field tests using the scale: 1 = very strong straw, 5 = very weak straw; based on percent lodging.
[c] Number of days from plant emergence until 50% of the panicles are visibly emerging from the boot.
[d] % HR/% TR = percent head rice and percent total rice.
[e] CLAY = Clay County, CHICOT = Chicot County, NEREC = Northeast Research and Extension Center, PTRS = Pine Tree Research Station, and RREC = Rice Research and Extension Center.

Performance Trials at five locations during 2017.

Milling yield[d]	Grain yield by location and seeding date[e]					
	CLAY 6 April	CHICOT 14 April	NEREC 7 April	PTRS 10 May	RREC 7 April	Mean
(%HR/%TR)	--(bu/acre)--					
58/70	197	161	157	151	170	167
58/70	199	178	195	186	200	191
61/71	190	181	196	171	189	185
60/70	192	184	195	191	189	190
60/70	187	177	186	160	186	180
52/68	218	195	181	174	196	193
56/69	227	208	204	177	214	206
59/67	218	208	210	184	198	203
56/70	201	197	179	172	194	188
55/68	195	201	190	152	194	186
57/70	176	144	185	134	174	163
60/70	209	186	205	184	197	196
52/70	218	--	181	199	208	202
50/69	244	206	201	213	206	214
57/70	237	237	203	222	192	218
56/69	227	202	217	219	210	215
49/70	230	222	214	201	231	220
55/69	218	219	226	207	218	218
59/71	190	184	184	177	182	183
57/70	194	188	193	162	188	185
51/68	198	212	214	164	214	200
56/71	191	191	196	164	166	182
62/71	197	168	185	169	162	176
63/71	202	186	192	157	192	186
57/69	229	217	205	201	201	210
55/68	237	201	208	172	229	209
58/68	205	205	206	204	191	202
58/70	205	191	182	182	192	190
61/70	193	165	162	183	187	178
53/69	181	148	190	173	199	178

Table 3. Arkansas rice cultivar reactions[a]

Cultivar	Sheath blight	Blast	Straight head	Bacterial panicle blight
Cheniere	S	MS	VS	MS
CL111	VS	MS	S	VS
CL151	S	VS	VS	VS
CL153	S	MS	--	MS
CL163	VS	S	--	MS
CL172	MS	MS	--	MS
CL272	S	MS	--	VS
Cocodrie	S	S	VS	S
Della-2	S	R	--	MS
Diamond	S	S	--	MS
Jazzman-2	S	MS	--	VS
Jupiter	S	S	S	MR
LaKast	MS	S	MS	MS
MM14	--	--	--	S
PVL01	S	S	--	S
Roy J	MS	S	S	S
RT 7311 CL	MS	R	--	--
RT 7812 CL	--	--	--	--
RT XL729 CL	MS	R	MS	MR
RT XL745 CL	S	R	R	MR
RT Gemini 214 CL	S	R	--	--
RT XP753	MS	R	MS	MR
RT XP760	MS	MR	--	MR
Taggart	MS	MS	R	MS
Thad	S	S	S	MS
Titan	S	MS	--	MS
Wells	S	S	S	S

[a] Reaction: R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible. Cells with no values indicate no definitive Arkansas disease rating information is available at this time. Reactions were determined based on historical and recent observations from test plots and grower fields across Arkansas and other rice states in southern USA. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development. *Table prepared by Y. Wamishe, Associate Professor/Extension Plant Pathologist.*

to diseases and lodging (2017).

Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
S	S	S	S	MR	MS
S	VS	S	S	MS	S
S	VS	S	S	S	S
S	--	S	S	MR	--
R	--	MS	--	MS	--
S	--	MS	S	MR	--
S	--	MS	--	MR	S
S	VS	S	S	MR	S
MS	--	--	--	--	--
--	S	S	VS	MS	--
S	--	S	S	--	--
MR	VS	MS	MS	S	MR
MS	S	S	S	MS	MS
--	--	--	S	--	--
--	--	--	VS	--	--
R	S	VS	S	MR	MS
--	--	S	S	MS	--
--	--	--	S	--	--
R	S	MS	S	S	S
R	S	S	S	S	S
--	--	MS	VS	MS	--
R	--	MS	S	MS	S
R	--	MS	VS	S	--
MS	S	S	S	MS	MS
--	--	S	VS	MR	-
--	--	MS	MS	MS	--
S	VS	S	S	MS	MS

Agronomics of Alternative Irrigation of Rice

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Abstract

The majority of rice in Arkansas is grown using a direct-seeded, delayed flood system. In recent years, growers have increased their interest in alternative irrigation management strategies. To begin addressing this, large block trials were initiated in 2017 to evaluate irrigation management practices of rice grown in a furrow-irrigated system and an alternate wetting and drying system. Large-block trials were conducted on a silt loam soil at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and on a clay soil at the Northeast Research and Extension Center (NEREC). Additional small-plot trials were conducted on a silt loam soil at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC). Water moisture tensions (deficits) of 15, 30, and 45 centibars (cb) were used to trigger irrigation events in both furrow-irrigated and alternate wetting and drying trials. A conventional permanent flood was also included for comparison of water use. First year results will be discussed.

Introduction

Approximately 95% of Arkansas rice is irrigated using a conventional flood system (Hardke, 2017). In this system, a permanent flood is initiated at the 4-5 leaf (lf) growth stage and maintained until near grain maturity. The remaining 5% in 2016 was irrigated using furrow-irrigation or alternate wetting and drying, which represents a 4% increase since 2014. In a furrow-irrigated rice (FIR) system, growers begin irrigation at the 4-5 lf growth stage, but a permanent flood is not established. In some cases, water is held at the bottom of the field, but the majority of the field is grown in a non-flooded environment. In an alternate wetting and drying (AWD) system, the permanent flood is established but then allowed to naturally subside before the water level is brought back to a permanent flood.

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With these changes in irrigation management, timing of irrigation events need to be refined to ensure maximum grain yields and minimal irrigation use. Those using FIR frequently irrigate on a schedule with irrigation events occurring every 3-5 days, but without accounting for available soil moisture. In an AWD system, the timing of re-establishing the permanent flood is typically based on a relative soil moisture level ranging from "muddy" to a small amount of standing water. In both of these systems, the decision to irrigate is highly subjective. To better define the timing of rice irrigation management in FIR and AWD systems, trials were initiated in 2017 to determine the optimum soil moisture level at which to initiate irrigation events.

Procedures

During 2017, studies were located at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) on a Calloway and Henry silt loam soil; the Northeast Research and Extension Center (NEREC) on a Sharkey silty clay; and the Rice Research and Extension Center (RREC) on a DeWitt silt loam.

Furrow-Irrigated rice

At PTRS, FIR trials were planted to RT CLXP756 at 24 lb seed/acre (11 seed/ft^2) with a 7.5-in spacing onto furrows with a 30-in bed spacing. Plots were large blocks 22 rows wide and 750 ft in length. The study followed soybean in rotation. The study was seeded on 10 May, emerged 18 May, and irrigation began on 17 July. Cultural management practices were modified from traditional delayed-flood production system recommendations. A single preflood nitrogen (N) application of 130 lb N/acre was made prior to beginning irrigation.

At NEREC, FIR trials were planted to RT CLXP756 at 27 lb seed/acre (12.5 seed/ft^2) with a 7.5-in spacing onto furrows with a 38-in bed spacing. Plots were large blocks 22 rows wide and 1000 ft in length. The study followed soybean in rotation. The study was seeded on 18 May, emerged 25 May, and irrigation began on 21 July. Cultural management practices were modified from traditional delayed-flood production system recommendations. A single preflood N application of 160 lb N/acre was made prior to beginning irrigation.

At both locations, watermark soil moisture sensors were installed in the top of beds at three locations in the upper, middle, and lower third of each plot at depths of 4, 8, and 12 inches. Irrigation events were triggered based on the soil moisture deficit of the 4-in. depth sensor. Irrigation treatments were 15, 30, and 45 centibar (cb) soil moisture tensions (deficits). Irrigation events occurred any time moisture sensors exceeded their treatment soil moisture deficit.

Alternate Wetting and Drying

At PTRS, AWD trials were planted to CL153 at 69 lb seed/acre (30 seed/ft^2) with a 7.5-in. spacing. Plots were large blocks 60 ft wide and 500-600 ft in length. The study followed soybean in rotation. The study was seeded on 10 May, emerged 18 May, and irrigation began on 14 July. Aside from irrigation management, cultural management practices followed those for a traditional, permanent flood system. A single preflood N application of 130 lb N/acre was made prior to initial flood establishment. Initial floods were maintained for 14 days prior to allowing natural flood dissipation to begin in the three moisture deficit treatments. Treatments included 15, 30, and 45 cb soil moisture deficits and a conventionally flooded control. The study was arranged as a randomized complete block design with two replications.

At NEREC, AWD trials were planted to CL153 at 80 lb seed/acre (35 seed/ft^2) with a 7.5-in. spacing. Plots were large blocks 45 ft wide and 600 ft in length. The study followed soybean in rotation. The study was seeded on 17 May, emerged 25 May, and irrigation began on 18 July. Aside from irrigation management, cultural management practices followed those for a traditional, permanent flood system. A single preflood N application of 160 lb N/acre was made prior to initial flood establishment. Initial floods were maintained for 14 days prior to allowing natural flood dissipation to begin in the three moisture deficit treatments. Treatments included 15, 30, and 45 cb soil moisture deficits and a conventionally flooded control. The study was arranged as a randomized complete block design with two replications.

At RREC, AWD trials were planted to CLXP756, CL153, XP753, and Diamond cultivars into plots 8 rows wide (7.5-in spacing) and 16.5 ft in length. Plots were seeded on 19 May, emerged 31 May, and irrigation began on 29 June. The pure-line cultivars CL153 and Diamond were planted at 30 seed/ft^2 and the hybrids CLXP756 and XP753 were planted at 10.3 seed/ft^2. Initial floods were maintained for 14 days prior to allowing natural flood dissipation to begin in the three moisture deficit treatments. A single preflood N application of 130 lb N/acre was made prior to initial flood establishment. The study was arranged as a split-block design with whole plots as soil moisture deficits of 15, 30, and 45 cb soil moisture deficits and a conventionally flooded control with two replications and sub-plots as cultivars with three replications.

Results and Discussion

Furrow Irrigated Rice

At PTRS, there were no significant differences in grain yield related to soil moisture deficit (Table 1). However, the 15 cb moisture deficit averaged 25 bu/acre greater than the 30 and 45 cb treatments. The 15 cb treatment did have significantly greater head rice yields compared to 30 and 45 cb treatments. No significant differences were observed for harvest moisture, test weight, total milled rice, or water use efficiency. Water use alone was not analyzed as irrigation events were made to the same treatments with a single flow meter for irrigation measurement. Water used ranged from 20 acre-in for the 15 cb treatment to 17 acre-in for the 45 cb treatment. Irrigation events for each treatment were 7, 6, and 4 for the 15, 30, and 45 cb treatments, respectively.

At NEREC, the only significant difference between soil moisture deficits was for water use efficiency with the 45 cb treatment having the highest water use efficiency (Table 2). Similar to PTRS, water use was not analyzed as a single flow meter was used for irrigation measurement. Measured water use was 54 acre-in for the 15 cb treatment, 27 acre-in for the 30 cb treatment, and 24 acre-in for the 45 cb treatment. Irrigation events for each treatment were 13, 5, and 5 for the 15, 30, and 45 cb treatments, respectively.

Alternate Wetting and Drying

At PTRS, there were no significant differences for any factors evaluated based on soil moisture deficit except for water use efficiency (Table 3). The 45 cb treatment had higher water use efficiency than all other treatments, and all moisture deficit treatments had higher water use efficiency compared to the permanent flood treatment. Measured water use ranged from 22 acre-in for the flood treatment to 11 acre-in for the 30 cb treatment. Following the initial permanent flood maintenance period of 14 days, the moisture deficit treatments were reflooded 1, 2, and 0 times for the 15, 30, and 45 cb treatments, respectively.

At NEREC, there were no significant differences for any factors evaluated based on soil moisture deficit (Table 4). Measured water use ranged from 49 acre-in for the flood treatment to 12 acre-in for the 45 cb treatment. Following the initial permanent flood maintenance period of 14 days, the moisture deficit treatments were reflooded 2, 1, and 0 times for the 15, 30, and 45 cb treatments, respectively.

At RREC, there was no interaction between cultivar and irrigation treatment, so irrigation treatments were analyzed by averaging across cultivars (Table 5). Across cultivars, the flood treatment produced significantly higher grain yields compared to the 15, 30, and 45 cb treatments. Despite the lack of interaction, the evaluation of individual cultivars by irrigation treatment are provided in Table 6.

Significance of Findings

Data collected from these studies will be used to give direction to future research efforts for irrigation management of furrow-irrigated and alternate wetting and drying rice systems. An increase in the number of replications used in large blocks trials appears necessary to adequately separate treatments in regard to grain yield and water use. However, based on the results of this single year, it appears that moisture deficits should be kept low to ensure optimal grain yield potential.

Acknowledgments

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Literature Cited

Hardke, J.T. 2017. Trends in Arkansas Rice Production, 2016. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 643:11-21.

Table 1. Furrow-irrigated rice trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. in 2017.

Soil moisture tension	Harvest moisture	Test weight	Grain yield	Head rice	Total rice	Water use	Water use efficiency
	(%)	(lb/bu)	(bu/acre)	(%)	(%)	(acre-in.)	(bu/acre-in.)
15 cb	22.0	42.3	173	58.4	70.2	20.7	8.4
30 cb	21.2	41.0	150	52.1	68.9	19.3	7.8
45 cb	21.1	40.0	150	50.8	69.8	17.4	8.7
P-value	0.721	0.227	0.198	0.599	0.835	n/a	0.355
$LSD_{0.10}$	NS†	NS	NS	NS	NS	n/a	NS

† NS = not significant.

Table 2. Furrow-irrigated rice trials at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark. in 2017.

Soil moisture tension	Harvest moisture	Test weight	Grain yield	Head rice	Total rice	Water use	Water use efficiency
	(%)	(lb/bu)	(bu/acre)	(%)	(%)	(acre-in.)	(bu/acre-in.)
15 cb	18.0	41.6	168	50.0	68.4	54.0	3.1 c†
30 cb	18.3	42.0	166	51.5	68.3	27.0	6.3 b
45 cb	17.8	41.9	170	52.3	68.3	24.0	7.0 a
P-value	0.676	0.658	0.641	0.211	0.923	n/a	<0.001
$LSD_{0.10}$	NS‡	NS	NS	NS	NS	n/a	0.2

† Means followed by the same letter within a column are not significantly different ($P > 0.10$).
‡ NS = not significant.

Table 3. Alternate wetting and drying rice trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. in 2017.

Soil moisture tension	Harvest moisture	Test weight	Grain yield	Head rice	Total rice	Water use	Water use efficiency
	(%)	(lb/bu)	(bu/acre)	(%)	(%)	(acre-in.)	(bu/acre-in.)
15 cb	16.4	39.7	119	59.8	67.6	12.0	10.2 b†
30 cb	16.7	37.8	121	59.1	68.9	13.7	9.0 b
45 cb	16.6	39.0	122	58.6	69.1	9.2	13.2 a
Flood	16.2	39.6	115	61.2	69.7	21.6	5.7 c
P-value	0.489	0.507	0.519	0.758	0.592	n/a	0.010
$LSD_{0.10}$	NS‡	NS	NS	NS	NS	n/a	1.9

† Means followed by the same letter within a column are not significantly different ($P > 0.10$).
‡ NS = not significant.

Table 4. Alternate wetting and drying rice trials at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark. in 2017.

Soil moisture tension	Harvest moisture	Test weight	Grain yield	Head rice	Total rice	Water use	Water use efficiency
	(%)	(lb/bu)	(bu/acre)	(%)	(%)	(acre-in.)	(bu/acre-in.)
15 cb	17.8	44.9	137	66.8	71.1	21.5	6.4
30 cb	17.8	44.9	142	68.1	71.8	15.7	9.1
45 cb	18.5	44.2	139	67.1	71.7	12.3	6.9
Flood	18.4	44.4	137	68.1	71.8	49.2	2.8
P-value	0.146	0.410	0.865	0.610	0.667	n/a	0.303
$LSD_{0.10}$	NS†	NS	NS	NS	NS	n/a	NS

† NS = not significant.

Table 5. Alternate wetting and drying rice trials at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2017.

Soil moisture tension	Harvest moisture	Test weight	Grain yield
	(%)	(lb/bu)	(bu/acre)
15 cb	16.7	39.2	207 b†
30 cb	16.5	39.3	208 b
45 cb	18.3	38.0	204 b
Flood	18.4	38.3	221 a
$LSD_{0.10}$	0.104	0.228	<0.001

† Means followed by the same letter within a column are not significantly different ($P > 0.05$).

Table 6. Alternate wetting and drying rice trials at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2017.

Cultivar	Soil moisture tension	Harvest moisture	Test weight	Grain yield
		(%)	(lb/bu)	(bu/acre)
CL153	15 cb	16.7	39.2	167 ab†
	30 cb	16.5	39.3	164 bc
	45 cb	18.3	38.0	158 c
	Flood	18.4	38.3	173 a
	$LSD_{0.10}$	0.107	0.108	0.031
CLXP756	15 cb	22.2	36.4	235
	30 cb	21.0	36.9	241
	45 cb	21.4	36.8	235
	Flood	22.3	36.6	249
	$LSD_{0.10}$	0.358	0.416	0.231
Diamond	15 cb	20.5	37.2	203 b
	30 cb	19.9	37.5	196 b
	45 cb	21.0	36.9	196 b
	Flood	21.7	36.8	224 a
	$LSD_{0.10}$	0.312	0.461	<0.001
XP753	15 cb	19.5	37.3	223 b
	30 cb	19.5	37.4	230 b
	45 cb	19.9	37.2	226 b
	Flood	19.8	37.3	242 a
	$LSD_{0.10}$	0.987	0.995	0.040

† Means followed by the same letter within a column are not significantly different ($P > 0.05$).

Grain Yield Response of Furrow-Irrigated Clearfield Hybrid XL745 to Different Nitrogen Sources

V. Kandpal[1] and C.G. Henry[1]

Abstract

A study was conducted to evaluate the performance of four different nitrogen (N) source treatments in a furrow-irrigated rice field during the season of 2017 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. on a Dewitt silt loam. The N sources used were 32% urea ammonium nitrate (UAN), Environmentally Safe Nitrogen (ESN), and urea applied in a single and two-way split application. No yield and water use efficiency differences between the N treatments were observed for the cultivar RT XL745 CL. Plant height differences were not observed between the treatments when blocked (as well as not blocked) by plant position along the furrow length. No influence of plant position at bed or furrow was observed on plant heights within the treatments. Normalized Difference Vegetation Index (NDVI) values indicated no additional N was needed in any treatment.

Introduction

Rice is one of the most important crops in the world which was consumed by almost 3 billion people worldwide in 2015 (Mosleh et al., 2015). In the United States, Arkansas is the largest producer of rice. In the last 3 years, Arkansas contributed 48.8% of the total rice production in the U.S. In 2016, 47% of the total rice production was contributed by Arkansas and 49.1% of the total rice acreage was also represented by Arkansas. (Hardke, 2017). Nitrogen fertilizer was applied to 97% of the 2006 Arkansas rice production area of 1,406,000 acres (568,988 ha) at an average rate of 206 lb N/acre (231 kg N/ ha) (USDA-NASS, 2007). Needless to say, N application plays a significant role in rice production as well as in the cost associated with it.

In a flood irrigated rice field, 150 lb N/acre is recommended for most rice cultivars which can be adjusted according to the soil texture, cultivar of the rice and previous crop (Davidson et al., 2016). Typically, N is applied through ammoniacal fertilizers like urea or ammonium sulfate. This fertilization can be done as a single application, when

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the plants are at 4-6 leaf stage, or it can be split into two applications where the first is applied at 4-6 leaf stage and the latter at the beginning of the reproductive stage (Frizzell et al., 2016 and Wilson et al., 1994). Urea is extensively used as the N source for these applications due to its low cost per pound of N (Wilson et al., 1994 and Golden et al., 2009). The use of ground rigs for applying urea is limited in a flooded field after the construction of levees. (Golden et al., 2009). Therefore aerial application of urea is conducted which significantly increases the cost of N application (Golden et al., 2009). It also creates a problem of uneven urea distribution in the field (Wilson, et al., 1994). The problem in this uneven distribution can be reduced by using urea ammonium nitrate (UAN) solution; however, it can be a substandard N source than urea for pre-flood application (Wilson et al, 1994). Aerial application can also cause delayed N application during the untimely rainfall events at the time of desired rice growth stage (Golden et al., 2009).

This problem can be eliminated in a furrow-irrigated rice field where the drainage of water from the field is easily manageable and the ground equipment can be extensively used for fertilizer and chemical application. However, little is known about the types of fertilizers that can be used in a furrow-irrigated rice field. In Arkansas, 2.7% of the rice acreage is furrow irrigated and it is gaining popularity among farmers because it helps to simplify crop rotation and management. However, no knowledge on the N use efficiency in furrow-irrigated rice is available.

Another kind of approach to increase N efficiency is to use controlled release fertilizers like Environmentally Safe Nitrogen (ESN). These types of fertilizers can help to reduce environmental losses by matching nutrient demand of crop with N release from the fertilizer (Blackshaw et al., 2011). It has been suggested in a study that N release from ESN is too rapid for rice cultivated in direct-seeded, delayed flood method. (Golden et al., 2009)

In the study presented in this paper, experiments were conducted to evaluate the effects of different types and timings of N fertilizer on grain yield of furrow-irrigated rice.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. in 2017. Due to the presence of a compaction layer, prior to the bed construction, a 37-acre field was deep tilled to a depth of 12 in. perpendicular to the slope of the field with a 5-shank no-till soil management system ripper (John Deere, Moline, Ill.). The soil in the field is predominately a DeWitt silt loam which was identified by soil tests conducted in Nebraska Soil testing lab. Raised beds were constructed on a 30-in. spacing. RiceTec hybrid XL745 CL was planted in the field. The field was divided into a total of 12 plots of approximately 1 acre for each treatment. Each plot consisted of 12 beds and 12 furrows (11 plus two half furrows). Four fertilizer treatments were performed in the field. Each treatment was replicated three times and was randomly distributed. The crop was planted at a seeding rate of 28 lb/acre on 18 May 2017. The four fertilizer treatments were: 1) Full = single N application of urea (45-0-0)–150 lb N/acre as urea with urease inhibitor applied on 13 June; 2) Split = two-way split application–75 lb N/acre of N as urea with a urease inhibitor applied on 13 June and 75 lb N/acre a urea without a urease inhibitor applied on 29 June; 3) ESN = two-way split application of urea and ESN (44-0-0)–75 lb N/acre as urea with urease inhibitor applied on 13 June and 55 lb N/acre as ESN applied on 29 June (a total of 440 lbs ESN was available, change in spreader calibration affected the number of pounds of N per acre actually applied); and 4) UAN = two-way split application of urea and UAN (32-0-0)–75 lb N/acre as urea with a urease inhibitor applied on 13 June and 75 lb N/acre as UAN applied on 30 June along with irrigation. A fertigation method was designed for UAN application. A "High flo" gold series 25 psi pump was used to pressurize the system. Netafim 2 l/h emitters, standard polyethylene 3/4-in. drip tube was laid at the top of the plots and emitters were installed in the furrows of the UAN treatment plots. An AMIAD 100 micron 3/4 in. disc filter was used.

The field was furrow-irrigated using a tail water recovery system. An application of 12.8 oz/acre of Command and 6.4 oz/acre of League with a gallon (for whole field) of VDrift was applied the same day after planting on 18 May. Twenty-four days post planting, a herbicide application of 33 oz/acre of FacetL, 128 oz/acre of Stam and 0.77 oz/acre of Permit Plus was applied. Mustang Maxx was applied for rice stink bugs on 23 August at 4 oz/acre. Irrigation management was done using soil moisture sensors, specifically an Aquatrac (AgSense, Huron, S.D.) and Watermark™ Sensors (Irrometer, Riverside, Calif.) and supplemented with visual observation. A threshold of 40 centibars (cb) was used as an irrigation trigger based on experience and soil water retention data for the soil type in the study.

The Greenseeker device was used to measure the NDVI of randomly selected plant canopy as well as reference strips in each plot during panicle initiation stage. Reference strips of 5 foot by 5 foot were managed by applying 1/3 cup extra urea than the rest of the plots. One reference strip each at top, middle and bottom position along the furrow length were set up on the border plot. The response index was calculated by dividing NDVI value of the reference strip by NDVI value of plants from the treatment plot for their respective positions along the furrow length.

Analysis of variance (ANOVA) was preformed using JMP Pro. Within varietal differences were analyzed for crop yield and water use efficiency. Differences in plant heights at different positions along the furrow length were analyzed within the cultivars. An ANOVA for randomized block design was performed to find any differences between plant heights along different positions by using treatments as block. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference (HSD) test at a 5% probability.

Results and Discussion

No significant yield and water use efficiency (WUE) differences were found between the four N treatments at a significance level of $P = 0.05$ (Table 1). Average yield of 152 bu/acre was calculated for all the N treatments. Response indices were observed to be similar for ESN, Split, and UAN and similar for ESN, UAN, and Full but the value for Split treatment was significantly lower than that for Full N treatment when treatments were blocked by positions (Table 2). Also, when data was blocked by treatments, the response index was found to be significantly higher for plants at middle and bottom position along the furrow length in comparison to plants at top position. No difference in response index was seen between treatments for top and middle positions; however for bottom positions, the response index for UAN was significantly higher than for the Split treatment (Table 3). For response index differences by positions, no differences were seen for ESN and Split treatment while differences were observed for Full and UAN treatments (Table 4). No differences in plant heights were observed between the N treatments when the treatments were blocked by position as well as when treatments were analyzed by position (Table 5). For plants at the bottom, the plant heights were significantly higher than those at top and middle positions along the furrow length when blocked by treatments (Table 6). Some differences in plant heights were observed within treatments when evaluated by the positions. Uniform plant heights were observed for UAN treatments while it varied for other N treatments (Table 7). For bed/furrow data, heights were averaged across N-Treatments for bed and furrows by positions. Data was normal according to the Shapiro Wilk test. There was no difference in height between bed and furrow ($P = 0.8916$; one way ANOVA at significance level of 0.05); no difference in height between bed and furrow by treatments blocked by position (as well as when not blocked; data not shown); and no difference between bed and furrow heights by position along furrow blocked by treatment (as well as when not blocked; data not shown). Also, the heading notes that were taken on 8 August 2017 have indicated most of the plants were 50 to 80% headed and were mostly in the R5 to R6 (milk) stage (Table 8).

Significance of Findings

The study results were surprising. The results suggest that a single application of urea may be all that is necessary for furrow-irrigated rice. It was expected there would be a difference between ESN and urea treatments, in that the polymer-coated ESN might float away, but this was not observed in the yield. The study also suggests that UAN could be fertigated in furrow-irrigated rice with no yield penalty, a practice with interesting potential.

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Literature Cited

Blackshaw, R.E, X. Hao, R.N. Brandt, G.W. Clayton, K.N. Harker, J.T. O'Donovan, E.N. Johnson, and C.L. Vera. (2011). Canola response to ESN and Urea in a four-year no-till cropping system. Agron. J. 103(1):92-99.

Davidson, J.T., T.L. Roberts, R.J. Norman, C.E. Greub, N.A. Slaton, and J.T. Hardke. (2016). Continued validation of the Nitrogen soil test for rice on clay soils in Arkansas. *In*: R.J. Norman and K.A.K. Moldehauer (eds.) B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 634:226-227. Fayetteville.

Frizzell, D.L., J.T. Hardke, T.L. Roberts, R.J. Norman, E. Castaneda-Gonzalez, G.J. Lee, and T.L. Clayton. (2016). Evaluation of alternative nitrogen fertilizer application timings in four water management regimes. *In*: R.J. Norman and K.A.K. Moldehauer (eds.) B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 634:233-235. Fayetteville.

Golden, B.R., N.A. Slaton, R.J. Norman, C.E. Wilson, Jr., and R.E. DeLong. (2009). Evaluation of polymer-coated urea for direct-seeded, delayed-flood rice production. Soil Sci. Soc. Amer. J. 73(2):375-383.

Hardke, J.T. (2017). Trends in Arkansas rice production, 2016. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 634:13-23. Fayetteville.

Mosleh, M. K., Q.K. Hassan, and E.H. Chowdhury. (2015). Application of remote sensors in mapping rice area and forecasting its production: A review. Sensors, 15(1):769-791.

USDA-NASS. 2007. United States Department of Agriculture- National Agricultural Statistics Service. Agricultural Statistics: Statistics of fertilizer and pesticides.

Wilson, Jr. C.E., B.R. Wells, and R.J. Norman. (1994). Fertilizer Nitrogen uptake by rice from Urea-Ammonium Nitrate solution vs granular urea. Soil Sci. Soc. Amer. J. 58:1825-1828.

Table 1. Yield differences between cultivar ($P = 0.9435$) and water use efficiency (WUE) differences between cultivar ($P < 0.0001$) revealed by analysis of variance.

Treatment	Yield	WUE
	(bu/acre)	(bu/acre-in.)
UAN†	153 a‡	8.05 a
Split	151 a	7.95 a
ESN	151 a	7.95 a
Full	153 a	8.05 a

† UAN = urea ammonium nitrate; ESN = Environmentally Smart Nitrogen.

‡ Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 2. Response index and plant height differences between treatments blocked by positions revealed by analysis of variance.

Position	Split	ESN†	UAN	Full
Response index ($P = 0.0262$)	1.0146 b‡	1.0311 ab	1.0322 ab	1.0324 a
Plant height ($P = 0.1920$)	3.71 a	3.67 a	3.66 a	3.64 a

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

‡ Means within a column followed by different letters are significantly different at $\alpha = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 3. Response index differences (Reference NDVI/ measured NDVI) by position between treatments revealed by analysis of variance.

Position	Top ($P = 0.1524$)	Middle ($P = 0.1175$)	Bottom ($P = 0.0085$)
Split	1.034 a‡	1.005 a	1.006 b
ESN†	1.050 a	1.024 a	1.019 ab
UAN	1.064 a	0.999 a	1.034 a
Full	1.069 a	1.015 a	1.019 ab

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

‡ Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 4. Response index differences (Reference NDVI/ measured NDVI) by position within treatments revealed by analysis of variance.

Position	ESN† (P = 0.0510)	Split (P = 0.0623)	Full (P = 0.0100)	UAN (P = 0.0007)
Bottom	1.019 a‡	1.006 a	1.019 b	1.034 b
Middle	1.024 a	1.005 a	1.015 b	0.999 c
Top	1.050 a	1.034 a	1.069 a	1.064 a

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 5. Height (average of bed and furrow) differences by position between treatments revealed by analysis of variance.

Position	Top (P = 0.2035)	Middle (P = 0.5533)	Bottom (P = 0.1212)
Split	3.642 a‡	3.617 a	3.867 a
ESN†	3.667 a	3.542 a	3.800 a
UAN	3.675 a	3.625 a	3.667 a
Full	3.592 a	3.567 a	3.758 a

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

‡ Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 6. Height (average of bed and furrow) differences between positions blocked by treatment (P < 0.0001) revealed by analysis of variance.

Position	Top	Middle	Bottom
Height	3.644 b†	3.587 b	3.773 a

† Means within a column followed by different letters are significantly different at P = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 7. Height differences by position within treatments revealed by analysis of variance.

Position	ESN† ($P = 0.0130$)	Split ($P = 0.0242$)	Full ($P = 0.0017$)	UAN ($P = 0.7674$)
Bottom	3.800 a‡	3.867 a	3.758 a	3.667 a
Middle	3.542 b	3.617 b	3.567 b	3.625 a
Top	3.667 ab	3.642 b	3.592 b	3.675 a

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

‡ Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 8. Heading notes taken on 8 August 2017 for all rice plots.

Treatment	Percent headed	Heading stage
101: ESN†	70% headed	R5 to R6 Stage (milk)
102: Split	50-60% headed	R5 to R6 Stage (milk)
103: Full	80% headed	R5 to R6 Stage (milk)
104: UAN	60% headed	R5 to R6 Stage (milk)
201: Split	50% headed	R5 to R6 Stage (milk)
202: Full	70-80% headed	R6 Stage (milk)
203: ESN	70% headed	R6 Stage (milk)
204: UAN	40-50% headed	R5 to R6 Stage (milk)
301: ESN	70-80% headed	R5 to R6 (milk)
302: UAN	55-60% headed	R5 to R6 Stage (milk)
303: Split	50-60% headed	R6 Stage (milk)
304: Full	70% headed	R6 Stage (milk)

† ESN = Environmentally Safe Nitrogen; UAN = urea ammonium nitrate.

Evaluating Performance of Different Rice Cultivars in a Furrow-Irrigated Rice Field in 2017

V. Kandpal[1] and C.G. Henry[2]

Abstract

A study was conducted to evaluate the performance of pure-line (conventional) and hybrid rice cultivars in a furrow-irrigated rice field during the growing season of 2017 at University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart, Ark. on a De-Witt silt loam. A total of 9 rice cultivars were studies of which 5 were hybrid and 4 were conventional rice cultivars. Results indicated that the yields of all hybrid rice cultivars were significantly better than the conventional rice cultivars. The highest yield was obtained from XP753 of 189 bu/acre. The average yield from all hybrid rice cultivars was calculated as 174 bu/acre while 130 bu/acre was calculated for conventional rice cultivars. Height of plants at the bottom of the field was significantly higher than those at the top and middle position along the furrow length and no difference in plant heights were seen for plants in the furrow and on the bed. The total water consumed by the crop was 11 acre-inches and total rainfall received was 9 acre-inches.

Introduction

Water is essential to support almost every process in a plant and availability of water can affect the yield of agricultural crops. Irrigation is a method to provide water to plants in conditions where rainfall is not adequate (Kramer and Boyer, 1995). Globally, 20% of the total cultivated area is under irrigation, although 40% of total food is produced from it (Schoengold and Zilberman, 2004). Clearly, the value of one acre of irrigated land is multiple times greater than an acre of rain-fed agricultural land (Schoengold and Zilberman, 2004; Foster and Cota, 2014). Statistics by United Nations have shown that the 7.2 billion population of the world in 2015 is likely to increase to 8.3 billion in 2030 and can go as high as 9.3 billion in 2050. World food demand has been increasing in all of these years and will continue to increase in the future. Higher yields from existing agricultural lands are possible if adequate irrigation is applied. However, the depletion

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of water resources can be a major factor in preventing the expansion of irrigation in some parts of the world like South Asia (FAO-UN, 2002). The U.S. Environmental Protection Agency in 2008 estimated that in the previous 5 years, almost every region of the United States has experienced water shortages (USEPA, 2008). In the United States, groundwater consumption has more than doubled from 1950 to 1975 (Hutson, 2004). The Lower Mississippi River Valley has always been blessed with abundant and less expensive water (Vories et al., 2002). However, the water from the alluvial aquifer has been used from a long period of time for irrigation which has resulted in a decrease in the groundwater level throughout the embayment area in Arkansas, Louisiana, Mississippi and Tennessee. However, Arkansas has been affected the most by the groundwater storage loss in the Mississippi River Valley alluvial aquifer (Konikow, 2013). Upholt (2015) estimated that the water level in the Mississippi River Alluvial Aquifer has declined by 1 to 1.5 ft/year over the past four decades.

In 2013, 7.3% of the total water used by the U.S. was consumed by Arkansas and 85% of the total water used on agricultural land in Arkansas was obtained from groundwater. The most common system of irrigation for rice in Arkansas is flood (Vories et al., 2002) and it utilizes about 24 to 32 acre-in. of water in one growing season (Henry et al., 2013). Some other irrigation methods like the alternate wetting and drying and furrow irrigation has started to gain interest in Arkansas; however, the percentage is very small (Hardke, 2017). Other than the water-saving benefits, there are other advantages associated with growing furrow-irrigated rice such as savings in levee construction and removal, easier access to the field during harvesting (Vories et al., 2002; Stephenson et al., 2008) and reduction in greenhouse gas emissions (Adhya et al., 2014). Also due to quick drying of the field, it is easier to use ground equipment for operations like fertilization and chemical treatments which can significantly reduce the total production cost. However, furrow-irrigated rice comes with a disadvantage of reduction in yield in comparison to flood irrigated rice (Vories et al., 2002; Tracy et al., 1993; Singh et al., 2006) and further research on the performance of different rice cultivars is needed. This research was conducted to study performance of different commonly grown conventional and hybrid rice cultivars in a furrow-irrigated production system.

Procedures

To evaluate the yield of different rice cultivars in a furrow-irrigated rice field, a study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. in 2017 on a Dewitt silt loam. The experimental plot for this year utilized shallow 30 in.-beds and was conducted in the same field used to grow furrow-irrigated rice in 2016. There were 9 rice cultivars which were planted this year using a Great Plains 1500 drill at a row-spacing of 7.5 in across the raised beds and furrows in a randomized complete block design with 3 replications. Out of 9 rice cultivars 4 were conventional; (i.e., Jupiter, Diamond, CL172 and CL153) and drill-seeded at 10% over the Extension recommended seeding rate for the specific cultivar, or around 73 lb/acre while the other 5 cultivars were hybrid; RT XP753, RT 7311 CL, RT XP4534 CL, RT XP754 and Gemini; and were drill seeded at 10% over the Cooperative Extension Service (CES) recommended seeding rate or around 27 lb/acre. The experimental plots were 30 ft by 1200 ft in size and each plot consisted of 12 beds and 12 furrows (11 plus two half furrows). Thirty foot wide buffer strips of XL Jupiter were also planted on the field borders and between replicate blocks. The planting was completed between 11 May and 18 May 2017.

Three herbicide treatments were done this year (7, 33 and 62 days from the planting day). The first treatment was done with Command and League, the second treatment with Facet, Stam, Permit Plus and COC and the third with Clincher and RebelX. One application of MustangMaxx was applied for stinkbugs on 23 August. The nitrogen (N) fertilizer was applied as urea at a rate of 150 lb N/acre in a two-way split of 75 lb N/acre on day 34 and 75 lb N/acre on day 50 after planting. The irrigation timings, irrigation technique, volume of water, and applications of fertilizer, herbicides and pesticides applications were same for all the plots.

A 12-inch diameter PVC (Poly-Vinyl Chloride by Delta Plastics®) pipe was used for irrigating the furrows. Each hole, of a diameter of 3/8 in., was punched for each furrow. The appropriate diameter of the holes was determined using Pipe Planner. The irrigation technique used to furrow-irrigate the field was tail-water recovery irrigation. A total of 11 acre-in. of water was applied from the source, 9 acre-in. of rainfall was received, 15 acre-in. was recirculated during the irrigation period and 7 acre-in. of water was lost as runoff which includes runoff from high rainfall events. Flow was monitored with Mccrometer propeller meters (Helmuth, Calif.) for both the inflow to the plots and outflow (if any) from the field. All flow volumes were recorded by manual readings before and after events.

The middle 20 feet (16 rows of rice) of each plot was harvested using a 1620 Case International Combine (CNH Industrial, London, U.K.) between 14 Sept. and 22 Sept. 2017. The weight of the harvested rice from each plot was obtained from a weigh-wagon and grain-moisture percent from each plot was obtained from "DICKEY-john GAC2100" grain analysis computer the same day they were cut. Length of harvested plot, harvest weight, and plant heights were recorded at the time of harvest. The harvest weights were corrected with a 12% moisture correction using the measured grain moisture from each plot.

Analysis of variance (ANOVA) was performed using JMP Pro. Differences within varieties were analyzed for crop yield and water use efficiency. Differences in plant heights at different positions along the furrow length were analyzed within the cultivars. An ANOVA for randomized block design was performed to find any differences between plant heights along different positions by using cultivars as block. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference test at 5% probability.

Results and Discussion

Soil matric potential trends (Fig. 1) show that twice during the irrigation season soil tension exceeded the field capacity (39 centi-bars) for several extended periods in spite of continuous irrigation events throughout the season. In the mid-season, an extended period of high moisture tension readings was observed. In between that period there were two irrigation events when the water was drained from the field and the field was allowed to dry for a couple of hours which resulted in the sealing up of the topmost layer of the soil. There was another period during the end of August when soil moisture readings increased rapidly. This was the period when low inflow rate was being applied and no irrigation was applied at night to the field. While there were high soil tension levels, no stress was observed in the plants in the field. At harvest, no visual differences in rice height as well as color were observed between the row and bed as is typical in furrow-irrigated rice that has experienced stress. While often the top of the bed was dry, saturated soil in the furrows appeared to be providing water to the bed and visually one could not detect any visual stress difference between a bed plant and a furrow plant. This observation was different from what researchers experienced in 2016.

In spite of a few problems in water management in the field, improved yields of hybrid crops were observed when compared to 2016. The best yield of 189 bu/acre was observed for the hybrid XP753 while an average yield of 174 bu/acre was observed for all hybrid rice cultivars (Table 1). The lowest yield of 123 bu/acre was measured for the conventional cultivar, CL172, while an average yield of 130 bu/acre was observed for all conventional rice cultivars. A significant difference in yields between conventional and hybrid rice cultivars was measured. Yields of all hybrid cultivars were not significantly different from each other and similarly that of conventional rice cultivars were not significantly different from each other. The yield of only one conventional rice cultivar, Jupiter (142 bu/acre), was not different from that of one hybrid rice cultivar, XP754 (157 bu/ac). Similar outcomes were detected for water use efficiency values. It should be noted that the field was in its second year of continuous rice production and the planting date was very late relative to the area. Thus yields are likely not representative of what farmers would expect to obtain in a rice-soybean rotation with an earlier planting date. Higher conventional yields would be expected with an earlier planting date.

No effect of plant position on the beds and in the furrows was detected on plant heights when averaged over cultivars. Also, no differences in plant heights in the furrow and on the bed within the cultivars were seen when blocked by position along the furrow length. Plant heights were not influenced by their position on the bed or in the furrow; however, their position along the furrow length (Top/Middle/Bottom, where Top is the top one-third furrow length, Middle is the middle one-third furrow length and Bottom is the bottom one-third furrow length) had a significant effect on plant heights. Plants at the bottom were the tallest; however, no significant differences were seen between the plant heights at the middle and top positions (Table 2). For plant height differences within cultivars, 8 out of the 9 rice cultivars were influenced by their position along the furrow length (Table 3). Plants at the top of the field were always the shortest.

Heading notes were taken on 12 August 2017. In general, most of the hybrid cultivars were headed anywhere between 60% and 90% and the conventional cultivars were headed between 0 and 60% (Table 4).

Significance of Findings

The research has indicated that hybrid rice cultivars have more potential of improving yield in a furrow-irrigated system than conventional rice cultivars. Water use in rice production can be substantially reduced by growing rice in a furrow-irrigated system; however, monitoring of soil moisture readings is needed to identify when high water demand is occurring.

Acknowledgments

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Literature Cited

Adhya, T. K., B. Linquist, T. Searchinger, R. Wassmann, and X. Yan. 2014. Wetting and drying: reducing greenhouse gas emissions and saving water from rice production. Working Paper, Installment 8 of Creating a Sustainable Food Future. World Resources Institute Washington, D.C.

FAO-UN. 2002. Food and Agriculture Organization of the United Nations. World agriculture towards 2015/2030: Summary report. Rome.

Foster, R. and A. Cota. 2014. Solar water pumping advances and comparative economics. Energy Procedia, 57:1431-1436.

Hardke, J.T. 2017. Trends in Arkansas rice production, 2016. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 634:13-23. Fayetteville.

Henry, C.G., M. Daniels, and J. Hardke. 2013. Water Management. *In*: ed. J.T. Hardke, Arkansas Rice Production Handbook. University of Arkansas Division of Agriculture, Cooperative Extension Service. Little Rock, Ark. MP192-2M-11-13RV.

Hutson, S.S. 2004. Estimated use of water in the United States in 2000 (No. 1268). Geological Survey (United States Geological Survey). Accessed 7 January 2018. Available at: http://pubs.usgs.gov/circ/2004/circ1268/

Konikow, L. 2013. Groundwater depletion in the United States (1900–2008). United States Geological Survey Scientific Investigations Report 2013–5079, 63 pp. Accessed 7 January 2018. Available at: http://pubs.usgs.gov/sir/2013/5079/

Kramer, P.J. and J.S. Boyer. 1995. Water relations of plants and soils. San Diego, Calif.: Academic Press.

Schoengold, K., and D. Zilberman. 2004. Water and development: the importance of irrigation in developing countries. Presentation, Berkeley.[Online]. Accessed 16 January 2018. Available at: http://are.berkeley.edu/courses/ARE253/2004/handouts/Bretton_Woods. pdf

Singh, S., L. Bhushan, J.K. Ladha, R.K. Gupta, A.N. Rao, and B. Sivaprasad. 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow-irrigated raised-bed planting system. Crop Protection, 25(5):487-495.

Stephenson IV, D.O., C.E. Wilson Jr, P. Tacker, and S.W. Lancaster. 2008. Determining the potential of furrow-irrigated rice using a 3-and 5-day irrigation schedule in a rice-production system. Rice Research Studies–2007. Series, 560:220-227.

Tracy, P. W., B.D. Sims, S.G. Hefner, and J.P. Cairns. 1993. Guidelines for producing rice using furrow irrigation. Extension publications (MU).

Upholt, B. 2015. An interstate battle for groundwater. The Atlantic. Accessed 7 January 2018. Available at: http://www.theatlantic.com/science/archive/2015/12/mississippi-memphis-tennesee-groundwater-aquifer/418809/.

USEPA. 2008. United States Environmental Protection Agency. Water supply and use in the United States.

Vories, E., P. Counce, and T. Keisling. 2002. Comparison of flooded and furrow-irrigated rice on clay. Irrigation Science, 21(3):139-144.

Table 1. Yield differences between cultivar ($P < 0.0001$) and water use efficiency (WUE) differences between cultivar ($P < 0.0001$) revealed by analysis of variance.

Cultivar	Yield	WUE
	(bu/acre)	(bu/acre-in.)
RT XP753	189 a†	9.96 a
RT XP4534	177 a	9.34 a
Gemini	174 a	9.14 a
RT 7311 CL	172 a	9.08 a
RT XP754	157 ab	8.28 ab
Jupiter	142 b	7.48 b
Diamond	133 b	6.99 b
CL153	124 b	6.54 b
CL172	123 b	6.49 b

† Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 2. Plant height differences between position along furrow length ($P < 0.0001$) revealed by analysis of variance blocked by cultivar.

Plant position along furrow length	Plant height (ft)
Bottom	3.46 a†
Middle	3.21 b
Top	3.14 b

† Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 3. Plant height differences by position within cultivar revealed by analysis of variance.

Position	CL153 ($P = 0.0012$)	CL172 ($P = 0.1262$)	RT 7311 CL ($P = 0.0066$)	Diamond ($P = 0.0463$)	Gemini ($P = 0.0014$)	Jupiter ($P = 0.0173$)	RT XP753 ($P = 0.0007$)	RT XP4534 ($P < 0.0001$)	RT XP754 ($P = 0.0257$)
Bottom	3.17 a†	2.85 a	3.82 a	3.39 a	4.10 a	3.05 a	3.79 a	3.27 a	3.67 a
Middle	2.96 b	2.68 a	3.49 b	3.39 a	3.66 b	3.03 a	3.48 b	2.87 b	3.32 b
Top	2.77 b	2.66 a	3.54 b	3.17 b	3.75 b	2.9 b	3.47 b	2.82 b	3.19 b

† Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 4. Heading notes taken on 12 August 2017 for all rice plots.

	% headed			Heading stage		
Cultivar	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
RT XP754	20	5	0-5	R5	R2	R2
RT 7311 CL	80	60	10-20 (grassy)	R6	R5-R6	R4
CL172	30	30-40 (grassy)	40 (grassy)	R4-R5	R4	R5
Jupiter	10	0 (grassy)	2	R4	R3-R4	R3
CL153	60-70	60	50	R5	R5	R5
RT XP4534	70	75	70	R5-R6	R6-R7	R6-R7
RT XP753	80-90	85	70-80	R5	R6	R6
Diamond	5-10	10	5	R4	R4	R3-R4
Gemini	30	40	10-20	R5	R6	R4

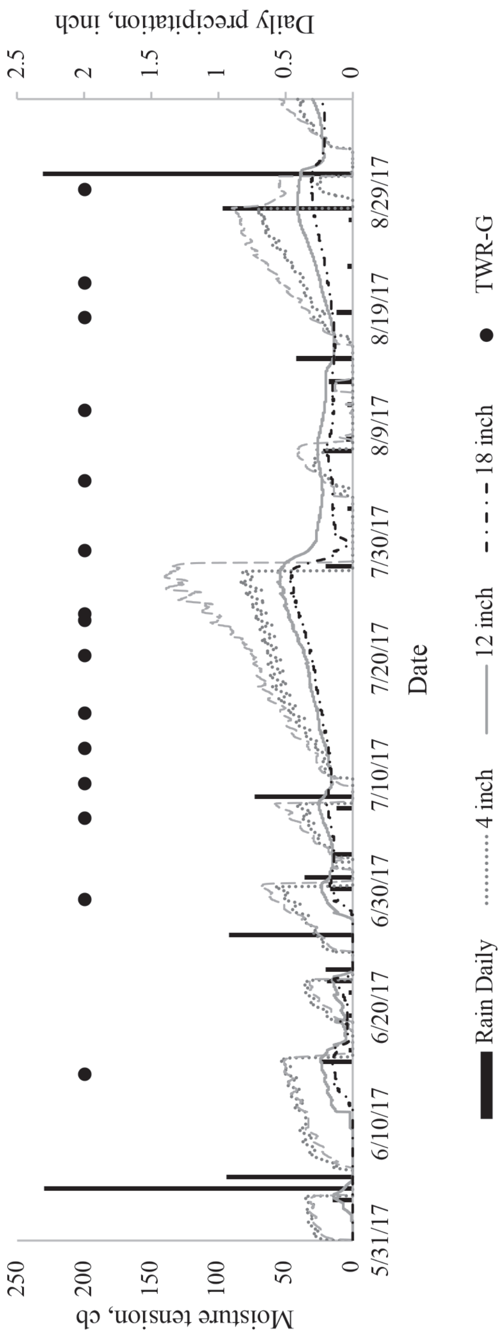

Fig. 1. Soil moisture tension curve with daily rain and irrigation events data.

Evaluating Performance of Different Rice Cultivars and Irrigation Efficiencies in a Furrow-Irrigated Rice Field in 2016

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(editor's note: this paper was inadvertently omitted from last year's report)

Abstract

A study was done to evaluate performance of both conventional (pure-line) and hybrid rice cultivars in a furrow-irrigated rice field during the growing season of 2016 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. on a DeWitt silt loam. Yields for all 5 hybrid rice cultivars were better than conventional rice cultivars; however, Jupiter was observed to have a similar yield compared to some hybrid rice cultivars. No influence of plant position at the bed or furrow was observed on plant heights. Plants positioned in the bottom one-third plot along the furrow length were taller followed by those at middle and bottom one-third plot portion of the field, respectively. Differences in plant heights within 4 rice cultivars were observed for plant positions along the furrow length. Water use efficiencies (WUE) were affected by rice cultivar in the same way the yield was affected; hybrids had better WUE compared to conventional cultivars.

Introduction

Water is essential to support "biological life, natural processes, communities, economy, society, and future generation" (Arnold, 2009). Water scarcity is one of the most important issues in the United States (Arnold et al., 2009). The U.S. Environmental Protection Agency in 2008 estimated that in the previous 5 years, almost every region of the country has come across water shortages (USEPA, 2008). Some of the reasons for the decrease in water supplies are groundwater depletion, drying of streams, water pollution and drought conditions triggered by climate change (Arnold, 2009).

Groundwater consumption has more than doubled from 1950 to 1975 in the United States (Hutson, 2004). In the Mississippi embayment area, the Mississippi River Valley alluvial aquifer forms the largest aquifer unit (Clark and Hart, 2009). The water from the alluvial aquifer has been used for a long period of time for irrigation which

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has resulted in a decrease in the groundwater level throughout the embayment area in Arkansas, Louisiana, Mississippi and Tennessee. However, Arkansas has been affected the most by the groundwater storage loss in the Mississippi River Valley alluvial aquifer (Konikow, 2013). Upholt (2015) estimated that the water level in the Mississippi River Alluvial Aquifer is declining by 1 to 1.5 feet/year over the past four decades.

Pugh and Holland (2015) estimated that in Arkansas, 85% of the total agricultural irrigation water use came from groundwater sources and that irrigation water use is responsible for 95% of all water withdrawn from Arkansas' groundwater sources. Rice is the most important staple food in the world which is consumed by almost 3 billion people worldwide (Mosleh et al., 2015). In 2012, Arkansas was the largest producer of rice and the third largest state in terms of irrigated acreage in the United States (Vilsack and Clark, 2014). In 2015, Arkansas produced 49% of total rice production in the U.S. (USDA-ERS, 2016). In 2010, rice production accounted for 51% of the total irrigation water applied, even though it only accounts for 36% of the total irrigated cropland in Arkansas (Pugh and Holland, 2015). Needless to say, rice production has a profound impact on groundwater sources. Due to the strong global demand for rice production and the resulting strain on already depleting aquifers, it is important to investigate methods and technologies in efforts to conserve water as well as to increase crop production.

Flood irrigation is typically the most common method for irrigating rice; however, other water saving methods are being adopted including furrow irrigation (Vories et al, 2002), alternate wetting and drying (Yamaguchi et al., 2016), and center pivot (Vories et al, 2013). In comparison to sprinkler systems, furrow irrigation methods generally saturate the soil and are, therefore, considered to work similar to a flooded field (Vories et al., 2002). Some benefits of furrow irrigation include energy and water savings, savings by avoiding levee construction, removal and regrading as well as quick soil drying giving easier/faster access to the field during harvesting (Vories et al., 2002; Stephenson et al., 2008). Another advantage is the reduction in greenhouse gas emissions due to an aerobic environment (Adhya et al., 2014), resulting from furrow-irrigated rice production practices. Reduction in yields from furrow-irrigated rice production systems have been reported (Vories et al., 2002 and Tracy et al., 1993; Singh et al., 2006) indicating needs to further improve this potential water saving production method to facilitate adoption. Furthermore, little is known about how various rice cultivars perform in a furrow rice production system.

Given the possible, logistical, monetary, and environmental advantages of furrow-irrigated rice production methods, investigations into application and management of these practices are needed. This study is a part of a larger ongoing study with the goal of improving furrow rice irrigation management practices. The goal of this study is to compare the performance of several commonly grown hybrid and conventional rice cultivars in a furrow-irrigated production system.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, near Stuttgart, Ark. in 2016. Due to the presence of a compaction layer, prior to the bed construction, a 32-acre field was deep tilled to a depth of 18 inches perpendicular to the slope of the field with a 5-shank no-till soil management system ripper (John Deere, Moline, Ill.). The soil in the field is predominately a DeWitt silt loam which was identified using Web-Soil (USDA-NRCS, 2016). Raised beds were constructed on a 30-inch spacing. Eleven rice cultivars (6 conventional and 5 hybrid) were direct seeded with a Great Plains 1500 drill with 7.5-inch row spacing across the raised beds and furrows in a randomized complete block design with three replications. Conventional rice cultivars; Titan, Francis, Jupiter, Diamond, Mermentau and 1099; were seeded at 72 lb/acre while hybrid rice cultivars; RT 4523, RT XP753, RT XL729, RT XL745 CL and RT XP756; were seeded at 30 lb/acre. Plots were 30 foot and consisted of 12 beds and 12 furrows (11 plus two half furrows). Thirty foot wide buffer strips of RT XL 729 were also planted on the field borders and between replicate blocks.

The field was furrow-irrigated; however, there were three different techniques of furrow irrigation which were performed throughout the growing season as a part of an investigation assessing the irrigation efficiency of these furrow irrigation methods. These methods included continuous flow furrow irrigation, surge irrigation, and tail-water recirculation. The irrigation timings, irrigation technique, volume of water, and applications of fertilizer, herbicides and pesticides applications were the same in the whole field. Nineteen inches of irrigation water, 11 inches of rain water and 5 inches of tail water was applied to the field. Flow was monitored with McCrometer propeller meters (Helmuth, Calif.) for the inflow supply. Drains in the fields were directed to two drains where runoff could be measured. These drain pipes were fitted with propeller meters and elbows to ensure full pipe flow. All flow volumes were recorded by manual readings before and after events. Irrigation efficiency was calculated by subtracting the tailwater volume from the volume of water applied to the field and dividing it by the water applied to the field times 100.

Irrigation management was done using soil moisture sensors, specifically an Aquatrac (AgSense, Huron, S.D.) and Watermark™ Sensors (Irrometer, Riverside, Calif.) and supplemented with visual observation. A threshold of 40 centibars (cb) was used as an irrigation trigger based on experience and soil water retention data for the soil type in the study. Researchers had difficulty maintaining soil tension less than 40 cb during some of the season, even though frequent irrigations were applied.

The field was planted on 13 May 2016 which was followed shortly by application of diammonium phosphate and zinc. Facet and Command were applied 20 days after planting according to labeled rates. Two applications of urea with Agrotain were applied on 9 June and 23 June and one application of Ravage (Innvictis, Loveland, Colo.) was applied on 13 August 2016. The middle 20 feet of length and 16 middle rows out of 32 rows of each rice cultivar plot was harvested using a 1620 Case International Combine (CNH Industrial, London, U.K.) between 16 Sept. and 17 Sept. 2016. The harvested rice was weighed in a weigh-wagon to obtain weight. A total of 33 rice plots (11 rice cultivars in 3 replications) were harvested. Harvest weight, grain moisture, and plant heights were recorded at the time of harvest. The harvest weights were corrected with a 12% moisture correction using the measured grain moisture from each plot.

Analysis of variance (ANOVA) was performed using JMP Pro. Within cultivar differences were analyzed for crop yield and water use efficiency. Differences in plant heights at different positions along the furrow length were analyzed within the cultivars.

An ANOVA for randomized block design was performed to find any differences between plant heights along different positions by using cultivars as a block. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's test at 5% probability.

Results and Discussion

Irrigation type and rain effect on soil moisture tension at four different depths, averaged across 15 locations are reported in Fig. 1. There was a significant interaction effect of cultivar on yield ($P < 0.0001$) (Table 1). Yields for hybrid rice cultivars were greater than the conventional rice cultivars, in general. The best yield of 168.5 bu/acre was observed for XP753 and the lowest study yield of 96.8 bu/acre was observed for 1099. Hybrid cultivars were not significantly different from each other and similarly conventional rice cultivars were not significantly different from each other. Yield of only one conventional rice cultivar, Jupiter (126.4 bu/acre), was not different from that of three hybrid rice cultivars (RT XP756, RT 4523 and RT XL745 CL). Water use efficiencies were calculated by dividing yield by total applied irrigation water. Cultivars had a similar effect on water use efficiencies as they had on crop yield (Table 1).

Soil matric potential trends (Fig. 1) show that several times during the irrigation season, soil tension exceeded field capacity (39 cb) for several extended periods. The 12-inch sensor was near 0 cb indicating well-saturated conditions from planting until 4 July, then it rose to around 20 cb for the remainder of the season, indicating a dryer condition in the surface profile. Between 16 July and 24 July, the 4-inch and 6-inch sensors showed high tension, during this time irrigation was taking place very frequently or nearly every day (only one dot is shown indicating the initiation of the event); however tension continued to increase. After a few days, a higher flow rate and a longer set time were used and the soil tension fell into the field capacity and saturated zone. This indicates that crop water demand may not have been met or a higher flow rate was needed to overcome sealing (crusting). We believe these irrigation shortcomings in furrow irrigation may help explain why furrow-irrigated rice does not generate the same yields as flooded rice. Thus, additional work is warranted to overcome these issues in furrow irrigation to maintain lower soil water thresholds for rice in this production system.

Irrigation efficiencies of three different practices resulted in some differences in irrigation efficiency (Table 2). Irrigation efficiencies for continuous flow furrow irrigation ranged from 47% to 83%, 34% to 88% for surge irrigation and 81% to 99% for tailwater recovery irrigation. In general, irrigation efficiency started out high earlier in the season irrespective of the method used, for example 83% for the first irrigation for continuous flow irrigation. However as the season progressed and soil sealing increased and water demand increased, efficiencies for continuous flow and surge decreased to 47% and 34%. However, tailwater recovery remained highly efficient even at the end of the season (93%). This data suggests that as the growing season progresses, irrigation efficiencies are reducing the water supplied to the rice plants at the time in the season when plant water demand is highest. This corresponds with sensor trends and suggests that monitoring of soil moisture and taking steps to improve irrigation efficiency later in the season is needed to improve water delivery to furrow-irrigated rice.

Plant heights were not influenced by their position on bed or furrow; however, their position along the furrow length (Top/Middle/Bottom, where Top is top one-third furrow length, Middle is middle one-third furrow length and Bottom is bottom one-third furrow length) had a significant effect on plant heights (Table 3). Plants at Bottom were the tallest followed by those at Middle and Top positions, respectively ($\alpha = 0.05$). Plant heights were analyzed to study differences within cultivars. Four out of eleven rice cultivar's plant heights were influenced by their positions along the furrow length (Table 4).

Heading notes were taken on 18 Aug. 2016. It was observed that all of the hybrid rice cultivars were 100% headed and were anywhere between R6 and R9 stage (Table 5). Most of the conventional rice cultivars were not completely headed and were anywhere between R4 and R6 (milk).

Significance of Findings

The research has indicated that hybrid rice cultivars have a greater potential of improving yield in a furrow-irrigated system than conventional rice cultivars. Water use in rice production can be substantially reduced by growing rice in a furrow-irrigated system. Evidence from soil moisture monitoring and irrigation flows suggests that irrigation efficiency decreases as the season progresses, reducing delivery to rice plants when demand is the highest.

Acknowledgments

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Literature Cited

Adhya, T. K., B. Linquist, T. Searchinger, R. Wassmann, and X. Yan. 2014. Wetting and drying: reducing greenhouse gas emissions and saving water from rice production. Working Paper, Installment 8 of Creating a Sustainable Food Future. World Resources Institute Washington, D.C.

Arnold, C.A. (Tony). 2009. Water Privatization Trends in the United States: Human Rights, National Security and Public Stewardship. William and Mary Environmental Law and Policy Review, 33:785

Arnold, C.A., C. Norton, and D. Wallen. 2009. A Handbook on Land Use and Water for Kentucky Communities. Kentucky Wet Growth Handbook. Louisville: University of Louisville.

Clark, B.R. and R.M. Hart. 2009. The Mississippi Embayment Regional Aquifer Study (MERAS): Documentation of a groundwater-flow model constructed to assess water availability in the Mississippi Embayment (No. 2009-5172). US Geological Survey. Retrieved from http://pubs.usgs.gov/sir/2009/5172/ on 2/1/2017

Hutson, S.S. 2004. Estimated use of water in the United States in 2000 (No. 1268). Geological Survey (United States Geological Survey). Retrieved from http://pubs.usgs.gov/circ/2004/circ1268/ on 2/1/2017

Konikow, L. 2013. Groundwater depletion in the United States (1900–2008). United States Geological Survey Scientific Investigations Report 2013–5079.

Mosleh, M.K., Q.K. Hassan, and E.H. Chowdhury. 2015. Application of remote sensors in mapping rice area and forecasting its production: A review. Sensors, 15(1):769-791.

Pugh, A.L. and T.W. Holland. 2015. Estimated water use in Arkansas, 2010: U.S. Geological Survey Scientific Investigations Report 2015–5062

Singh, S., L. Bhushan, J.K. Ladha, R.K. Gupta, A.N. Rao, and B. Sivaprasad. 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow-irrigated raised-bed planting system. Crop Protection, 25(5), 487-495.

Stephenson IV, D.O., C.E. Wilson Jr., P. Tacker, and S.W. Lancaster. 2008. Determining the potential of furrow-irrigated rice using a 3-and 5-day irrigation schedule in a rice-production system. Rice Research Studies–2007. Series, 560:220-227.

Tracy, P. W., B.D. Sims, S.G. Hefner, and J.P. Cairns. 1993. Guidelines for producing rice using furrow irrigation. Extension publications (MU).

Upholt, B. 2015. An interstate battle for groundwater. The Atlantic. Retrieved from http://www.theatlantic.com/science/archive/2015/12/mississippi-memphis-tennesee-groundwater-aquifer/418809/ on 2/1/2017.

USDA-NRCS. United States Department of Agriculture Natural Resources Conservation Service. 2016. Web Soil Survey. Retrieved from https://websoilsurvey.sc.egov.usda.gov/ on 2/07/2017

USDA-ERS. 2016. United States Department of Agriculture Economic Research Service. Rice Yearbook 2016. Retrieved from https://www.ers.usda.gov/data-products/rice-yearbook/ on 2/1/2017

USEPA. 2008. United States Environmental Protection Agency. Water supply and use in the United States.

Vilsack, V. and C.Z.F. Clark. 2014. 2012 Census of Agriculture. United States Summary and State Data. United States Department of Agriculture. Geographic Area Series, 1:332-443.

Vories, E., P. Counce, and T. Keisling. 2002. Comparison of flooded and furrow-irrigated rice on clay. Irrigation Science, 21(3):139-144.

Vories, E.D., W.E. Stevens, P.L. Tacker, T.W. Griffin, and P.A. Counce. 2013. Rice production with center pivot irrigation. Applied Engineering in Agriculture, 29(1), 51-60.

Yamaguchi, T., M.T. Luu, K. Minamikawa, and S. Yokoyama. 2016. Alternate Wetting and Drying (AWD) Irrigation Technology Uptake in Rice Paddies of the Mekong Delta, Vietnam: Relationship between Local Conditions and the Practiced Technology, 15(2), 234-256.

Table 1. Yield differences between cultivar (*P* < 0.0001) and water use efficiency differences between cultivar (*P* < 0.0001) revealed by analysis of variance.

Cultivar	Yield (bu/acre)	WUE† (bu/acre-in.)
RT XP753	168.5 a‡	5.6 a‡
RT XL729	164.7 a	5.5 a
RT XP756	159.4 ab	5.3 ab
RT 4523	159.4 ab	5.3 ab
RT XL745	154.4 ab	5.1 ab
Jupiter	126.4 bc	4.2 bc
Mermentau	116.2 c	3.9 c
Diamond	108.4 c	3.6 c
Francis	103.7 c	3.5 c
Titan	99.2 c	3.3 c
1099	96.8 c	3.2 c

† WUE = water use efficiency.
‡ Means within a column followed by different letters are significantly different at *P* = 0.05 level. Tukey's honestly significant difference method was used for mean comparison.

Table 2. Irrigation method and efficiency.

Irrigation method	Date	Irrigation efficiency (%)
Continuous flow	6/10/2016	83
Continuous flow (terminated too early)	6/19/2016	97
Continuous flow	6/26/2016	82
Continuous flow	8/2/2016	47
Surge	6/29/2016	96
Surge	7/7/2016	82
Surge	9/1/2016	34
TWR	7/14/2016	99
TWR	8/5/2016	81
TWR	8/11/2016	92
TWR	8/28/2016	93.3

Table 3. Plant height differences between position along furrow length ($P < 0.0001$) revealed by analysis of variance blocked by cultivar.

Plant position along furrow length	Plant height (ft)
Bottom	3.55 a†
Top	3.44 b
Middle	3.36 c

† Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 4. Plant height differences by position within cultivar revealed by analysis of variance.

Position	RT XL729 ($P = 0.0006$)	RT XL745 ($P = 0.0135$)	RT XP756 ($P = 0.0325$)	RT XP753 ($P = 0.0674$)	Francis ($P = 0.2040$)	
Bottom	4.24 a†	4.06 a	3.91 a	3.98 a	3.49 a	
Middle	3.78 b	3.85 b	3.66 b	3.62 a	3.32 a	
Top	3.95 b	3.91 ab	3.86 ab	3.74 a	3.34 a	
	1099 ($P = 0.6415$)	Diamond ($P = 0.0102$)	RT 4523 ($P = 0.2210$)	Mermentau ($P = 0.3115$)	Jupiter ($P = 0.1038$)	Titan ($P = 0.2273$)
Bottom	3.40 a	3.44 a	3.29 a	3.29 a	3.11 a	2.86 a
Middle	3.37 a	3.15 b	3.11 a	3.21 a	3.04 a	2.87 a
Top	3.34 a	3.35 ab	3.31 a	3.18 a	2.88 a	2.94 a

† Means within a column followed by different letters are significantly different at $P = 0.05$ level. Tukey's honestly significant difference method was used for mean comparison.

Table 5. Heading notes taken on 18 August 2016 for all rice plots.

Cultivar	% headed	Heading stage
RT XL729	100	R6 Stage (milk to soft dough)
RT XP753	100	R6 Stage (milk to soft dough)
1099	100	R6 Stage (milk to soft dough)
RT XL745	10	R6 (milk)
RT XP756	50	R4 to R5
RT 4523	100	R8 to R9
Diamond	90	R5
Jupiter	80	R5
Mermentau	100	R5 to R6 (milk)
Titan	90	R6 (milk)
Francis	100	R6 (milk)

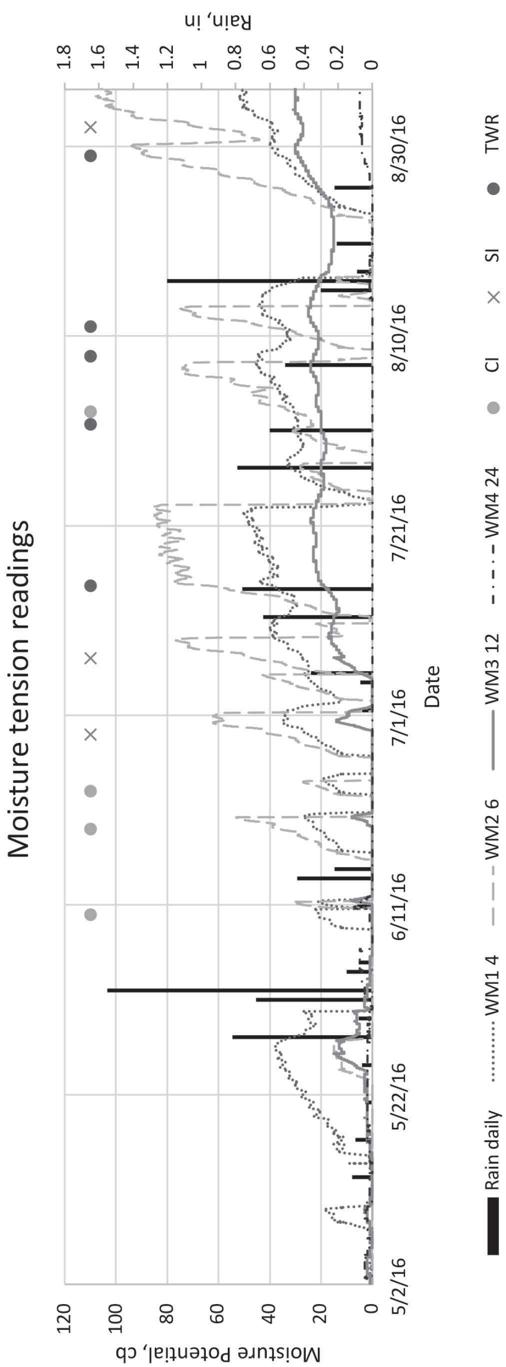

Fig. 1. Soil moisture tension rain and irrigation events. Continuous flow irrigation (CI), Surge irrigation (SI), and Tailwater recovery (TWR). ND = not determined.

Starter Nitrogen Source and Preflood Nitrogen Rate Effects on Rice Grown on Clayey Soils

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Abstract

Farmers often apply 'starter' fertilizer nitrogen shortly after rice emergence to stimulate seedling growth. Our research objective was to examine the effects of starter-N source and preflood-N rate on the grain yield of rice grown on clayey-textured soils. Research was conducted on a Sharkey/Desha clay at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Arkansas and on a Commerce silty clay at the Mississippi State University Delta Research and Extension Center (DREC) in Mississippi. Four starter-N sources including no N, ammonium sulfate, diammonium phosphate, and urea treated with N-(n-butyl) thiophosphoric triamide were applied at 21 lb N/acre at the two-leaf stage in combination with five preflood-N rates (0, 50, 100, 150, 200 lb N/acre) applied to five-leaf rice. Two cultivars, CL153 and Rice Tec XL745 CL, were grown at the DREC and CL153 was grown at the RRS. Aboveground N uptake by RT XL745 CL was affected only by preflood-N rate and uptake increased as preflood-N rate increased. The fertilizer-N recovery efficiency of rice receiving no starter-N ranged from 51% to 61%. Grain yields of CL153 and RT XL745 CL at the DREC were affected by the starter-N source by preflood-N rate interaction and were generally maximized by application of 150 to 200 lb preflood-N/acre. Although significant differences among starter-N sources occasionally occurred within the preflood-N rates ranging from 50 to 200 lb preflood-N/acre, no single starter-N source consistently produced greater grain yields than another. At the RRS, grain yield increased significantly with each increase in preflood-N rate with a maximum yield of 164 bu/acre for rice fertilized with 200 lb preflood-N/acre. Based on the three trials conducted in 2017, starter-N had no influence on rice grain yield when optimal preflood-N rates were applied.

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Introduction

Nitrogen is the mineral nutrient needed in the greatest amount and, in most fields, the soil is N deficient requiring that fertilizer N be supplied to maximize rice yield potential. Seedling rice often grows very slowly on clayey soils and seedlings tend to be smaller at the five-leaf stage than rice grown on most loamy soils.

Research has shown starter-N applied to other crops can improve early-season vigor and sometimes yield. Starter-N applied at planting has been shown to increase the yields of cotton (Bednarz et al., 2000) and corn (Niehues et al., 2004). Walker et al. (2008) reported that starter-N produced a nominal but significant increase in the yield of rice grown on clayey soils in Mississippi and Louisiana. Golden et al. (2017) showed that starter-N aided rice recovery from clomazone injury and increased yield compared to clomazone injured rice that received no starter-N. The objectives of this research are to examine whether rice grown on clayey soil will respond to starter-N source and, if so, how starter-N may interact and influence rice response to preflood urea-N rate.

Procedures

Field trials were established at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) near Rohwer, Ark. on soil mapped as a Sharkey/Desha clay and the Mississippi State University Delta Research and Extension Center (DREC), in Stoneville, Miss. on a Commerce silty clay. Soybean was the previous crop grown at both locations. At the RRS, individual plots measured 6.5-ft wide and 18-ft long allowing for 9 rows of rice spaced 6 in. apart in the center of the plot area. The field was cultivated multiple times before planting. The rice cultivar CL153 was treated with NipsIt Suite [2.9 oz/hundredweight (cwt)] and AV-1011 (bird repellent, 18.3 oz/cwt) and planted at 78 lb seed/acre (Table 1). At the DREC, individual plots were 6.5-ft wide and 15-ft long and contained 8 rows spaced 8 in. apart. The field was conventionally tilled and CL153 rice treated with Cruiser Maxx was planted at 88 lb seed/acre and RT XL745 CL treated with NipsIt and gibberellic acid was drilled at 34 lb seed/acre in a separate plot area. Each experiment contained a total of 20 treatments and 4 replicates arranged in a randomized complete block design. The 20 treatments included four starter-N sources including no starter-N, ammonium sulfate (AMS), diammonium phosphate (DAP), and N-(n-butyl) thiophosphoric triamide (NBPT)-treated urea (UREA) and five preflood-N rates. The starter treatments were applied at the two-leaf stage at 21 lb N/acre. Preflood-N rates of 0, 50, 100, 150, and 200 lb N/acre were applied at the five-leaf stage with NBPT-treated urea as the N source. Following preflood urea application to a dry soil, rice was flooded within 1 to 3 days.

At early heading (~R3), plant samples were taken from a 6-ft section of one inside drill row of each plot of RT XL745 CL at the DREC (Table 1). Plant samples were oven-dried, weighed for total dry matter (lb/acre), and a subsample was combusted to determine total N concentration. The aboveground N content (lb N/acre) was calculated as the product of N content and dry matter at the R3 growth stage. Fertilizer-N recovery efficiency was calculated by the difference method, which involves subtracting N content of rice that received no starter or preflood-N from the N content of each treatment (Table

2). The middle five rows of rice were harvested with a small plot combine and grain weight was adjusted to a uniform moisture content of 12% for calculating grain yield.

Each experiment was a randomized complete block design with a 2 by 5 factorial structure that included four blocks. The analysis of variance was performed by site and cultivar using the MIXED procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with significant differences defined at the 0.05 level.

Results and Discussion

The aboveground N content at early heading in RT XL745 CL was affected only by preflood-N rate. Rice receiving no N contained 43 lb N/acre at early heading (R3 stage). Nitrogen uptake increased with each increase in preflood-N rate (69, 91, 117, and 135 lb N/acre for rice applied with 50, 100, 150, and 200 lb preflood-N/acre, respectively, LSD (0.05) = 13 lb N/acre) but starter-N source had no effect on N content. The fertilizer-N recovery efficiency for rice with no starter-N and applied preflood-N rates at 50 to 200 lb N/acre ranged from 51% to 61%.

The grain yields of CL153 and RT XL745 CL at the DREC were significant ($P < 0.05$) for the starter-N source and preflood-N rates. Although significantly different, starter-N source and preflood-N rate interactions were inconsistent among the starter-N sources. Grain yields of each cultivar were maximized by application of 150 or 200 lb N/acre (Tables 2 and 3). Starter-N source had the greatest effect when rice received no preflood-N then diminished as preflood-N rate increased.

At the RRS, grain yield of CL153 was significantly affected ($P < 0.0001$) only by preflood-N rate, averaged across starter-N sources. Grain yield increased with each increase in preflood-N rate (70, 111, 137, 151, 164 bu/acre for rice receiving 0, 50, 100, 150, 200 lb preflood-N/acre, respectively, LSD (0.05) = 7 bu/acre). Starter-N source, averaged across preflood-N rates, had no effect on CL153 yield.

Significance of Findings

The first year results suggest that starter-N source did not benefit the grain yields of CL153 or RT XL745 CL when near optimal preflood-N rates were applied on clayey-textured soils. The lack of a significant benefit from starter N was not surprising due to the low starter-N rate, the likelihood of N loss from the application timing, and the nominal benefits documented from prior research. The research will be continued in 2018 and will place special emphasis on measuring early-season vigor to document potential management benefits.

Acknowledgments

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research to be conducted at their stations. Also acknowledged is the Altheimer Lab in Fayetteville, Ark. for processing the plant samples for analysis.

Literature Cited

Bednarz, C.W., G.H. Harris, and W.D. Shurley. 2000. "Agronomic and economic analyses of cotton starter fertilizers." Agron. J. 92:766-771.

Golden, B.R., B.H. Lawrence, J.A. Bond, M.H. Edwards, and T.W. Walker. 2017. "Clomazone and starter nitrogen fertilizer effects on growth and yield of hybrid and inbred rice cultivars." Online. Weed Technology doi:10.1017/wet.2016.33.

Niehues, B.J., R.E. Lamond, C.B. Godsey, and C.J. Olsen. 2004. "Starter fertilizer management for no-till corn production." Agron. J. 96:1412-1418.

Walker, T.W., J.A. Bond, B.V. Ottis, and D.L. Harrell. 2008. "The effects of starter nitrogen to rice seeded at various densities." Online. Crop Management doi:10.1094/CM-2008-0911-01-RS.

Table 1. Dates of selected agronomic management events for three starter N trials established at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in Rohwer, Ark. and the Delta Research and Extension Center (DREC) in Stoneville, Miss.

Location	Cultivar	Seeding rate	Planting date	Starter-N applied	Preflood-N applied	Flood established	Sample date
		lb/ac			Month / day		
DREC	CL153	88	10 May	23 May	9 June	12 June	N/A[a]
DREC	CLXL745	34	8 May	23 May	21 June	22 June	26 July
RRS	CL153	78	10 May	31 May	20 June	21 June	N/A

[a] N/A = not available.

Table 2. Grain yield of CL153 rice as affected by the interaction between starter-N source and preflood-N rate for a trial conducted at the Delta Research and Extension Center (DREC) in 2017.

Preflood-N	Starter-N source applied at two-leaf stage[a]			
rate	No N	AMS	DAP	UREA
lb N/acre	--------------------------bu/acre--------------------------			
0	131	138	152	166
50	188	171	186	186
100	192	192	205	190
150	207	196	210	209
200	213	202	205	203
$LSD_{0.05}$		14		

[a] Starter-N source abbreviations: AMS, ammonium sulfate; DAP, diammonium phosphate; and UREA, urea treated with N-(n-butyl) thiophosphoric triamide urease inhibitor.

Table 3. Grain yield of CLXL745 rice as affected by the interaction between starter-N source and preflood-N rate for a trial conducted at the Delta Research and Extension Center (DREC) in 2017.

Preflood-N	Starter-N source applied at two-leaf stage[a]			
rate	No N	AMS	DAP	UREA
lb N/acre	----------------------------bu/acre----------------------------			
0	129	128	135	153
50	170	190	184	175
100	208	215	216	204
150	228	232	223	211
200	234	242	239	241
$LSD_{0.05}$		14		

[a] Starter-N source abbreviations: AMS, ammonium sulfate; DAP, diammonium phosphate; and UREA, urea treated with N-(n-butyl) thiophosphoric triamide urease inhibitor.

Grain Yield Response of Six New Rice Cultivars to Nitrogen Fertilization

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Abstract

The cultivar × nitrogen (N) fertilizer rate studies determine the proper N fertilizer rates for the new rice cultivars across the array of soil and climatic conditions which exist in the Arkansas rice-growing region. The six rice cultivars studied in 2017 were: Diamond, Titan, Horizon AG's Clearfield CL153 and CL272, BASF and Horizon AG's PVL01, and Thad. Grain yields were excellent for most of the cultivars studied in 2017 at the chosen locations, except at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) location where a phosphorus deficiency played a role in reducing yields for all of the cultivars, except possibly Diamond. This was the first year PVL01 and Thad were in the cultivar × N-rate studies and thus there is not enough data to make a recommendation at this time. The multiple years of results for Diamond, Titan, CL153 and CL272 indicate these cultivars should yield well with minimal to no lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

Introduction

The cultivar × N fertilizer rate studies measure the grain yield performance of the new rice cultivars over a range of N fertilizer rates on representative clay and silt loam soils and determines the proper N fertilizer rates to maximize yield on these soils under the climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from

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private industry are evaluated in these studies. Six new rice cultivars were entered and studied in 2017 at three locations as follows: the University of Arkansas entered the short stature, long-grain Diamond, and the semi-dwarf, medium-grain Titan; Horizon AG entered the Clearfield semi-dwarf, long-grain CL153 and the Clearfield semi-dwarf, medium-grain CL272 in cooperation with Louisiana State University; BASF and Horizon AG entered the Provisia semi-dwarf, long-grain PVL01 in cooperation with Louisiana State University; and Mississippi State University entered the short stature, long-grain cultivar Thad (which has higher amylose content for processing quality). Clearfield rice cultivars are tolerant to the broad spectrum herbicide imazethapyr (Newpath) and the Provisia cultivar is resistant to the grass herbicide quizalofop (the Provisia system herbicide).

Procedures

Locations where the cultivar × N fertilizer rate studies were conducted and corresponding soil series are as follows: University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts); PTRS, near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs); and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam (Typic Albaqualfs). The experimental design utilized at all locations for each of the rice cultivars studied was a randomized complete block with four replications. A single preflood N fertilizer application was utilized for all cultivars and was applied as urea, treated with the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT), on to a dry soil surface at the four- to five-leaf stage. The preflood N rates were: 0, 60, 90, 120, 150, 180, and 210 lb N/acre. The studies on the two silt loam soils at the PTRS and the RREC received the 0 to 180 lb N/acre fertilizer rates and the studies on the clay soil at the NEREC received the 0 to 210 lb N/acre N rates with the 60 lb N/acre rate omitted. Rice usually requires about 20 to 30 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. All of the rice cultivars were drill-seeded on the silt loams and clay soil at rates of 73 and 91 lb/acre, respectively, in plots 9 rows wide (row spacing of 7 in.), 15 ft in length. Pertinent agronomic dates and practices at each location are shown in Table 1. The studies were flooded at each location when the rice was at the four- to five-leaf stage and within a day of preflood N fertilization at all locations. The studies remained flooded until the rice was mature. At maturity, the center 5 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 least significant difference ($P = 0.05$) where appropriate (Tables 2-8).

Results and Discussion

A single, optimum preflood N application method was adopted in 2008 in all cultivar × N fertilizer rate studies due to the rising cost of N fertilizer and the preference of the short stature and semi-dwarf rice plant types currently being grown. The currently grown rice cultivars typically reach a maximum yield with less N when the N is applied in a single preflood application compared to a two-way split application. Usually the rice cultivars require 20 to 30 lb N/acre less when the N is applied in a single preflood application compared to a two-split application where the second split is applied between beginning internode elongation and 1/2-in. internode elongation. Thus, if 150 lb N/acre is recommended for a two-way split application then 120 to 130 lb N/acre is recommended for a single preflood N application. Conditions critical for use of the single, optimum preflood N application method are: the field can be flooded timely, the urea is treated with the urease inhibitor NBPT or ammonium sulfate used (unless the field can be flooded in 2 days or less for silt loam soils and 7 days or less for clay soils), and a 2- to 4- in. flood depth is maintained for at least 3 weeks following flood establishment.

Grain yields in the 2017 cultivar × N-rate studies were excellent for most of the cultivars studied. Unfortunately, a phosphorus deficiency at PTRS appeared to cause reduced yields for most of the cultivars. Diamond seemed to tolerate the phosphorus deficiency at PTRS better than the other cultivars studied. The new Provisia cultivar PVL01 appeared to have a yield drag associated with other new cultivars released with a tolerance to a herbicide. Pertinent agronomic information such as planting, herbicide, fertilization and flood dates are shown in Table 1.

Diamond achieved grain yields over 200 bu/acre on the clay soil at NEREC when 150 lb N/acre or more were applied preflood and did not significantly increase in grain yield when more than 150 lb N/acre was applied (Table 2). Diamond achieved a grain yield of 200 bu/acre when 150 lb N/acre was applied to the silt loam soil at PTRS, but did not significantly increase in yield when more than 120 lb N/acre was applied preflood. The grain yield of the Diamond cultivar seemed to be little affected by the phosphorus deficiency at PTRS that caused dramatic yield decreases in other cultivars when compared to yields recorded at other locations. Diamond achieved a grain yield of over 200 bu/acre on the silt loam soil at the RREC when 120 to 180 lb N/acre was applied. Similar to 2015 (Norman et al., 2016) and 2016 (Norman et al., 2017), Diamond exhibited a stable yield over a wide range of N fertilizer rates when the rate to achieve maximum yield was obtained and displayed minimal to no lodging. After 3 years of study, Diamond should yield well with an N-rate of 150 lb N/acre applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

Titan achieved a maximum grain yield of 209 bu/acre when 150 lb N/acre was applied preflood on the clay soil at the NEREC and did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood (Table 3). Titan was able to maintain a grain yield of over 200 bu/acre when up to 210 lb N/acre was applied at the NEREC. The phosphorus deficiency on the silt loam soil at the PTRS caused Titan to only achieve a maximum grain yield of 166 bu/acre. This low maximum grain yield was also observed for all of the other cultivars studied at PTRS, except possibly Diamond.

At the RREC, Titan did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood to this silt loam soil. Titan achieved a maximum grain of 228 bu/acre at the RREC and maintained a stable yield of over 200 bu/acre when 120 to 180 lb N/acre was applied preflood. Somewhat similar to 2016 (Norman et al., 2017), Titan maintained a stable grain yield when the N fertilizer rate required to maximize grain yield was exceeded by up to 60 lb N/acre with minimal to no lodging. After 3 years of study, it would appear Titan has a stable yield over a wide range of N fertilizer rates and should yield well with minimal to no lodging with an N-rate of 150 lb N/acre applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

Cultivar CL153 did not significantly increase in grain yield when more than 150 lb N/acre was applied preflood on the clay soil at the NEREC (Table 4). Cultivar CL153 maintained a grain yield in the 191 to 197 bu/acre range when 150 to 210 lb N/acre was applied at the NEREC with no lodging. The phosphorus deficiency on the silt loam soil at the PTRS caused CL153 to achieve a maximum grain yield of only 175 bu/acre at this location and did not significantly increase in grain yield when more than 60 lb N/acre was applied preflood. On the silt loam soil at the RREC, CL153 achieved a maximum yield of 203 bu/acre when 180 lb N/acre was applied preflood, but did not significantly increase in yield when more than 120 lb N/acre was applied preflood. The CL153 cultivar appears to have a stable grain yield over a wide N fertilizer rate range when the rate to achieve maximum yield is achieved and also appears to have good lodging resistance. After 2 years of study, it would appear CL153 should yield well with minimal to no lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

The grain yield of the medium grain CL272 did not significantly increase when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC (Table 5). Cultivar CL272 attained a maximum grain yield of 203 and 204 bu/acre when 180 and 210 lb N/acre was applied preflood at the NEREC. Unlike in 2016 (Norman et al., 2017), CL272 displayed no lodging at NEREC or for that matter at any of the locations in 2017. Grain yields did not significantly increase at the PTRS when more than 60 lb N/acre was applied preflood because of the phosphorus deficiency. Cultivar CL272 reached a peak yield of 181 bu/acre at PTRS and had a yield range of 167 to 181 bu/acre when 60 to 180 lb N/acre were applied. The yield of CL272 did not significantly increase at the RREC when more than 90 lb N/acre was applied preflood. Cultivar CL272 obtained a maximum yield of 201 bu/acre when 150 lb N/acre was applied preflood on the silt loam soil at RREC. After 2 years of study, it would appear CL272 should yield well with minimal to no lodging if 150 lb N/acre is applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and 180 lb N/acre in a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

The new Provisia rice cultivar PVL01 did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC and reached a maximum grain yield of 164 bu/acre at this location (Table 6). The grain yield of PVL01 did not significantly increase when more than 120 lb N/acre was applied to the silt loam soil at the PTRS. The phosphorus deficiency at the PTRS caused PVL01 to obtain a maximum yield of only 140 bu/acre. Cultivar PVL01 achieved a maximum grain yield of around 190 bu/acre, its highest of the three locations, on the silt loam soil at the RREC when 150 or 180 lb N/acre was applied preflood, but did not significantly increase in grain yield when greater than 120 lb N/acre was applied preflood. Cultivar PVL01 showed no signs of lodging at any of the three locations it was studied in 2017. This was the first year PVL01 was in the cultivar × N-rate studies and one to two more years of research will be required before an N-rate recommendation can be made.

The grain yield of Thad did not significantly increase when more than 150 lb N/acre was applied preflood on the clay soil at the NEREC (Table 7). Thad attained a maximum grain yield of 200 bu/acre at the NEREC when 180 lb N/acre was applied preflood. Unfortunately, Thad obtained a maximum grain yield of only 156 bu/acre on the silt loam soil at the PTRS when 180 lb N/acre was applied preflood due to the phosphorus deficiency at this location. The grain yield of Thad steadily increased on the silt loam soil at the RREC as the N fertilizer rate increased. The grain yield of Thad did not reach a maximum of 210 bu/acre at the RREC until the highest N-rate of 180 lb N/acre was applied preflood. The steady, significant yield increase as N fertilizer rate increased combined with the maximum yield not being obtained until 180 lb N/acre was applied indicates Thad may require more N fertilizer than the other cultivars. However, this is the first year Thad was in the cultivar × N fertilizer rate studies and one to two more years of research will be required before an N-rate recommendation can be made.

The Wells rice cultivar was included in the studies as a control and to give a frame of reference for comparing the grain yield performance and lodging percentage of the new cultivars over the N fertilizer rates applied at the three locations (Table 8). The N fertilizer rate recommendation for Wells is 150 lb N/acre applied in a two-way split of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on silt loam soils and a two-way split of 135 lb N/acre at preflood and 45 lb N/acre at midseason when grown on clay soils.

Significance of Findings

The cultivar × N fertilizer rate studies examines the grain yield performance of a new rice cultivar across a range of N fertilizer rates on representative soils and under climatic conditions that exist in the Arkansas rice-growing region. Thus, these studies are able to estimate the proper N fertilizer rate for a cultivar to achieve maximum grain yield when grown commercially in the Arkansas rice-growing region. The six cultivars studied in 2017 were: Diamond, Titan, CL153, CL272, PVL01, and Thad. The data generated from multiple years of testing of each cultivar will be used to determine the proper N fertilizer rate to achieve maximum yield when grown commercially on most silt loam and clay soils in Arkansas

Acknowledgments

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Literature Cited

Norman, R.J., T.L Roberts, J.T. Hardke, N.A. Slaton, K.A.K. Moldenhauer, X. Sha, D.L. Frizzell, M.W. Duren, E. Castaneda-Gonzalez, and G.J. Lee. 2016. Grain yield response of six new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Arkansas Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series. 634:295-306. Fayetteville.

Norman, R.J., T.L Roberts, J.T. Hardke, N.A. Slaton, K.A.K. Moldenhauer, X. Sha, D.L. Frizzell, A.D. Smartt, M.W. Duren, E. Castaneda-Gonzalez, G.J. Lee, and T.L. Clayton. 2017. Grain yield response of six new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.), B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series. 643:294-304. Fayetteville.

Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., the Pine Tree Research Station (PTRS), Colt, Ark., and the Rice Research and Extension Center (RREC), Stuttgart, Ark., during 2017.

Practices	NEREC	PTRS[a]	RREC
Preplant fertilizers	---------------	22 March 0-60-90 + 10 lbs Zn/acre as $ZnSO_4$	21 March 0-60-90 + 10 lbs Zn/acre as $ZnSO_4$
Planting date	14 April	05 May	13 April
Emergence date	08 May	18 May	21 April
Herbicide spray date and procedures	14 April 1.5 pt Command/acre + 43 oz Facet L/acre	22 March 32 oz Devour/acre + 1oz COC	18 April 20 oz Obey/acre
Herbicide spray date and procedures	22 May 4 qt Propanil/acre + 1 oz/acre Permit	15 May 2 pts Prowl H_2O/acre + 20 oz Facet L/acre	11 May 15 oz Clincher/acre
Herbicide spray date and procedures	30 May 15 oz Clincher/acre + 1% COC	---------------	--------------
Herbicide Spray date and procedures	02 June 4 qt Propanil/acre	---------------	--------------
Preflood N date	08 June	20 June	23 May
Flood date	09 June	21 June	24 May
Drain date	28 August	08 September	18 August
Harvest date	21 September	28 September	23 August

[a] Even though P was applied preplant at PTRS, a P deficiency developed after flooding and an addition application of 0-46-0 as triple super phosphate was applied on 15 June. Yields of some cultivars were negatively affected by the P deficiency.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
---(lb N/acre)---	(bu/acre)		
0	82	128	75
60	----	173	185
90	168	189	194
120	189	190	212
150	206	200	216
180	215	195	234
210	217	----	----
$LSD_{0.05}$[b]	15.1	15.6	20.6
C.V.[c]	5.32	5.62	5.02

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

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

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Titan rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
----(lb N/acre)-----	(bu/acre)		
0	80.0	100	118
60	----	126	156
90	183	139	191
120	196	166	215
150	209	156	228
180	208	162	220
210	203	----	----
$LSD_{0.05}$[b]	18.3	21.1	28.6
C.V.[c]	6.73	9.88	8.02

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, AR; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

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

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CL153 rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
-----(lb N/acre-----	--------(bu/acre)--------		
0	86	131	112
60	----	168	149
90	156	175	180
120	176	171	190
150	191	171	197
180	194	163	203
210	197	----	----
$LSD_{0.05}$[b]	13.4	15.0	16.0
C.V.[c]	4.87	6.09	5.13

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of CL272 rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
----(lb N/acre)----	--------(bu/acre)--------		
0	83	132	108
60	----	167	159
90	171	172	176
120	183	170	189
150	186	170	201
180	202	181	178
210	204	----	----
$LSD_{0.05}$[b]	25.2	14.1	27.5
C.V.[c]	9.75	5.63	8.99

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
[b] LSD = least significant difference.
[c] C.V. = coefficient of variation.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL01 rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
----(lb N/acre)----		----(bu/acre)----	
0	61	60	89
60	----	108	139
90	122	125	160
120	142	131	181
150	156	140	190
180	150	140	191
210	164	----	----
$LSD_{0.05}$[b]	24.0	11.0	23.0
C.V.[c]	12.0	6.27	8.00

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

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

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Thad rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	NEREC[a]	PTRS	RREC
----(lb N/acre)----		----(bu/acre)----	
0	81	68	92
60	----	114	136
90	161	132	161
120	176	146	186
150	195	148	193
180	200	156	210
210	186	----	----
$LSD_{0.05}$[b]	17.6	9.38	16.4
C.V.[c]	7.00	4.89	5.53

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

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

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of Wells rice at three locations during 2017.

	Grain Yield		
N Fertilizer Rate	**NEREC[a]**	**PTRS**	**RREC**
----(lb N/acre)----	**---------------------------- (bu/acre) -----------------------------**		
0	82	71	84
60	----	116	132
90	150	134	143
120	172	149	161
150	187	149	184
180	195	159	180
210	192	----	----
$LSD_{0.05}$[b]	16.5	19.8	12.0
C.V.[c]	6.73	10.1	4.47

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] LSD = least significant difference.

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

Management of a Soybean Crop to Maximize a Following Rice Crop's Profit

C. C. Ortel[1], T. L. Roberts[1], R.J. Norman[1], N.A. Slaton[1], and K. A. Hoegenauer[1]

Abstract

The cost of nitrogen (N) fertilization for a rice (*Oryza sativa*) producer is a determining factor in the profit returned from a rice crop. In 2016, 68% of the rice grown in Arkansas was grown in rotation with soybean (*Glycine max*), the leading crop in both profit and acres harvested in the state (Hardke, 2017). Variety selection and management of the soybean crop may influence soil-N credits returned to the soil and ultimately the N rate needed to maximize yield in the successive rice crop. A rice crop's performance and input cost is strongly related to the plant-available N. The potential to reduce the amount of N fertilizer required by the rice through management of the previous soybean crop could provide savings with no additional input cost to a rice producer. The total N uptake (TNU), yield, and soil-N credits developed were measured in four maturity groups (MGs) of soybean. A single cultivar of rice followed all four MGs to compare the rice TNU and yield between previous MGs and N rate applied as a single pre-flood treatment of urea. The results from the 2016 soybean crop and 2017 rice crop show no significant difference between soybean MG grown and rice yield ($P = 0.9502$). There was no significant difference ($P = 0.8067$) in plant-available N between previous MGs the following spring, nor was there a significant difference between previous MG and rice total N uptake ($P = 0.9677$). The preliminary data suggest MG of soybean alone does not have an impact on a following rice crop's success under the conditions of this initial year's study. Further research will be conducted to evaluate the impact of soybean planting date on a following rice crop.

Introduction

The soybean–rice crop rotation system is widely used for the benefits provided to both crops. One specific benefit is the N credit supplied to the rice crop through biological N fixation with soil bacteria and mineralization of the soybean residue returned to the soil system after harvest. Soybean residue has a relatively high N concentration and a low C/N ratio compared to crops grown in a similar rotation, promoting net mineralization and development of plant-available N (Clark et al., 2015). This reduction

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of N fertilizer required results in a large savings of input costs associated with the rice crop, helping the producer to maximize profitability, as N fertilizer is often the largest input cost to a rice producer (Roberts et al., 2013). Increasing the amount of soil-N available to a following rice crop may be accomplished through soybean maturity group (MG) selection and planting date. Different MGs of soybeans will produce a different yield and harvest index, thus returning differing amounts of N to the soil system. The degree of N credits generated by each MG is dependent on many factors including environmental and physiological characteristics of the soybean cultivar. Soil-N credits were measured using Nitrogen-Soil Test for Rice (N-STaR) soil samples to assess the potentially mineralizable-N in the soil system at the beginning of the rice cropping season. The goal of this research was to investigate the variances in different soybean MGs and the impact they have on N fertilizer recommendations for a following rice crop. The soybean yield, total N uptake (TNU), and soil-N credits were evaluated in an attempt to link the soybean management style to the optimal rice N fertilization rate.

Procedures

A soybean–rice crop rotation was grown on a Calhoun silt loam soil (Fine-silty, mixed, active, thermic Typic Glossaqualfs) at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas. Four MGs of soybean were drill-seeded in strips in the field on 9 June 2016, a relatively late planting date for full-season soybean production. All were Pioneer cultivars with the 'R' trait and did not receive any seed treatment. The cultivars planted are listed in Table 1. The soybean crop was sampled at full seed (R6.5) for TNU and again at maturity for grain N and yield. The recorded grain N was subtracted from the total N to estimate the biomass N which was returned to the soil system. Plants at the full seed growth stage have taken up a large majority of the season total N while retaining the leaves (Bender et al., 2015). At maturity, each plot was harvested and yield data was collected and adjusted to 13.5% moisture. Between crops, the soil was left fallow and the soybean residue was spread evenly within each plot.

Lakast, a pure-line (conventional), long-grain cultivar, was planted the following spring on 27 April 2017. At rice emergence, N-STaR soil samples were taken from the 0-45 cm depth to quantify the soil-N credits. At the V4- V5 leaf stage, six rates of a single preflood treatment of N-(n-butyl) thiophosphoric triamide (NBPT) treated urea were applied. The treatments include 0, 40, 80, 120, 160, and 200 lb N/acre. The rice crop was sampled at 50% heading for TNU using 3-foot samples from a border rows. On 5 Sept., the rice reached about 20% moisture and was harvested, and grain yield weights and moistures were recorded. All grain yields were adjusted to 12% moisture and are expressed in bushels (bu/acre).

The overall analysis of variance design was randomized complete block with four blocks per replication. Four MGs were planted in each replication. The data was analyzed using a split plot design with MG as the whole plot factor and rice N rate as the split plot factor. Means separation was done using the least significant difference test for those effects having significant F-tests. Comparisons were done at the $\alpha = 0.05$ significance level.

Results and Discussion

The results from the 2016 soybean crop and 2017 rice crop show no significant difference between previous soybean MG grown and rice yield (Fig. 1). There was no significant difference ($P = 0.8067$) in plant-available-N between previous soybean MGs the following spring, nor was there a significant difference between previous MG and rice TNU (Table 2). The rice crop was affected by the single pre-flood N treatment applied in both the TNU and grain yield. A steady increase in N uptake was observed as N fertilizer rate increased; with each N fertilizer rate increase resulting in a significant and/or numerically higher N uptake. The highest N uptake recorded, 193 lb N/acre, received 200 lb N/acre SPF. Treatment four, 120 lb N/acre, reached 94% relative grain yield and was not significantly different than higher N fertilizer rates. Treatment five, 160 lb N/acre, reached 99% relative grain yield. These results confirm the N-STaR recommendation of 135 lb N/acre which was just above the treatment four N rate of 120 lb N/acre.

There were differences in TNU among soybean MGs (Fig. 2). Significantly higher TNU was measured in the determinate cultivars than the indeterminate cultivars. This may be due to the longer growing season and longer time spent in vegetative growth stages compared to the indeterminate cultivars. Soybean yield differences were observed among MGs (Fig. 3). The 4.7 and 5.4 MGs yielded the highest, followed by 5.6 and then 3.5 MG. This trend is relative to the MGs typically grown in Arkansas, with the most common MGs (4 and early 5) yielding the highest.

One possible factor which could be contributing to the lack of significance in findings in the complete rotation is the low sample size. Only one site year of data with four replications was considered, leaving this analysis with a relatively small sample size (N = 96) and a low degree of freedom. This decreases the range of least significant differences. This study will be continued to increase the sample size with 4 site-years of data added.

Significance of Findings

Maturity group of soybean alone does not appear to have an impact on a following rice crop's success. However, management of a crop rotation includes numerous factors, including the planting date of each crop. Future research will incorporate an 'early' and 'late' soybean planting date along with soybean MG, investigating its impact on soil-N credits and a following rice crop's optimal N rate. Four additional site-years of data will be added; incorporating two locations and two planting dates. Regardless of MG, incorporating a legume within a crop rotation allows for a reduced N rate of a following rice crop while helping to break up pest cycles.

Acknowledgments

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Literature Cited

Bender, R. R., J. W. Haegele, and F. E. Below. 2015. Nutrient Uptake, Partitioning, and Remobilization in Modern Soybean Varieties. Agronomy Journal 107.2.

Clark, L. A., T. L. Roberts, N. A. Slaton. 2015. Estimation of Mineralizable Nitrogen from 15N-Labelled Crop Residues using Alkaline- Hydrolyzable Nitrogen Methods. Soil Sci. Soc. Am. J. 79:1243-1248

Hardke, J. T. 2017. Trends in Arkansas Production, 2016. R.J. Norman and K.A.K. Moldenhauer. Arkansas Agricultural Experiment Station. Research Series 643.

Soybeans Seed Guide, DuPont Pioneer, 2017. www.pioneer.com/home/site/us/products/soybeans/seed-guide

Roberts, T. L., R. J. Norman, A. M. Fulford, N. A. Slaton. 2013. Field Validation of N-STaR for Rice Produced on Silt Loam Soils in Arkansas. Soil Sci. Soc. Am. J. 77.2:539-545.

Table 1. Soybean cultivar comparisons using information obtained on the seed distributors website (Soybeans Seed Guide, DuPont Pioneer, 2017).

Cultivar	Seed company	Relative maturity	Growth habit†	Chloride sensitivity‡	Pod color
P35T48	Pioneer	3.5	Ind	-	Brown
P47T36	Pioneer	4.7	Ind	8	Brown
P54T94	Pioneer	5.4	De	9	Brown
P56T12	Pioneer	5.6	De	-	-

† Ind, indeterminate; De, determinate.

‡ Numeric ratings, 9 = Excellent; 1 = Poor; Blank = Insufficient data or cultivar not tested.

Table 2. Analysis of variance results for total N uptake (TNU) and grain yield of both soybeans and rice.

		Soybean		Rice	
	DF	TNU Prob > F	Yield Prob > F	TNU Prob > F	Yield Prob > F
Maturity Group (MG)	3	<0.0001	<0.0001	0.7601	0.5552
N Rate	5	--	--	<0.0001	<0.0001
MG x N rate	15	--	--	0.9536	0.8839

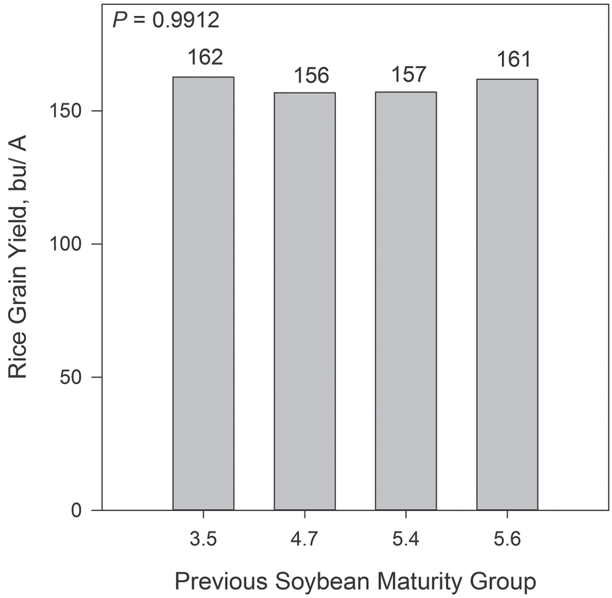

Fig. 1. Influence of soybean maturity group (MG) on a following rice grain yield.

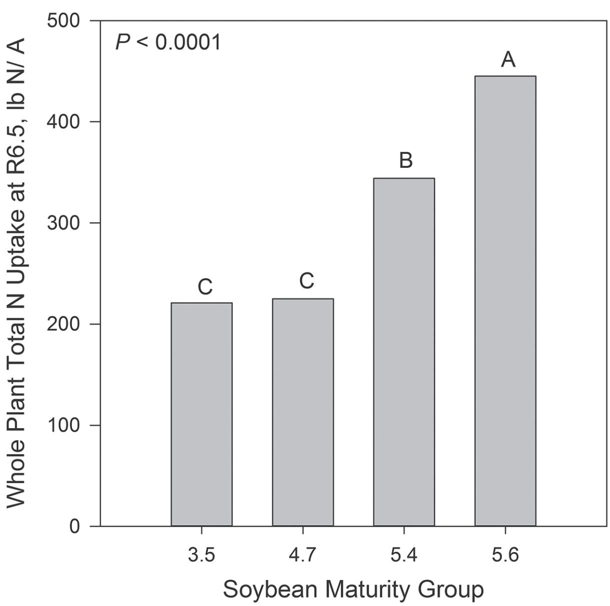

Fig. 2. Influence of soybean maturity group (MG) on the whole plant total nitrogen uptake (TNU)at full seed (R6.5). Means with different letters are significantly different (Students *T*, *P* < 0.05).

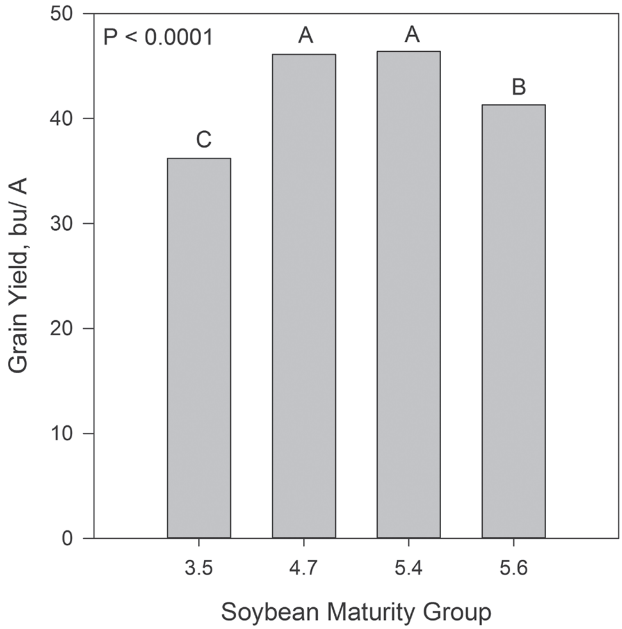

Fig. 3. Soybean yield as influenced by maturity group (MG). Means with different letters are significantly different (Students *T*, *P* < 0.05).

Utilization of On-Farm Testing to Evaluate Rice Cultivars, 2017

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Abstract

On-farm testing provides researchers the opportunity to evaluate cultivars in a more unpredictable environment than that of the experiment stations or traditional test plots. The Producer Rice Evaluation Program (PREP) utilizes commercial rice fields throughout the state to evaluate experimental lines and various commercial cultivars for disease, lodging, grain yield potential, and milling yield in diverse growing conditions, soil types and farming practices. For producers, knowing the optimum cultivar for each field is their biggest and most important tool. On-farm testing can indicate which cultivars are suited for a particular growing situation. Field studies were located in Craighead, Drew, Lafayette, Lawrence, Phillips, Poinsett, Prairie, and White counties during the 2017 growing season. Twenty cultivars were selected for evaluation in the on-farm tests. The average grain yield across all locations was 211 bu/acre and the mean milling yield, percent head rice and percent total white rice (%HR/%TR), was 59/70. The cultivars with the highest grain yields averaged across locations were RT XP753, RT 7311 CL, RT 7812 CL, Titan, RT XP760, RT Gemini 214 CL, Jupiter, and Diamond. Cultivars CL172, CL153, CL111, and RT 7812 CL had the highest milling yields averaged across locations.

Introduction

One goal of the University of Arkansas System Division of Agriculture is to offer a complete production package to producers when southern U.S. rice cultivars are released, including grain and milling yield potential, disease reactions, fertilizer recommendations, and Degree-Day 50 (DD50) Program thresholds. Factors that can influence grain yield potential include: seeding date, soil fertility, water quality and management, disease pressure, weather events, and cultural management practices.

Rice disease can be a major factor in the profitability of any rice field in Arkansas. Host-plant resistance, optimum farming practices, and fungicides (when necessary based

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on integrated pest management practices) are the best line of defense we have against these profit robbing diseases. The use of resistant cultivars, combined with optimum cultural practices, provide growers with the opportunity to maximize profit at the lowest disease control expense by avoiding the use of costly fungicide applications.

New rice cultivars are developed and evaluated each year at the University of Arkansas System Division of Agriculture experiment stations under controlled conditions. A large set of data on grain yield, grain quality, plant growth habit, and major disease resistance is collected during this process. Unfortunately, the dataset under these conditions is not complete for many of the environments where rice is grown in Arkansas because potential problems may not be evident in nurseries grown on experiment stations. With information obtained from field research coupled with knowledge of a particular field history, growers can select the cultivar that offers the highest yield potential for their particular situation. The Producer Rice Evaluation Program (PREP) was designed to better address the many risks faced by newly released cultivars across the rice-growing regions of Arkansas. The on-farm evaluation of new and commercial cultivars provides better information on disease development, lodging, grain yield potential, and milling yield under different environmental conditions and crop management practices. These studies also provide a hands-on educational opportunity for county agents, consultants, and producers.

The objectives of the PREP include: 1) to compare the yield potential of commercially available cultivars and advanced experimental lines under commercial production field conditions; 2) to monitor disease pressure in the different regions of Arkansas; and 3) to evaluate the performance of rice cultivars under those conditions not commonly observed on experiment stations.

Procedures

Field studies were located in Craighead, Drew, Lafayette, Lawrence, Phillips, Poinsett, Prairie, and White counties during the 2017 growing season. Twenty cultivars were selected for evaluation in the on-farm tests. Non-Clearfield entries evaluated during 2017 included Diamond, Jupiter, LaKast, MM14, RT XP753, RT XP760, Roy J, Thad, and Titan. Clearfield lines included CL111, CL151, CL153, CL163, CL172, CL272, RT 7812 CL, RT 7311 CL, RT XL745 CL, RT Gemini 214 CL and the Provisia rice line PVL01.

Plots were 8 rows (7.5-in spacing) wide and 16.5-ft in length arranged in a randomized complete block design with four replications. Pure-line cultivars (varieties) were seeded at a rate of approximately 30 seed/ft^2 (loam soil) or 36 seed/ft^2 (clay soil), while hybrids were seeded at a rate of 10.3 seed/ft^2 (loam soil) or 12.4 seed/ft^2 (clay soil). Trials were seeded on 28 March (Lafayette), 29 March (Phillips), 10 April (Craighead and Drew), 12 April (White), 18 April (Poinsett), 20 April (Lawrence) and 8 May (Prairie). Since these experiments contain both Clearfield, conventional (i.e., pure-line and hybrids) and Provisia entries, all plots were managed as conventional cultivars.

Plots were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control, but in most cases did not receive a fungicide application. If a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically and rated for disease. Percent lodging notes were taken immediately prior to harvest. At maturity, the center 4 rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for milling purposes. Grain yields were adjusted to 12% moisture and reported on a bushels/acre (bu/acre) basis. The dried rice was milled to obtain percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide a milling yield expressed as %HR/%TR. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test (P = 0.05).

Results and Discussion

All cultivars were represented at all locations during the 2017 growing season; a summary of the results by county and corresponding date of seeding is presented in Table 1. Across counties, the grain yield averaged 211 bu/acre. Cultivars RT XP753 and RT 7311 CL were the highest-yielding followed by RT 7812 CL, Titan, RT XP760 and RT Gemini 214 CL. In the Craighead Co. trial (Table 2), grain yield averaged 190 bu/acre. The highest-yielding entries were RT 7812 CL, RT XP753, RT 7311 CL, Jupiter, LaKast and Diamond. The highest-yielding entries for %HR were Roy J, Jupiter, CL172, CL153, CL111, and MM14. In the Drew Co. trial (Table 3), grain yield for the location averaged 235 bu/acre. Drew Co. was the highest yielding trial in 2017. The highest yielding cultivars were RT 7812 CL, RT 7311 CL, RT XP753, Titan and RT XL760. Percent head rice averaged 59% at Drew Co. during 2017. The highest-yielding entries for %HR were CL172, CL151, CL153, Thad, Titan, and RT 7812 CL. RT 7311 CL, RT XP753, Thad, RT 7812 CL, and CL172 were the highest-yielding cultivars in the Lafayette Co. trial (Table 4). There was notable lodging at this location due a hurricane event immediately prior to harvest. Percent head rice of 55% was measured for CL172 and RT 7812 CL in the Lafayette Co. trial, followed by Roy J and PVL01 at 53% HR. The Lawrence Co. trial average grain yield was 219 bu/acre, and cultivars with the highest grain yield included RT 7311 CL, Titan, Jupiter, RT Gemini 214 CL, and RT 7812 CL (Table 5). Highest %HR was noted for CL172, CL272 and Titan. In the Phillips Co. trial, RT XP753, Titan, RT 7311 CL, Diamond and Thad were the highest yielding cultivars and the average yield for the location was 230 bu/acre (Table 6). Cultivars with the highest %HR included CL172, PVL01, Roy J, Thad, Jupiter, and RT 7812 CL. The highest yielding cultivars in Poinsett Co. were RT 7812 CL, RT XP760, RT XP753, RT 7311 CL, and RT Gemini 214 CL. The location average grain yield was 207 bu/acre (Table 7). Percent head rice at Poinsett Co. during 2017 was highest for Jupiter and RT 7812 CL followed by MM14, RT XL760, CL111, and CL272. Cultivars in the trial at Prairie Co. averaged 191 bu/acre (Table 8). The highest yielding cultivars at Prairie Co. were RT XP753, RT 7311 CL, Gemini 214 CL, RT 7812 CL, and RT XP760. Titan, CL111 and CL272 had the highest %HR at Prairie Co. with 65%, followed by CL172 and RT XP753. RT XP753, Titan, RT 7812 CL, RT 7311 CL, and

CL151 were the highest grain yielding cultivars for White Co. (Table 9). This location averaged 225 bu/acre during 2017. Highest %HR was measured for LaKast, CL111, CL153, CL172, and Thad.

Monitoring cultivar response to disease presence and the severity of reactions is a significant part of this program. The observations obtained from these plots are often the basis for disease ratings developed for use by growers (Table 10). This is particularly true for minor diseases that may not be encountered frequently, such as narrow brown leaf spot, false smut, and kernel smut.

Yield variability among the study sites represents differences in environments and management practices, but also susceptibility to lodging and disease pressure present at individual locations.

Significance of Findings

The 2017 Producer Rice Evaluation Program provided additional data to the rice breeding and disease resistance programs. The program also provided supplemental performance and disease reaction data on new cultivars that will be more widely grown in Arkansas during 2018.

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Table 1. Results of the Producer Rice Evaluation

Cultivar	Grain length[a]	Lodging	Moisture	Milling yield[b]	Grain yield by location and planting date: Craighead 4/10	Grain yield by location and planting date: Drew 4/10
		%	%	%HR/%TR	-----------bu/acre-----------	
Diamond	L	3.1	19.3	59/69	208	231
LaKast	L	5.3	17.7	60/71	208	222
Roy J	L	2.5	19.4	61/71	191	207
Thad	L	0.9	17.6	60/71	174	228
Titan	M	10.2	17.9	57/69	206	267
Jupiter	M	12.9	20.9	61/67	214	231
CL272	M	8.6	18.3	60/68	196	217
CL111	L	3.1	17.0	62/71	126	219
CL151	L	20.3	18.3	60/70	173	238
CL153	L	5.3	17.6	62/71	180	215
CL163	L	10.8	17.9	60/70	176	218
CL172	L	0.0	18.7	63/71	185	216
RT CLXL745	L	7.1	16.9	57/71	147	245
RT 7311 CL	L	3.6	17.2	55/70	222	275
RT 7812 CL	L	4.5	19.9	62/71	245	277
RT Gemini 214 CL	L	10.3	17.8	57/69	204	248
RT XP753	L	0.0	17.3	55/71	231	269
RT XP760	L	13.3	17.8	58/69	177	266
PVL01	L	0.0	19.0	60/70	141	204
MM14	M	1.9	18.9	60/68	196	207
Mean	--	6.2	18.3	59/70	190	235
$LSD_{0.05}$[c]	--	6.7	0.7	1.7/0.5	23.0	15.2

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice/% total milled rice.
[c] LSD = least significant difference.

Program (PREP) at eight locations during 2017.

Grain yield by location and planting date						
Lafayette 3/28	**Lawrence 4/20**	**Phillips 3/29**	**Poinsett 4/18**	**Prairie 5/8**	**White 4/12**	**Mean**
---bu/acre---						
200	225	241	204	193	217	215
188	207	234	209	190	225	211
187	198	230	186	164	222	199
210	191	240	174	186	215	203
200	258	247	226	188	257	232
157	255	237	207	200	230	217
157	224	230	166	185	203	198
164	202	216	182	163	221	187
161	205	230	197	179	235	203
183	216	223	186	174	230	201
178	173	223	183	173	208	192
204	194	207	177	178	215	197
168	231	232	221	202	215	208
237	260	243	247	219	239	243
207	239	238	260	212	243	241
183	244	239	232	212	229	224
232	236	247	249	234	261	245
204	215	239	252	211	233	227
177	179	198	169	159	183	177
200	224	205	199	191	199	203
190	219	230	206	191	224	211
35.0	27.0	13.9	14.4	15.8	16.7	8.2

Table 2. Results of Craighead Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted April 10; harvested September 18.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	15.8	208.1	63/72
LaKast	L	0.0	14.6	208.4	63/73
Roy J	L	0.0	16.7	191.5	66/74
Thad	L	0.0	15.4	174.2	62/72
Titan	M	15.0	11.7	206.9	50/70
Jupiter	M	5.0	16.8	214.0	65/70
CL272	M	0.0	14.7	196.9	64/70
CL111	L	0.0	14.7	126.7	63/72
CL151	L	17.5	15.0	173.4	62/72
CL153	L	0.0	14.1	180.7	64/73
CL163	L	12.5	15.1	176.0	62/71
CL172	L	0.0	15.0	185.0	65/72
RT XL745 CL	L	2.5	13.4	147.4	51/70
RT 7311 CL	L	5.0	13.8	222.0	53/70
RT 7812 CL	L	5.0	15.4	245.9	60/72
RT Gemini 214 CL	L	15.0	13.7	204.6	59/71
RT XP753	L	0.0	13.3	231.0	44/70
RT XP760	L	15.0	13.9	177.1	59/70
PVL01	L	0.0	14.5	141.3	59/72
MM14	M	0.0	15.6	196.3	64/70
Mean	--	4.6	14.6	190.3	60/71
$LSD_{0.05}$[c]	--	16.7	2.7	23.0	3.8/0.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 3. Results of Drew Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted April 10; harvested August 22

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	20.7	231.1	59/68
LaKast	L	0.0	18.8	222.1	59/70
Roy J	L	0.0	19.5	207.5	60/69
Thad	L	0.0	18.1	228.2	61/70
Titan	M	0.0	19.2	267.3	61/67
Jupiter	M	0.0	24.3	231.0	58/63
CL272	M	0.0	18.9	217.3	60/65
CL111	L	0.0	17.4	219.8	60/70
CL151	L	0.0	18.2	238.6	62/69
CL153	L	0.0	18.1	215.0	62/70
CL163	L	0.0	17.8	218.8	60/68
CL172	L	0.0	20.3	216.7	64/70
RT XL745 CL	L	0.0	16.4	245.4	57/69
RT 7311 CL	L	0.0	18.0	275.8	56/68
RT 7812 CL	L	0.0	20.1	277.6	61/68
RT Gemini 214 CL	L	0.0	18.4	248.6	56/67
RT XP753	L	0.0	17.8	269.3	58/69
RT XP760	L	0.0	18.4	266.4	58/68
PVL01	L	0.0	21.0	204.8	60/69
MM14	M	0.0	19.5	207.5	59/66
Mean	--	0.0	19.0	235.4	59/68
$LSD_{0.05}$[c]	--	0.0	1.2	15.2	2.8/1.3

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 4. Results of Lafayette Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted March 28; harvested September 12.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	24.5	14.7	200.1	48/69
LaKast	L	42.0	14.7	188.2	48/70
Roy J	L	20.0	16.0	187.6	53/71
Thad	L	7.5	13.7	210.7	46/69
Titan	M	66.5	13.7	200.0	33/67
Jupiter	M	98.0	15.3	157.6	52/69
CL272	M	68.5	14.9	157.7	45/69
CL111	L	24.5	13.9	164.1	51/70
CL151	L	98.0	14.5	161.8	47/69
CL153	L	42.0	14.2	183.6	50/70
CL163	L	74.0	13.5	178.7	52/69
CL172	L	0.0	14.6	204.7	55/70
RT XL745 CL	L	54.5	13.6	168.1	42/69
RT 7311 CL	L	23.8	13.6	237.0	36/68
RT 7812 CL	L	31.3	16.3	207.7	55/71
RT Gemini 214 CL	L	55.0	14.6	183.5	45/68
RT XP753	L	0.0	13.3	232.1	36/69
RT XP760	L	57.0	13.9	204.0	47/68
PVL01	L	0.0	14.6	177.5	53/69
MM14	M	15.0	15.0	200.9	48/69
Mean	--	40.1	14.4	190.3	47/69
$LSD_{0.05}$[c]	--	38.1	1.1	35.0	6.4/1.2

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 5. Results of Lawrence Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted April 20; harvested September 18.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	25.0	225.5	63/70
LaKast	L	0.0	21.9	207.8	65/72
Roy J	L	0.0	25.0	198.3	61/69
Thad	L	0.0	20.7	191.5	65/71
Titan	M	0.0	22.4	258.6	67/71
Jupiter	M	0.0	24.1	255.1	63/67
CL272	M	0.0	22.0	224.3	67/70
CL111	L	0.0	20.1	202.8	66/72
CL151	L	43.8	22.4	205.2	66/71
CL153	L	0.0	21.0	216.0	66/72
CL163	L	0.0	24.1	173.7	61/70
CL172	L	0.0	21.7	194.2	67/72
RT XL745 CL	L	0.0	21.2	231.1	65/72
RT 7311 CL	L	0.0	20.0	260.6	64/72
RT 7812 CL	L	0.0	24.6	239.9	65/71
RT Gemini 214 CL	L	12.5	21.8	244.4	64/71
RT XP753	L	0.0	23.1	236.8	66/72
RT XP760	L	35.0	21.7	215.6	63/71
PVL01	L	0.0	21.5	179.8	64/71
MM14	M	0.0	23.1	224.5	64/68
Mean	--	4.6	22.4	219.3	64/70
$LSD_{0.05}$[c]	--	15.4	3.1	27.0	1.9/0.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 6. Results of Phillips Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted March 29; harvested August 29.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/ac)	(%HR/%TR)
Diamond	L	0.0	19.4	241.6	58/69
LaKast	L	0.0	18.1	234.1	52/69
Roy J	L	0.0	19.5	230.2	61/71
Thad	L	0.0	19.9	240.2	61/73
Titan	M	0.0	19.2	247.6	51/67
Jupiter	M	0.0	21.7	237.3	61/66
CL272	M	0.0	19.0	230.4	56/67
CL111	L	0.0	18.2	216.1	58/70
CL151	L	0.0	18.9	230.3	55/70
CL153	L	0.0	18.1	223.5	59/70
CL163	L	0.0	17.7	223.7	58/69
CL172	L	0.0	19.5	207.7	64/72
RT XL745 CL	L	0.0	18.2	232.3	54/70
RT 7311 CL	L	0.0	18.5	243.9	49/67
RT 7812 CL	L	0.0	19.5	238.7	61/71
RT Gemini 214 CL	L	0.0	17.0	239.4	51/67
RT XP753	L	0.0	17.5	247.9	50/70
RT XP760	L	0.0	18.3	239.4	53/68
PVL01	L	0.0	19.2	198.6	62/71
MM14	M	0.0	20.2	205.8	59/67
Mean	--	0.0	18.9	230.4	57/69
$LSD_{0.05}$[c]	--	--	1.6	13.9	4.4/2.8

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 7. Results of Poinsett Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted April 18; harvested September 26.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	16.6	204.2	58/69
LaKast	L	0.0	15.4	209.6	59/71
Roy J	L	0.0	15.7	186.5	59/70
Thad	L	0.0	15.2	174.5	55/68
Titan	M	0.0	16.2	226.9	60/69
Jupiter	M	0.0	18.3	207.2	62/67
CL272	M	0.0	16.3	166.2	60/67
CL111	L	0.0	15.2	182.1	60/70
CL151	L	0.0	15.2	197.2	57/68
CL153	L	0.0	15.3	186.6	58/67
CL163	L	0.0	14.9	183.9	56/69
CL172	L	0.0	15.9	177.6	58/69
RT XL745 CL	L	0.0	14.9	221.4	58/70
RT 7311 CL	L	0.0	15.1	247.3	58/70
RT 7812 CL	L	0.0	16.9	260.3	62/71
RT Gemini 214 CL	L	0.0	15.2	232.8	58/69
RT XP753	L	0.0	14.0	249.8	54/71
RT XP760	L	0.0	15.0	252.5	60/70
PVL01	L	0.0	16.9	169.1	59/69
MM14	M	0.0	16.5	199.6	61/68
Mean	--	0.0	15.7	206.8	58/69
$LSD_{0.05}$[c]	--	--	1.2	14.4	2.3/1.2

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

[b] %HR/%TR = % head rice and % total milled rice.

[c] LSD = least significant difference.

Table 8. Results of Prairie Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted May 8; harvested September 14.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	20.7	193.1	59/67
LaKast	L	0.0	18.3	190.6	62/71
Roy J	L	0.0	20.2	164.8	59/68
Thad	L	0.0	18.9	186.3	62/69
Titan	M	0.0	20.9	188.7	65/69
Jupiter	M	0.0	22.4	200.8	63/66
CL272	M	0.0	19.5	185.9	65/68
CL111	L	0.0	17.5	163.1	65/71
CL151	L	3.7	19.6	179.3	62/69
CL153	L	0.0	18.4	174.4	64/70
CL163	L	0.0	18.7	173.3	62/69
CL172	L	0.0	20.8	178.6	64/70
RT XL745 CL	L	0.0	17.8	202.9	60/70
RT 7311 CL	L	0.0	18.6	219.0	59/70
RT 7812 CL	L	0.0	22.7	212.1	62/69
RT Gemini 214 CL	L	0.0	20.3	212.5	61/69
RT XP753	L	0.0	18.2	234.5	63/71
RT XP760	L	0.0	20.0	211.4	59/68
PVL01	L	0.0	19.7	159.0	59/68
MM14	M	0.0	20.2	191.3	62/67
Mean	--	0.1	19.6	191.1	62/69
$LSD_{0.05}$[c]	--	2.3	1.2	15.8	1.5/0.9

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 9. Results of White Co. Producer Rice Evaluation Program (PREP) Trial during 2017. Planted April 12; harvested September 7.

Cultivar	Grain length[a]	Lodging	Moisture	Grain yield	Milling yield[b]
		(%)	(%)	(bu/acre)	(%HR/%TR)
Diamond	L	0.0	23.2	217.3	65/70
LaKast	L	0.0	20.1	225.6	69/73
Roy J	L	0.0	23.0	222.6	66/71
Thad	L	0.0	19.3	215.6	67/72
Titan	M	0.0	20.3	257.3	67/70
Jupiter	M	0.0	24.1	230.9	63/66
CL272	M	0.0	21.3	203.1	65/68
CL111	L	0.0	19.3	221.8	68/72
CL151	L	0.0	22.2	235.8	66/70
CL153	L	0.0	21.8	230.3	68/72
CL163	L	0.0	21.3	208.6	66/72
CL172	L	0.0	21.9	215.0	67/72
RT XL745 CL	L	0.0	19.7	215.5	65/72
RT 7311 CL	L	0.0	20.1	239.8	63/71
RT 7812 CL	L	0.0	23.6	243.0	65/71
RT Gemini 214 CL	L	0.0	21.8	229.9	64/70
RT XP753	L	0.0	20.1	261.8	66/72
RT XP760	L	0.0	21.6	233.3	64/71
PVL01	L	0.0	23.5	183.4	65/71
MM14	M	0.0	21.3	199.0	65/68
Mean	--	0.0	21.5	224.5	66/71
$LSD_{0.05}$[c]	--	--	1.3	16.7	1.5/1.1

[a] Grain length: L = long-grain; M = medium-grain.
[b] %HR/%TR = % head rice and % total milled rice.
[c] LSD = least significant difference.

Table 10. Rice cultivar reactions[a] to diseases (2017).

Cultivar	Sheath blight	Blast	Straight head	Bacterial panicle blight	Narrow brown leaf spot	Stem rot	Kernel smut	False smut	Lodging	Black sheath rot
Cheniere	S	MS	VS	MS	S	S	S	S	MR	MS
CL111	VS	MS	S	VS	S	VS	S	S	MS	S
CL151	S	VS	VS	VS	S	VS	S	S	S	S
CL153	S	MS	--	MS	S	--	S	S	MR	--
CL163	VS	S	--	MS	R	--	MS	--	MS	--
CL172	MS	MS	--	MS	S	--	MS	S	MR	--
CL272	S	MS	--	VS	S	--	MS	--	MR	S
Cocodrie	S	S	VS	S	S	VS	S	S	MR	S
Della-2	S	R	--	MS	MS	--	--	--	--	--
Diamond	S	S	--	MS	--	S	S	VS	MS	--
Jazzman-2	S	MS	--	VS	S	--	S	S	--	--
Jupiter	S	S	S	MR	MR	VS	MS	MS	S	MR
LaKast	MS	S	MS	MS	MS	S	S	S	MS	MS
MM14	--	--	--	S	--	--	--	S	--	--
PVL01	S	S	--	S	--	--	--	VS	--	--
Roy J	MS	S	S	S	R	S	VS	S	MR	MS
RT 7311 CL	MS	R	--	--	--	--	S	S	MS	--
RT 7812 CL	--	--	--	--	--	--	--	S	--	--
RT XL729 CL	MS	R	MS	MR	R	S	MS	S	S	S
RT XL745 CL	S	R	R	MR	R	S	S	S	S	S
RT Gemini 214 CL	S	R	--	--	--	--	MS	VS	MS	--
RT XP753	MS	R	MS	MR	R	--	MS	S	MS	S
RT XP760	MS	MR	--	MR	R	--	MS	VS	S	--
Taggart	MS	MS	R	MS	MS	S	S	S	MS	MS
Thad	S	S	S	MS	--	--	S	VS	MR	-
Titan	S	MS	--	MS	--	--	MS	MS	MS	--
Wells	S	S	S	S	S	VS	S	S	MS	MS

[a] Reaction: R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible. Cells with no values indicate no definitive Arkansas disease rating information is available at this time. Reactions were determined based on historical and recent observations from test plots and grower fields across Arkansas and other rice states in southern U.S. In general, these ratings represent expected cultivar reactions to disease under conditions that most favor severe disease development. Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist.

Nitrogen Management in Rice Under Suboptimal Soil Conditions

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Abstract

In mid-South rice (*Oryza sativa*, L.) production, nitrogen (N) fertilizer is most often recommended as a single preflood application (SPF) or a two-way split (2WS) application in a dry-seeded, delayed-flood system. The majority of N fertilizer is typically applied at the 4-6 leaf stage onto dry soil, and the second application, if necessary, into the floodwater as a midseason application. Environmental factors do not always allow growers to apply early N fertilizer onto optimal dry soil conditions using these recommendations. This study was conducted to determine N fertilization best management practices in rice when faced with dry, wet, and flooded soil conditions. The study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) and at the Southeast Rice Research and Extension Center (SEREC) on two differing soil types, a silt loam and a clay, respectively, to evaluate N fertilizer treatments to the cultivar Diamond. Treatments included a control receiving no N, SPF and 2WS treatments applied to dry soils, wet soils, and wet soils at elevated fertilizer rates, and several treatments using single and multiple N applications into flooded conditions. Standard recommended N treatments applied to dry soil and wet soil at elevated N rates were among the highest yielding treatments at both locations, while spoon-fed treatments at RREC and single applications at flood initiation into flooded conditions at SEREC were not significantly different than standard recommendations.

Introduction

There are currently two common N fertilizer application recommendations in Arkansas, one being a single preflood application and the other being a standard two-way split consisting of a large preflood application followed by a midseason application. The preflood application suggested at 65-100% of the total N rate should be applied around the 4-5 leaf stage followed immediately by flood establishment to incorporate the N fertilizer (Hardke and Wilson, 2013). This application most often takes 3 weeks

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to be completely taken up by the plant (Wilson et al., 1989). If soil conditions are dry, the flood can be established in a timely manner (2 days or less on a silt loam, 7 days or less on a clay soil), and the flood maintained for at least 3 weeks; the optimum single preflood method is recommended, which in a study by Frizzell et.al. (2017) resulted in the greatest yields. If these goals cannot be achieved, the two-way split is the best N management approach.

The midseason N application timing must meet two requirements in order to be effective after application: 1) preflood N must have been incorporated by the permanent flood for a minimum of 21 days, and 2) the rice should have begun reproductive growth (i.e., beginning internode elongation; Frizzell et al., 2017). The presence of muddy or flooded field conditions during application windows is a frequent concern among rice growers in the mid-South. When dry soil conditions are not present and a flood cannot be managed timely, ammonia volatilization and denitrification become major loss pathways, due to poor incorporation of the N fertilizer into the soil. A study was conducted in 2017 to determine N fertilization best management practices in rice when faced with dry, wet, and flooded soil conditions.

Procedures

Studies involving N fertilizer management in rice under optimum and suboptimal soil conditions were conducted during the 2017 rice growing season at both the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam and the Southeast Research and Extension Center (SEREC) near Rohwer, Ark., on a Perry/Sharky clay. At the RREC, the rice cultivar Diamond was drill-seeded on 26 April at a rate of 30 seed/ft^2 (71 lb seed/acre). At the SEREC, Diamond was drill-seeded on 11 May at a rate of 36 seed/ft^2 (85 lb seed/acre). Plots at both locations were 8 rows wide on 7.5-in. spacing by 16.5 ft in length. Rice emerged at the RREC and SEREC on 7 May and 23 May, respectively. All N fertilizer application dates were determined using heat accumulation units in the Arkansas Degree-Day 50 (DD50) Rice Management Program.

Each location consisted of 16 treatments with 4 replications set up in a randomized complete block design. All other cultural practices followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommended practices for maximum yield. Standard treatments applied to dry soil included both the single preflood (SPF; 100 lb N/acre) and two-way split (2WS; 75 lb N/acre preflood followed by 46 lb N/acre at midseason) methods. Treatments applied to wet soil included the SPF and 2WS rates described above, as well as SPF and 2WS onto wet soil at elevated preflood N rates of 130 and 105 lb of N/acre, respectively. Treatments applied directly into standing floodwater ("spoon-fed") included: 1) 46 lb of N/acre applied to wet, muddy soil preflood followed by three weekly applications of 46 lb N/acre beginning one week after flood initiation, 2) five weekly applications of 46 lb N/acre beginning at flood initiation and another treatment beginning at the final recommended time to apply N based on the DD50 program, and 3) four applications of 46 lb N/acre beginning at the final DD50 date. All spoon-fed treatments were applied in 7 day intervals. While not normally recommended, single applications of 100 and 130 lb N/acre were made into the floodwater at both flood initiation and at the final DD50 date. A control plot, receiving 0 lb N/acre, and a high N reference plot receiving 180 lb of N/acre as a single preflood application were both included in the study and used as references. All treatments except those spoon-fed increased in rate by 80 lb N/acre at the SEREC site due to clay soil recommendations by N-STaR. All N fertilizer as urea applied to dry or muddy soil was treated with N-(n-butyl) thiophosphoric triamide (NBPT) to minimize N losses associated with ammonia volatilization.

Wet, muddy ground was imitated on individual plots via sprinkler systems. Portable PVC cages, (6.0-ft wide × 16.5-ft long × 2.5-ft tall), designed with Rainbird sprinkler systems were used to simulate a 1-in. rainfall until the ground was saturated. All sides of the PVC cages were enclosed by tarps to help mitigate water movement by wind. The system was attached to two water tanks and evenly distributed 56 gal of water within the rainfall simulator (90 ft^2). Immediately after all rain simulation was complete, preflood N fertilizer was applied followed by flood initiation. Rain simulation, preflood N fertilization, and permanent flood initiation occurred at RREC and SEREC on 31 May and 21 June, respectively. Flood initiation treatments started the day following flood initiation at each location, 1 June at RREC and 22 June at the SEREC. Treatments based on the final recommended time to apply N based on the DD50 Rice Management program began at the RREC and SEREC on 12 June and 29 June, respectively. Midseason N applications were made 29 June at the RREC and 20 July at the SEREC. All plots that received treatments into the flood were surrounded by galvanized metal frames that rested at the soil surface to prevent N fertilizer from drifting to adjacent plots.

At maturity, the center 4 rows of each plot were harvested to evaluate moisture content, weight of grain, and lodging percentages. Subsamples were taken from harvested grain to later determine and compare milling yields. Grain yields were adjusted to 12% moisture and reported as bushels/acre (bu/acre). Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.1$).

Results and Discussion

During 2017, due to a treatment by location interaction, data was analyzed independently by site (Tables 1 and 2). On the silt loam soil at the RREC, N treatments applied to dry soil according to standard recommendations, applied to wet soil with elevated N rates, and those applied in multiple applications into the flood ("spoon-fed") were the highest yielding treatments, while standard N rates applied to wet soil and single applications of high N rates into flooded conditions had statistically lower yields (Table 1). On the clay soil at the SEREC, N treatments applied to dry soil according to standard recommendations, applied in a single application into flooded conditions at flood initiation, applied to wet soil, and spoon-fed treatments applied at the elevated

N rate were the highest yielding treatments (Table 2). The lowest yielding were the spoon-fed treatments applied at the non-elevated 184 lb N/acre rate and the single applications into flooded conditions at the DD50 Final.

The results on the silt loam indicated that standard N fertilizer recommendations onto dry soil, onto wet soil with elevated N rates for compensation of loss, and multiple spoon-fed applications resulted in the highest yielding treatments (Table 1). The results on the clay soil indicated that standard N recommendations applied on to dry and wet soil and spoon-fed treatments applied at elevated N fertilizer rates were the highest yielding treatments (Table 2). Single applications of N even at high rates into the water were not hypothesized to yield well and are not normally recommended due to high N loss potential. However on the clay soil, these applications at the earlier application timing (Flood initiation) were not significantly different from the recommended treatments. Spoon-fed treatments applied at the non-elevated N rate did not perform as well as expected. Based on results in 2017, N applications made to dry soil were the most efficient in producing the highest grain yields while additional N was needed to produce similar yields when faced with wet or flooded soil conditions.

Significance of Findings

This study and its findings will allow University of Arkansas System Division of Agriculture personnel to help assist growers concerned with management decisions in rice, when faced with suboptimal soil conditions.

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Literature Cited

Frizzell D.L., J.T. Hardke, T.L. Roberts, R.J. Norman, N.A. Slaton, E. Castaneda-Gonzalez, G.J. Lee, and T.L. Clayton. 2017. Effect of Delayed Nitrogen Fertilization into the Floodwater. *In*: Norman and Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series 643:240-244. Fayetteville.

Hardke, J.T. and C.E. Wilson Jr. 2013. Introduction. In J.T. Hardke (ed.) Arkansas Rice Production Handbook. University of Arkansas. Division of Agriculture Cooperative Extension Service MP 192, Fayetteville. pp. 1-8.

Wilson, C. E., Jr., R.J. Norman, and B.R. Wells. 1989. Seasonal uptake patterns of fertilizer nitrogen applied in split applications to rice. Soil Sci. Soc. Am. J. 53:1884-1887.

Table 1. Influence of nitrogen (N) fertilizer applications effects on Diamond rice grain yield at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2017 when applied to dry, wet, and flooded soil conditions.

Treatment No.	N Timing[†§]	Initiation[†¶]	Pre-flood	Mid-season	Other	Total N applied	Grain yield[‡]
			(lb N/acre)	(lb N/acre)	(lb N/acre)	(lb N/acre)	
1	Control	none	0	0	0	0	123.5 f
2	SPF	pf	100	.	.	100	214.2 ab
3	SPF wet	pf	100	.	.	100	189.0 cd
4	SPF wet high	pf	130	.	.	130	205.2 bc
5	2WS dry	pf fb ms	75	46	.	121	220.6 ab
6	2WS wet	pf fb ms	75	46	.	121	194.7 cd
7	2WS wet high	pf fb ms	105	46	.	141	226.0 a
8	Wet / flood	pf fb spoon	46	.	3x46	184	218.7 ab
9	7 d	Flood initiation	.	.	5x46	230	230.0 a
10	7 d	DD50 Final	.	.	5x46	230	222.9 a
11	7 d	DD50 Final	.	.	4x46	184	228.9 a
12	SPF in flood	Flood initiation	100	.	.	100	155.7 e
13	SPF in flood	DD50 Final	100	.	.	100	155.2 e
14	SPF in flood high	Flood initiation	130	.	.	130	157.9 e
15	SPF in flood high	DD50 Final	130	.	.	130	181.5 d
16	Greenseeker check	pf	180	.	.	180	218.3 ab

† SPF = single preflood, pf = preflood, 2WS = two-way split, fb = followed by, ms = midseason.

‡ Means followed by the same letter are not significantly different, least significant difference (0.10).

§ Preflood N applied to "dry" or "wet" soil surface or fertilizer applied into the flood "flood".

¶ Flood initiation = one-day post flood, Degree-Day 50 (DD50) Final = Final recommended date to apply preflood N fertilizer based on DD50 Rice Management Program.

Table 2. Influence of nitrogen (N) fertilizer applications effects on Diamond rice grain yield at the University of Arkansas System Division of Agriculture Southeast Rice Research and Extension Center near Rohwer, Ark. during 2017 when applied to dry, wet, and flooded soil conditions.

Treatment no.	N Timing[†§]	Initiation[†¶]	Pre-flood	Mid-season	Other	Total N applied	Grain yield[‡]
			(lb N/acre)	(lb N/acre)	(lb N/acre)	(lb N/acre)	
1	Control	none	0	0	0	0	124.3 e
2	SPF	pf	180	.	.	180	214.1 ab
3	SPF wet	pf	180	.	.	180	209.1 ab
4	SPF wet high	pf	210	.	.	210	210.0 ab
5	2WS dry	pf fb ms	155	46	.	201	227.0 a
6	2WS wet	pf fb ms	155	46	.	210	203.0 b
7	2WS wet high	pf fb ms	185	46	.	231	208.2 ab
8	Wet / Flood	pf fb spoon	46	.	3x46	184	174.0 c
9	7 d	Flood initiation	.	.	5x46	230	216.6 ab
10	7 d	DD50 Final	.	.	5x46	230	201.4 b
11	7 d	DD50 Final	.	.	4x46	184	174.7 c
12	SPF in flood	Flood initiation	180	.	.	180	217.7 ab
13	SPF in flood	DD50 Final	180	.	.	180	149.3 d
14	SPF in flood high	Flood initiation	210	.	.	210	223.9 a
15	SPF in flood high	DD50 Final	210	.	.	210	163.8 cd
16	Greenseeker check	pf	210	.	.	210	198.3 b

† SPF = single preflood, pf = preflood, 2WS = two-way split, fb = followed by, ms = midseason.

‡ Means followed by the same letter are not significantly different, least significant difference (0.10).

§ Preflood N applied to “dry” or “wet” soil surface or fertilizer applied into the flood “flood”.

¶ Flood initiation=one-day post flood, Degree-Day 50 (DD50) Final = Final recommended date to apply preflood N fertilizer based on DD50 Rice Management Program.

Summary of Crop Yield and Soil-Test Phosphorus and Potassium Responses to Long-Term Fertilization Rate

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Abstract

Long-term fertilization trials provide insight about crop yield and soil test responses that are important components of developing profitable fertilization practices. This report summarizes the 11-year history of phosphorus (P) and potassium (K) fertilizer rate trials established in 2007 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center. Four research areas were established on a Dewitt silt loam and generally cropped to a 1:1 rice (*Oryza sativa* L.)-soybean [*Glycine max* (L.)] rotation with annual fertilizer rates of 0, 40, 80, 120 and 160 lb K_2O or P_2O_5/acre/year. Soil-test P declined from 19 to 15 ppm when no P fertilizer was applied and increased from 19 ppm to 29 to 95 ppm after 10 annual applications of 40 to 160 lb P_2O_5/acre. After 10 years, soil-test K declined by approximately 7 ppm/year when no K was applied and declined at slower rates with annual-K rates of 40 to 120 lb K_2O/acre/year. The initial soil-test K was increased or maintained annually only by applying 160 lb K_2O/acre/year. Rice yields (153-155 bu/acre average) were not affected by annual-K rate. Neither rice (151-152 bu/acre) nor soybean yields (58-60 bu/acre) were significantly affected by annual fertilizer-P rate. Soybean yields were affected by annual-K rate with the 11-year average yields of 40 to 160 lb K_2O/acre being 2.6 to 4.5 bu/acre/year greater than soybean receiving no fertilizer K (52.5 bu/acre/year). After 11 crop years, both rice and soybean are starting to show growth differences due to the annual fertilization rates and the trials will be continued.

Introduction

Arkansas rice growers apply an average of 65 lb P_2O_5 and 85 lb K_2O/acre to 76% and 56%, respectively, of the rice acres produced in Arkansas (USDA-NASS, 2013). Phosphorus and K fertilization practices of rice and soybean, the primary crop grown

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in rotation with rice, have changed during the past 30 years with greater per acre rates and percentage of cropped acres now receiving P and K fertilizer. During this period, the University of Arkansas' soil-test based fertilizer recommendations have changed several times with changes based on field observations coupled with a database of fertilization research results.

Flood-irrigated rice, as a general rule, is less responsive to P and K fertilization than other row crops, due, in part, to its large superficial root system and enhanced nutrient mobility and availability in the flooded soil. Although the flooded soil is beneficial for nutrient availability, the anaerobic soil condition creates a different nutrient availability environment than what is simulated in routine soil testing methods. Soil-test K has been shown to be a reasonably accurate assessment of relative soil K availability and assessing rice response to K fertilization; but research in Arkansas (Fryer, 2015) and around the world, has shown that soil-test P methods are poorly correlated with rice response to P fertilization. Long-term experiments were established with both P and K to assess how Mehlich-3 extractable soil-test concentrations and rice and soybean yields change across time to long-term P and K fertilization. The overall goal of this research was to create a similarly managed soil with different nutrient availability levels that produce crops that range from deficient to sufficient in P and K availability so that we can develop more accurate fertilization tools.

Procedures

A long-term field trial was established at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center in 2007 on a Dewitt silt loam and, in most years, cropped to a 1:1 rice-soybean rotation. The research contained adjacent and duplicate trials for each nutrient that allowed both rice and soybean to be grown each year and sufficient border area to establish additional research objectives involving each nutrient. The exception to this was that soybean was grown in both plot areas during 2009 and 2012 (due to failed rice stand) resulting in a total of 9 rice crops and 13 soybean crops in the last 11 years. Individual plots measure 15-ft wide and 25-ft long, which allows at least two passes with a small plot (8- or 9-row) drill with 7.5-in row spacings. All four research blocks have been managed with no-tillage since their establishment and receive periodic, low rates of pelleted lime to maintain pH between 5.5 and 6.2. The same fertilizer-P and -K treatments have been applied to each plot since the trial was initiated with applications made to the soil surface as early as February (preplant) to immediately following planting. The rates were 0, 40, 80, 120 and 160 lb K_2O or P_2O_5/acre/year applied as muriate of potash or triple superphosphate. Ample rates of fertilizer-K are applied uniformly to the P rate trial area (and vice versa, P to K rate trial) to ensure that only the nutrient of interest within each research area is potentially limiting crop growth.

Management of rice and soybean with respect to stand establishment, pest control, irrigation, nitrogen (N) and zinc (Zn) fertilization, and other practices have closely followed University of Arkansas System Division of Agriculture guidelines for full-season soybean and direct-seeded, delayed-flood rice production. At maturity, plots were trimmed, measured, and the middle rows harvested with a small-plot combine. Grain weights and moistures were determined by hand and used to adjust grain yields to 12% (rice) or 13% (soybean) moisture by weight for statistical analysis. The relative yield (percent of maximum) of each treatment was calculated by replicate for each year and crop by dividing each plot yield by the highest yield in each block.

Composite soil samples (0- to 4-in depth) were collected from each plot immediately before the trial was started and each subsequent year in mid to late winter (January–March). Soil samples were oven-dried at 149 °F (65 °C), crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture, extracted using the Mehlich-3 method, and elemental concentrations were determined by inductively coupled plasma atomic emission spectroscopy. Selected soil chemical property means are listed in Table 1.

Each experiment was a randomized complete block design with 6 blocks that contained each fertilizer-P or -K rate. The annual soil-test P and K values (replicate data) for the two research areas were regressed using a model that included linear and quadratic time terms and their interaction with annual nutrient rate (intercept term) using the Mixed procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Analysis of variance was performed on actual and relative yield by crop and nutrient with the MIXED procedure in SAS with significant differences interpreted when $P < 0.10$. To examine the effect of K rate on the yield of each crop, year was considered a random effect. Mean separations were performed by Fisher's protected least significant difference test.

Results and Discussion

The mean Mehlich-3 extractable P and K concentrations in each research area changed after the fertilization and harvest of 10 crops with different annual-P and -K rates (Table 1). Soil-test K has followed a nonlinear (quadratic) trend across time that depended on annual-K rate (Fig. 1). The final model had an R^2 of 0.71 indicating that time and annual-K rate explained a large proportion of the variability in soil-test K. The soil-test K in soil receiving 0, 40 or 80 lb K_2O/acre/year has declined across time with the rate of decline increasing as annual-K rate decreased from 80 to 0 lb K_2O. Soil fertilized with 120 and 160 lb K_2O/acre/year initially increased but both are now declining. The current soil-test K is within 10 ppm of the initial soil-test K in 2007 only for soil receiving 160 lb K_2O/acre/year. Soil receiving no K for the duration of the first 10 years of cropping has declined at a rate of about 7 ppm K/year. The average rate of K removal in harvested grain by the highest mean yields (Table 2) is about 25 lb K_2O for rice and 68 lb K_2O for soybean with the average annual removal (mean 47 lb K_2O) being slightly greater than the lowest annual fertilizer-K rate.

Soil-test P was also a quadratic function of time that depended on annual fertilizer-P rate (Fig. 2.) with time and annual-P rate explaining 91% of the variability in soil-test P. On average, application of no fertilizer P has resulted in a 4 ppm decline in soil-test P over the first 10 years of the trial. The soil-test P has increased from 19 ppm in 2007 to 29 and 95 ppm for soil receiving 40 and 160 lb P_2O_5/acre/year. Thus, in contrast to soil-test K, soil-test P has increased across time, even when the average fertilizer-P rate is slightly less than the mean average P removed by harvested grain (approximately 46 lb and 44 P_2O_5/acre/year for rice and soybean, respectively). Although the exact causes for the different trends in soil-test P and K are unknown, it may involve interactions between relative nutrient mobility (nutrient losses), soil cation exchange capacity, and lack of tillage (increasing nutrient stratification by depth). We have reported similar soil-test K trends from another long-term K trial established on a Calhoun silt loam (Slaton et al., 2017).

The overall average actual and relative yields for 9 rice crops have not been affected by annual-K fertilization rate, but the average yield of 13 soybean harvests has been affected by annual-K rate (Table 2). Mean soybean yield has been 2.6 to 4.5 bu/acre/year greater when 40 to 160 lb K_2O/acre/year has been applied. Assuming \$10.00/bu soybean price, \$0.30/lb K_2O cost, \$6.00/acre/year application fee, and no yield change in the rotation crop, the net income increases of \$14.00 and \$33.00/acre calculate that the breakeven annual-K rates would range from 23 to 55 lb K_2O/acre/year. The lowest K rate applied in this trial, 40 lb K_2O/acre/year, is within the range and would produce near maximal yield and provide the greatest return per unit of fertilizer K applied (0.065 bu/lb K_2O). The application of P fertilizer has had no influence on average rice and soybean yields during the past 11 years (Table 3).

Despite the initial low soil-test P, the failure of annual-P fertilization rate to increase rice and soybean yields is good reason to use fertilizer P very judiciously to minimize loss of profit from applying fertilizer with no return on investment. Because soil-test P is not a good indicator of crop response to P fertilization and the difficulty in correcting P deficiency, a moderate approach of applying a minimal annual P rate when soil-test values are low seems appropriate.

Rice and soybean yield response within each year were not fully examined in this report but it is important to mention that during 2016 and 2017, early season growth differences for both rice and soybean were observed in the P trials and symptoms of K deficiency were observed on soybean for the first time. The use of fertilization strategies (e.g., application of K only to soybean) other than what was used in this study may be warranted. As the soil becomes depleted of P and K with future cropping, we expect that fertilization differences will become more pronounced and frequent in both crops and nutrients.

Significance of Findings

Ten years of soil-test results and 11 years of crop yields provide insight on how crop yields and soil fertility indices respond to cropping and different fertilization rates. Overall, the results suggest that soybean is more sensitive to K deficiency than rice and that fertilization programs should consider whether there is a return on investment in the form of yield benefit from applied fertilizer. Fertilization to meet soil-test goals whether the goal be to build or maintain high soil-test levels may result in large expenditures with little or no return on investment. These results support the philosophy that fertilizer rates should be based on expected crop response and calibration curves rather than soil nutrient building and maintenance equations. Soils receiving high rates of P or K fertilizer have not produced yields that are greater than the same soil receiving lower rates of the same fertilizer indicating that nutrient availability is only one of many factors that influence crop yields.

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Literature Cited

Fryer, M.S. 2015. Validation of soil-test-based phosphorus and potassium fertilizer recommendations for rice and soybean. M.S. Thesis. University of Arkansas, Fayetteville Available from ProQuest Dissertations and Theses database. No. 1605004.

Slaton, N.A., R.J. Norman, T.L. Roberts, J.T. Hardke, R.E. DeLong, Y.D. Liyew, and D.L. Frizzell. 2017. Summary of crop yield and soil-test potassium responses to long-term potassium fertilization. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Arkansas Rice Research Series 2016. University of Arkansas Agricultural Experiment Station Research Series 643:321-327.

USDA-NASS. 2013. United States Department of Agriculture National Agricultural Statistics Service. 2013 Peanuts and Rice Chemical Use. Accessed 26 Dec 2017. https://www.nass.usda.gov/Data_and_Statistics/Pre-Pefined_Queries/2013_Peanuts_and_Rice/

Table 1. Soil pH and Mehlich-3 extractable P and K from the 0 to 4 in. depth (*n* = 12) from the no fertilizer-P or -K control including the initial soil properties (2007) and the subsequent annual values after 1 through 10 harvested crops (2017).

	K trials			P trial averaged		
Year	pH	P	K	pH	P	K
		ppm (SD)†	ppm (SD)		ppm (SD)	ppm (SD)
2007	5.4	25 (3)	144 (14)	5.6	18 (3)	127 (10)
2008	5.4	23 (5)	142 (14)	5.5	15 (3)	147 (18)
2009	5.6	29 (8)	139 (16)	5.8	18 (4)	132 (9)
2010	5.9	37 (7)	98 (14)	5.9	16 (4)	94 (10)
2011	5.6	30 (8)	109 (12)	5.5	14 (3)	118 (14)
2012	5.4	34 (5)	95 (14)	5.5	16 (4)	119 (14)
2013	5.9	33 (5)	81 (12)	5.8	15 (5)	121 (13)
2014	5.8	36 (6)	89 (15)	5.6	11 (4)	130 (8)
2015	5.7	38 (5)	85 (11)	5.6	13 (3)	129 (17)
2016	5.8	41 (6)	84 (7)	5.5	14 (3)	126 (8)
2017	5.6	46 (5)	76 (11)	5.4	14 (4)	134 (14)

† SD, standard deviation of mean.

Table 2. Summary of the rice (mean of 9 crops) and soybean (mean of 13 crops) yields averaged across crop years as affected by annual fertilizer-K rate on a Dewitt silt loam soil.

Annual-K	Mean crop yield†			
Rate	Rice	Relative yield	Soybean	Relative yield
lb K_2O/acre	bu/acre	% of maximum	bu/acre	% of maximum
0	153	94	52.5 c	85.3 c
40	155	95	55.1 ab	89.2 b
80	155	95	55.5 ab	90.0 ab
120	153	94	56.4 ab	91.6 ab
160	153	94	57.0 a	91.9 ab
P-value	0.4254	0.4900	0.0002	0.0009

† Within each column with a significant *P* value (<0.10), means followed by different lowercase letters indicate statistically significant differences.

Table 3. Summary of the rice (mean of 9 crops) and soybean (mean of 13 crops) yields averaged across crop years as affected by annual fertilizer-P rate on a Dewitt silt loam soil.

	Mean crop yield			
Annual-P rate	Rice	Relative yield	Soybean	Relative yield
lb P_2O_5/acre	bu/acre	% of maximum	bu/acre	% of maximum
0	151	95	58	88
40	152	95	60	91
80	152	95	60	92
120	151	95	59	89
160	151	93	59	91
P-value	0.9547	0.1813	0.3125	0.3527

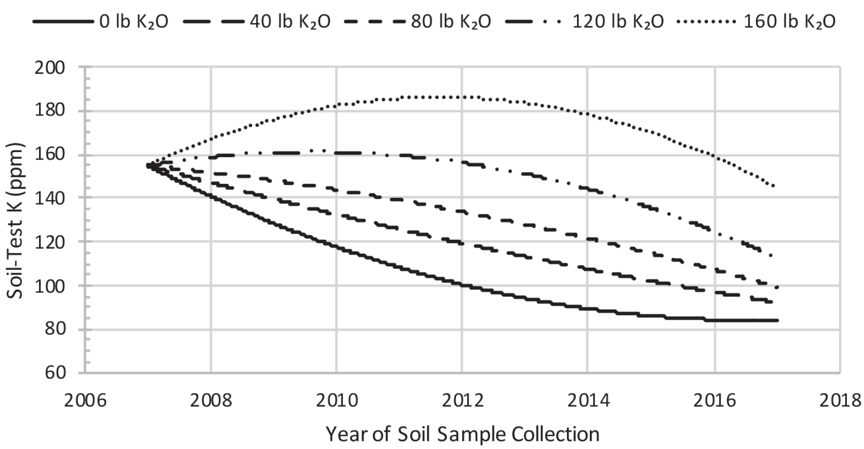

Fig. 1. Mehlich-3 extractable soil K response to annual fertilizer-K rate after 10-years of cropping and fertilization.

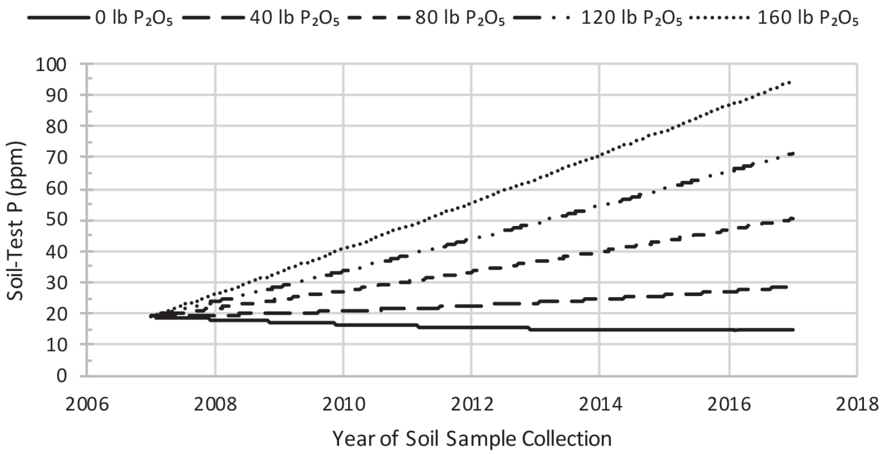

Fig. 2. Mehlich-3 extractable soil P response to annual fertilizer-P rate after 10-years of cropping and fertilization.

Late-Season Nitrogen Application to Hybrid Rice

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Abstract

Hybrid rice cultivars have accounted for approximately 40% of harvested rice acres in Arkansas in recent years. The current University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendation for hybrid cultivars, besides preflood nitrogen (N), is for an additional 30 lb N/acre, termed late-boot N, to be applied between late boot and beginning heading in order to reduce lodging and enhance grain and milling yields. This recommendation is based on N-rate and distribution studies conducted up to 12 years ago on hybrid cultivars that are no longer in production. In order to determine the validity of this recommendation on current hybrid cultivars, this study was initiated to examine the effects of late-boot N application on the grain yield, milling yield, and lodging of new hybrid rice cultivars. The RiceTec hybrids most commonly grown in Arkansas, RT XL745 CL and XP753, were seeded at three University of Arkansas System Division of Agriculture experiment centers/stations. Results of this study suggest that the late-boot N application generally has a positive impact on milling yields of RiceTec XL745 CL and XP753, where percent head rice was often significantly greater and percent total white rice sometimes significantly greater when late-boot N was applied, relative to receiving no boot N. Lodging, which was only substantial in RT XL745 CL at the Northeast Research and Extension Center (NEREC), was numerically reduced by the late-boot N application at all preflood N rates, although not statistically significant. Similarly, though the late-boot N application only significantly improved the grain yield of XP753 at the Rice Research and Extension Center (RREC), there was a clear trend of the late-boot N application increasing hybrid grain yields, particularly at low preflood N rates. The late-boot N application resulted in numerically greater grain yields of XP753 at all preflood N rates at the RREC. The potential benefits of a 30 lb N/acre late-boot N application to hybrids are apparent, but it will be important to collect more data to further understand and clarify the statistical relationship of the late-boot N application on lodging, milling yields, and grain yields of current hybrid cultivars.

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Introduction

Hybrid rice cultivars have accounted for approximately 40% of harvested rice acres in Arkansas in recent years, with the two predominant hybrids, RiceTec's XL745 CL and XP753, making up 79% to 92% of those hybrid acres from 2013 to 2016 (Hardke, 2015, 2017). While the management of preflood N is similar between currently grown hybrids and pure-line cultivars, the recommended amount and timing of a second N application varies when using a two-way split N application method. A midseason application of 45 lb N/acre following beginning internode elongation is recommended for pure-line cultivars, while a rate of 30 lb N/acre, termed late-boot N, should be applied between late boot and beginning heading for hybrid cultivars (Norman et al., 2013). The late-boot N application to hybrids typically results in reduced lodging and has potential to enhance grain (Norman et al., 2006, 2007, 2008) and milling (Walker et al., 2008) yields. The current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendation is based on N-rate and distribution studies conducted 9 to 12 years ago on hybrid cultivars that are no longer in production. In order to determine the validity of this recommendation on current hybrid cultivars, it is necessary to examine the effects of late-boot N application on grain yield, milling yield, and lodging of new hybrid rice cultivars. Therefore, a study, initiated in 2016, was continued in 2017 to determine the possible benefits of the late-boot N application to hybrid cultivars, as recommended by CES guidelines.

Procedures

The studies were conducted in 2017 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calhoun silt loam; and the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam. The RiceTec hybrids, XL745 CL and XP753, were drill-seeded at average rates of 23.5 and 28.2 lb seed/acre on the silt-loam and clay soils, respectively, in plots 8 rows (7.5-in. spacing) wide and 15.5 ft in length. Pertinent agronomic information for each location is shown in Table 1. Preflood N fertilizer, in the form of N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea, was applied to a dry soil surface at the 4- to 5-leaf growth stage at each of the three locations. Preflood N rates of 90, 120, and 150 lb N/acre and 100, 130, and 160 lb N/acre were utilized on the silt-loam soils at the RREC and the PTRS, respectively, based on differences in native-soil N availability at the two locations. Greater preflood N rates of 130, 160, and 190 lb N/acre were used at the NEREC, based on the CES recommendation to increase preflood N rates by 30 lb/acre on clay soils (Norman et al., 2013). A flood was established 12 days after preflood N application at each of the three locations and was maintained until the rice reached maturity. At the late-boot growth stage, just prior to beginning heading, an additional treatment of either no N fertilizer or 30 lb N/acre as urea was implemented in all plots. The center 4 rows of each plot were harvested at maturity using a small-plot combine, the moisture content and weight of grain were determined, and yields were calculated based on 12% moisture and a 45-lb bushel (bu) weight. A subsample of grain from each plot was milled to determine percent head rice (%HR, whole kernels) and percent total white rice (%TR) to provide milling yields expressed as %HR/%TR. At all three locations, each hybrid was arranged in a 4 replicate, randomized complete block factorial design with 3 preflood N application rate treatments and 2 late-boot N application treatments. Analysis of variance was performed on the grain yield and milling data using SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). When necessary, differences among means were compared using Fisher's protected least significant difference (LSD) procedure at a $P = 0.05$ probability level.

Results and Discussion

Preflood N rate, late-boot N application, or their interaction did not significantly impact ($P > 0.05$) the grain yield of the rice hybrid RT XL745 CL at any of the three study locations in 2017. Increasing the preflood N rate, however, consistently resulted in a numerical increase in grain yields at all three locations when no boot N was applied (Table 2). Without a boot N application, grain yields increased by 19, 12, and 23 bu/acre at NEREC, PTRS, and RREC, respectively, when preflood N was increased from low to high application rates. The impact of preflood N rate was reduced, however, by the application of 30 lb N/acre at late boot, where increases in grain yield between low and high preflood N rates ranged from 1 bu/acre at NEREC to 8 bu/acre at PTRS. The effect of a late-boot N application was apparent at low preflood N rates at all locations, resulting in numerical increases of 17, 4, and 12 bu/acre at the NEREC, PTRS, and RREC, respectively. The boot N application was less effective at intermediate preflood N rates, where no increase in grain yield occurred at PTRS and increases of 9 and 5 bu/acre occurred at NEREC and RREC, respectively, from a late-boot N application of 30 lb N/acre. The late-boot N application did not positively impact grain yields of RT XL745 CL at any location when high preflood N rates were used. While lodging of RT XL745 CL was minor at PTRS and RREC in 2017, the late-boot N application numerically reduced lodging at NEREC when the low and high preflood N rates were applied.

For the hybrid RT XL745 CL, preflood N rate and late-boot N application significantly impacted %HR at NEREC and RREC, but not at PTRS (Table 3). Percent total white rice for RT XL745 CL was not affected by preflood N rate or late-boot N application at any location in 2017. At the NEREC and RREC, %HR significantly increased from low to intermediate preflood N rates, though smaller increases from intermediate to high preflood N rates were not significant. While not always significant, %HR increased consistently from low to intermediate to high preflood N rates, where %HR ranged from 50.8% to 57.7% at the NEREC, 53.1% to 58.4% at the PTRS, and 52.4% to 58.3% at the RREC for low and high preflood N rates, respectively. Percent total white rice was fairly consistent among preflood N rates and locations, ranging from 69.3% to 71.6%. The general trend of %HR increasing as preflood N rates increase is consistent with results from RT XL745 CL studied in 2016 (Frizzell et al., 2017). The late-boot N application of 30 lb N/acre significantly increased %HR of RT XL745 CL by 2.7 and 2.8 percentage points at the NEREC and RREC, respectively, while the increase from 54.0 to 55.8 %HR was not significant at PTRS. Similarly, Frizzell et al. (2017) observed an increase in %HR, though not always significant, from RT XL745 CL when late-boot N was applied.

Preflood N rate significantly impacted the grain yield of XP753 at the PTRS and RREC in 2017 (Table 4). The grain yield increased from 161 to 182 bu/acre at the PTRS when the preflood N rate was increased from 100 to 130 lb N/acre, while increasing the preflood N rate to 160 lb N/acre resulted in no further increase in grain yield. At the RREC, grain yield increased as preflood N rate increased and resulted in grain yields of 194, 214, and 234 bu/acre at preflood N rates of 90, 120, and 150 lb N/acre, respectively. Although not significant, grain yields from XP753 at the NEREC in 2017 also increased as preflood N rate increased. The influence of a late-boot N application, averaged across preflood N rates, was only significant at the RREC, where an 11 bu/acre increase from XP753 resulted from a 30 lb N/acre late-boot application.

The cultivar XP753 at the PTRS exhibited a trend of decreasing impact of the late-boot N application on grain yield as preflood N rate was increased (Table 5), similar to the trend observed for RT XL745 CL at the three locations (Table 2). Although not statistically significant, the relationship between preflood N rate, late-boot N application, and grain yield was quite different for XP753 compared to RT XL745 CL at the NEREC and RREC. At the NEREC, the late-boot N application had little impact on the grain yield of XP753, resulting in a slight yield increase at the high preflood N rate, while not affecting grain yield at low and intermediate preflood N rates (Table 5). Somewhat similarly, the late-boot N application increased grain yields by 14 bu/acre at both intermediate and high preflood N rates at the RREC, while the low preflood N rate only increased the grain yield by 5 bu/acre. The general trend of the late-boot N application being more effective at lower preflood N rates and decreasing in impact as preflood N rates are increased to meet or exceed total N requirements is expected and was exhibited by RT XL745 CL at all locations, but XP753 only at the PTRS. The positive impact of the late-boot N application on XP753 grain yield at the RREC, however, was apparent at all three preflood N rates of 90, 120, and 150 lb N/acre. Although not as pronounced, results from 2016 similarly indicated that the effectiveness of a late-boot N application was greater for XP753 than for RT XL745 CL at high preflood N rates (Frizzell et al., 2017). There was no substantial lodging of XP753 during 2017 at any location, so the impact of preflood N rates and late-boot N application on lodging of XP753 were not evaluated.

Preflood N rate significantly impacted %HR of XP753 at all locations in 2017 (Table 6). At the NEREC, %HR of XP753 was significantly greater at the high preflood N rate at 55.5%, which was 14 and 9 percentage points greater than %HR at low and intermediate preflood N rates, respectively, which did not differ significantly from each other. Percent head rice at the PTRS increased by 8 percentage points as the preflood N rate was increased from the low to the intermediate preflood N rate, but did not increase further at the high preflood N rate. Percent head rice for XP753 at the RREC increased incrementally from 41.7% to 46.3% to 50.1% at the low, intermediate, and high preflood N rates, respectively. The effect of preflood N rate on %TR of XP753 was only significant at the RREC, where %TR was less at the low preflood N rate than at the intermediate or high preflood N rates, which did not differ. The late-boot N application did not significantly impact milling yields of XP753 at the NEREC in 2017, but the late-boot N application numerically increased both %HR and %TR relative to when no late-boot N was applied. Percent head rice, however, at the PTRS and RREC was greater when late-boot N was applied to XP753 than with no late-boot N application. Similarly, the late-boot N application to XP753 increased %TR at the RREC in 2017, but the numerical increase at the PTRS was not significant.

Significance of Findings

Results of this study indicate several potential benefits of a late-boot N application to hybrid rice. Substantial lodging in 2017 only occurred in RT XL745 CL at the NEREC, where the late-boot N application seemed to effectively reduce lodging. Further research will be necessary to clearly understand the relationship between a late-boot N application, lodging, and grain yields in hybrid rice cultivars. The positive impact of the late-boot N application on milling yield was apparent in 2017, consistently resulting in increased %HR and %TR, relative to rice receiving no late-boot N application. When averaged across preflood N rates, the boot N application resulted in a statistically significant increase in the grain yield of XP753 at the RREC, while it did not significantly impact grain yields of XP753 at the NEREC or PTRS, or grain yields of RT XL745 CL at any of the three locations. The practical significance, however, should not be overlooked as the late-boot N application increased grain yields of RT XL745 CL and XP753 by as much as 17 and 20 bu/acre, respectively. As expected, a common trend was for the late-boot N application to have the greatest impact on grain yields at low preflood N rates and decrease in effectiveness as preflood N rates increased (e.g., RT XL745 CL at NEREC and RREC, XP753 at PTRS). The grain yield of XP753 at the RREC, however, was positively impacted by a late-boot N application at all three preflood N rates and late-boot N applications had little effect on grain yields of RT XL745 CL at the PTRS and XP753 at the NEREC at any preflood N rate. Collecting data from additional growing seasons and hybrid cultivars will be necessary to more clearly understand the impact of the late-boot N application on lodging, milling yields, and grain yields of hybrid rice.

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Literature Cited

Frizzell, D.L., R.J. Norman, A.D. Smartt, J.T. Hardke, T.L. Roberts, N.A. Slaton, E. Castaneda-Gonzalez, G.J. Lee, M.W. Duren, and T.L. Clayton. 2017. Late-season nitrogen application to hybrid rice – First year results. *In*: R.J. Norman and

K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series. 643:230-239. Fayetteville.

Hardke, J.T. 2015. Trends in Arkansas rice production, 2014. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2014. University of Arkansas Agricultural Experiment Station Research Series. 626:11-22. Fayetteville.

Hardke, J.T. 2017. Trends in Arkansas rice production, 2016. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2016. University of Arkansas Agricultural Experiment Station Research Series. 643:11-21. Fayetteville.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. pp. 69-101. *In*: J.T. Hardke (ed.). Arkansas rice production handbook. Misc. Publ. 192. University of Arkansas Cooperative Extension Service, Little Rock.

Norman, R.J., C.E. Wilson Jr., N.A. Slaton, D.L. Frizzell, J.D. Branson, M.W. Duren, K.A.K. Moldenhauer, and J.W. Gibbons. 2008. Grain yield response of fourteen new rice cultivars to nitrogen fertilization. *In*: R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2007. University of Arkansas Agricultural Experiment Station Research Series. 560:183-194. Fayetteville.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton, D.L. Frizzell, M.W. Duren, A.L. Richards, J.W. Gibbons, and K.A.K. Moldenhauer. 2007. Grain yield response of ten new rice cultivars to nitrogen fertilization. *In*: R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2006. University of Arkansas Agricultural Experiment Station Research Series. 550:303-314. Fayetteville.

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton, D.L. Frizzell, A.L. Richards, M.W. Duren, J.W. Gibbons, and K.A.K. Moldenhauer. 2006. Grain yield response of fifteen new rice cultivars to nitrogen fertilization. *In*: R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2005. University of Arkansas Agricultural Experiment Station Research Series. 540:276-290. Fayetteville.

Walker, T.W., J.A. Bond, B.V. Ottis, P.D. Gerard, and D.L. Harrell. 2008. Hybrid rice response to nitrogen fertilization for midsouthern United States rice production. Agron. J. 100:381-386.

Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center (RREC) during 2017.

Practices	NEREC	PTRS	RREC
Preplant fertilizer	----	60 lb P_2O_5/acre 90 lb K_2O/acre + 10 lb Zn/acre	60 lb P_2O_5/acre 90 lb K_2O/acre + 10 lb Zn/acre
Planting dates	14 April	10 May	13 April
Herbicide spray dates and spray procedures	14 April 1.4 pt/acre Command + 43 oz/acre Facet	22 March 32 oz/acre Devour + 1% COC	18 April 20 oz/acre Obey
Herbicide spray dates and spray procedures	22 May 4 qt/acre Propanil + 1 oz/acre Permit	13 April 6 oz/acre First Shot + 0.5% COC	11 May 15 oz/acre Clincher
Herbicide spray dates and spray procedures	30 May 15 oz/acre Clincher + COC	15 May 2 pt/acre Prowl H_2O + 20 oz Facet L	----
Emergence dates	8 May	18 May	21 April
Preflood N dates	8 June	20 June	23 May
Flood dates	9 June	21 June	24 May
Boot N application	26 July	2 August (RT XL745 CL) 3 August (XL753)	12 July
Drain dates	28 August		18 August
Harvest dates	21 September	27 September	24 August

Table 2. Influence of preflood (PF) nitrogen (N) fertilizer rate and late-boot N application on the grain yield and lodging of RiceTec XL745 CL hybrid rice at three locations during 2017.

	Grain yield and lodging					
	Location/ boot N rate (lb N/acre)					
	NEREC[†]		PTRS		RREC	
PF N rate[‡]	0	30	0	30	0	30
	(bu/acre)					
Low	169	186	157	161	191	203
Med.	170	179	164	164	204	209
High	188	187	169	169	214	207
$LSD_{0.05}$[§]	N.S.[¶]		N.S.		N.S.	
	(% lodged)					
Low	22.5	10.0	0	0	3.3	0
Med.	14.4	14.1	0	0	0	3.3
High	26.3	15.0	7.5	5.0	0	3.3
$LSD_{0.05}$	N.S.		N.S.		N.S.	

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Preflood N rates of low, med., and high correspond to 130, 160, and 190 lb N/acre, respectively, at NEREC, 100, 130, and 160 lb N/acre, respectively, at PTRS, and 90, 120, and 150 lb N/acre, respectively, at RREC.

[§] LSD = least significant difference.

[¶] N.S. = not significant at 0.05 alpha level.

Table 3. Influence of preflood (PF) nitrogen (N) fertilizer rate and late-boot N application on the milling yield of RiceTec XL745 CL hybrid rice at three locations during 2017.

	Milling yield		
Treatment	**NEREC**[†]	**PTRS**	**RREC**
PF N rate[‡]	---------------------- (%HR/%TR[§]) ----------------------		
Low	50.8/71.3	53.1/70.2	52.4/70.7
Med.	55.1/71.2	53.2/69.3	56.4/71.6
High	57.7/70.8	58.4/70.9	58.3/71.1
%HR $LSD_{0.05}$[¶]	2.6	N.S.[#]	2.3
%TR $LSD_{0.05}$	N.S.	N.S.	N.S.
Boot N rate			
0 lb N/acre	53.2/70.9	54.0/69.8	54.3/70.8
30 lb N/acre	55.9/71.3	55.8/70.4	57.1/71.4
%HR $LSD_{0.05}$	2.1	N.S.	1.9
%TR $LSD_{0.05}$	N.S.	N.S.	N.S.

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Preflood N rates of low, med., and high correspond to 130, 160, and 190 lb N/acre, respectively, at NEREC, 100, 130, and 160 lb N/acre, respectively, at PTRS, and 90, 120, and 150 lb N/acre, respectively, at RREC.

[§] %HR/%TR = % head rice and % total white rice.

[¶] LSD = least significant difference.

[#] N.S. = not significant at 0.05 alpha level.

Table 4. Influence of preflood (PF) nitrogen (N) fertilizer rate and late-boot N application on the grain yield of RiceTec XP753 hybrid rice at three locations during 2017.

	Grain yield		
Treatment	**NEREC**[†]	**PTRS**	**RREC**
PF N rate[‡]	(bu/acre)		
Low	216	161 b[§]	194 c
Med.	221	182 a	214 b
High	248	180 a	234 a
$LSD_{0.05}$[¶]	N.S.[#]	15.5	11.6
Boot N rate			
0 lb N/acre	227	169	208 b
30 lb N/acre	229	180	219 a
$LSD_{0.05}$	N.S.	N.S.	9.5

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Preflood N rates of low, med., and high correspond to 130, 160, and 190 lb N/acre, respectively, at NEREC, 100, 130, and 160 lb N/acre, respectively, at PTRS, and 90, 120, and 150 lb N/acre, respectively, at RREC.

[§] Values in the same column followed by different letters are significantly different ($P < 0.05$).

[¶] LSD = least significant difference.

[#] N.S. = not significant at 0.05 alpha level.

Table 5. Influence of preflood (PF) nitrogen (N) fertilizer rate and late-boot N application on the grain yield of RiceTec XP753 hybrid rice at three locations during 2017.

	Grain yield					
	Location/ boot N rate (lb N/acre)					
	NEREC[†]		**PTRS**		**RREC**	
PF N rate[‡]	**0**	**30**	**0**	**30**	**0**	**30**
	(bu/acre)					
Low	216	216	151	171	191	196
Med.	221	221	178	186	207	221
High	244	252	177	182	227	241
$LSD_{0.05}$[§]	N.S.[¶]		N.S.		N.S.	

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Preflood N rates of low, med., and high correspond to 130, 160, and 190 lb N/acre, respectively, at NEREC, 100, 130, and 160 lb N/acre, respectively, at PTRS, and 90, 120, and 150 lb N/acre, respectively, at RREC.

[§] LSD = least significant difference.

[¶] N.S. = not significant at 0.05 alpha level.

Table 6. Influence of preflood (PF) nitrogen (N) fertilizer rate and late-boot N application on the milling yield of RiceTec XP753 hybrid rice at three locations during 2017.

	Milling yield		
Treatment	**NEREC**†	**PTRS**	**RREC**
PF N rate‡	------------------------(%HR/%TR§)------------------------		
Low	41.5/69.1	42.7/67.6	41.7/69.3
Med.	46.3/70.1	50.7/69.0	46.3/69.8
High	55.5/70.6	50.7/68.7	50.1/70.2
%HR $LSD_{0.05}$¶	5.9	3.9	3.2
%TR $LSD_{0.05}$	N.S.#	N.S.	0.5
Boot N rate			
0 lb N/acre	45.4/69.1	45.8/67.8	43.1/69.3
30 lb N/acre	50.1/70.8	50.2/69.1	49.0/70.2
%HR $LSD_{0.05}$	N.S.	3.2	2.6
%TR $LSD_{0.05}$	N.S.	N.S.	0.4

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Preflood N rates of low, med., and high correspond to 130, 160, and 190 lb N/acre, respectively, at NEREC, 100, 130, and 160 lb N/acre, respectively, at PTRS, and 90, 120, and 150 lb N/acre, respectively, at RREC.

§ %HR/%TR = % head rice and % total white rice.

¶ LSD = least significant difference.

N.S. = not significant at 0.05 alpha level.

Response of Two Rice Cultivars to Midseason Nitrogen Fertilizer Application Timing

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Abstract

A study was conducted at two locations in 2017 to examine the influence of midseason nitrogen (N) application timing on the grain yield of conventional, pure-line rice (*Oryza sativa* L.) cultivars from Louisiana and Arkansas. The conventional rice cultivars chosen for the study at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC) were the Horizon Ag semi-dwarf, long-grain CL151 and the Arkansas short-stature, long-grain Diamond. There were two preflood N rates and five midseason N application timings at beginning internode elongation (BIE), BIE+7 days, BIE+14 days, BIE+21 days, and BIE+28 days. There was also a control, or no midseason N application, and an optimum single preflood N application treatment. Diamond produced a greater yield than CL153 at the NEREC and RREC at both preflood N rates. At the NEREC, midseason N timing had no effect on grain yield and did not differ from an optimum single preflood N rate at either preflood N rate. At the lower preflood N rate at the RREC, midseason N applied at BIE+7 or BIE+14 days resulted in greater yields than when not applied or when applied at BIE or BIE+28 days, but did not differ from application at BIE+21 days or a single preflood N application. When a higher preflood N rate was used at the RREC, grain yields were greater when midseason N was applied at BIE or BIE+7 days than when applied at BIE+28 days, when no midseason N was applied, and when a single preflood N rate was used. An optimum single preflood N application did not result in greater grain yields than when midseason N was applied at any timing for either preflood N rate at the RREC. The midseason N application window appeared to span multiple weeks at the RREC, where applications made up to BIE+21 days did not result in different grain yields from numerical maximums at BIE+14 and

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BIE+7 days at preflood N rates of 85 and 105 lb N/acre, respectively. Results from this and previous studies have led to the new recommendation that the midseason N application should be applied no earlier than BIE and at least 3 weeks after the preflood N application; both of these conditions must be met to obtain the full grain yield benefit from the midseason N application.

Introduction

Nitrogen fertilizer typically is applied in a two-way split application for conventional, pure-line rice cultivars in dry-seeded, delayed-flood systems (Norman et al., 2013b). The first N application occurs preflood, onto dry soil, at beginning tillering and the second N application occurs into the floodwater at midseason between beginning internode elongation (BIE) and BIE+7 days, or approximately 0.5-inch IE (Norman et al., 2013b). The preflood N application is the larger of the two and ranges, for pure-line cultivars, from 75 to 105 lb N/acre depending on the cultivar (Roberts and Hardke, 2016). The preflood N rate is increased by 30 lb N/acre for rice grown on clay soils, but the midseason N application rate of 45 lb N/acre is consistent among all conventional, pure-line cultivars and soil textural classes (Roberts and Hardke, 2016). The current recommendation for midseason N application to occur from BIE to 0.5-inch IE has not been updated for nearly 20 years (Wilson et al., 1998). Due to the introduction of several new rice cultivars since the last midseason N timing studies were conducted, new studies have been initiated in order to determine how recently released conventional, pure-line rice cultivars respond to midseason N application and the optimal application timing window.

Recent research has indicated some of the new cultivars do not consistently respond to midseason N application, particularly when an adequate rate of preflood N has been applied. Furthermore, the results of recent studies indicate, when midseason N application produces a yield response, the midseason N application time window may be wider and/or later than the week between BIE and 0.5-inch IE as suggested by Wilson et al. (1998). Results of a 2011 midseason N application study indicated a positive influence on rice grain yield when midseason N was applied from BIE to BIE+14, while BIE+21 days was not tested (Norman et al., 2012). The 2012 study indicated midseason N applied from BIE to BIE+21 days significantly increased rice grain yield at two locations, while none of the midseason N application timings resulted in a yield increase at the third location (Norman et al., 2013a). Similarly, the 2013 study showed midseason N applications from BIE to BIE+21 days generally increased grain yield for both preflood N rates at the University of Arkansas System Division of Agriculture Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC), while no midseason N application timings produced a yield response at the Pine Tree Research Station (PTRS) with the greater preflood N rate (Norman et al., 2014). Consequently, the midseason N application timing study was continued in 2017 to further clarify the impact of midseason N applied five times from BIE to BIE+28 days on the grain yield of rice based on two preflood N application rates. Based on yield responses to midseason N applied at BIE+21 days in previous studies, an additional application at BIE+28 days was introduced in this study to determine how late-midseason N could be applied and still benefit grain yield.

Procedures

The study was conducted in 2017 at the University of Arkansas System Division of Agriculture's RREC, near Stuttgart, Ark., on a DeWitt silt loam and the NEREC, Keiser, Ark., on a Sharkey clay. The two conventional, pure-line rice cultivars chosen for the study were the Horizon Ag long-grain, semi-dwarf CL153, and the Arkansas long-grain, short-stature cultivar Diamond. Two preflood N rates were utilized at each location along with five midseason N application timings. Urea was the N fertilizer source used for preflood and midseason N applications. Preflood N application rates of 85 and 105 lb N/acre were used at the RREC, while larger rates of 115 and 135 lb N/acre were used on the clay soil at the NEREC. The midseason N rate was 45 lb N/acre at both locations and was applied at BIE, BIE+7, BIE+14, BIE+21, or BIE+28 days. Additional treatments were a control, where no midseason N was applied, and an optimum single preflood N application of 130 and 160 lb N/acre at the RREC and NEREC, respectively. All treatments were replicated 4 times at each location. Preflood N was applied onto dry soil, which was flooded within 24 hours, and midseason N applications occurred directly into the floodwater.

The rice was drill-seeded in plots 8 rows wide and 15.5 ft in length with row spacing of 7.5 inches at a rate of 70 lb/acre on the silt-loam soil at the RREC and 84 lb/acre on the clay soil at the NEREC. Rice was seeded at the NEREC on 14 April and emerged on 8 May, the preflood N was applied on 8 June, and the BIE application occurred on 28 June. Rice was seeded at the RREC on 13 April and emerged on 21 April, the preflood N was applied on 23 May, and the BIE application occurred on 14 June. A permanent flood was established at both locations the day after preflood N application when the rice was at the 5- to 7-leaf stage and maintained until the rice reached maturity. The center 4 rows of each plot were harvested at maturity, the moisture content and weight of grain were determined, and yields were calculated based on 12% moisture and a 45-lb bushel (bu) weight.

Treatments were arranged in a 4 replicate randomized complete block factorial design with 2 cultivars × 5 midseason N application timings. A control with no midseason N application and an optimum single preflood N application treatment were included, each with four replications at both locations. Analysis of variance was performed on the grain yield data for each preflood N rate and location combination utilizing SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). When necessary, differences among means were compared using Fisher's protected least significant difference (LSD) procedure at a $P = 0.05$ probability level.

Results and Discussion

Analysis of variance *P* values for the studies indicated there were no significant ($P = 0.05$) interactions of cultivar × midseason N timing on grain yield at either of the two locations (Table 1). There were, however, significant ($P < 0.05$) main effects of cultivar for both preflood N rates at both locations and midseason N timing on rice grain yield for both preflood N rates at RREC.

Averaged across midseason N timing, the cultivar Diamond produced greater yields than CL153 for all location/preflood N rate combinations (Table 2). Grain yields of Diamond averaged 15 and 22 bu/acre greater than CL153 at preflood N rates of 85 and 105 lb N/acre, respectively, at the RREC. At the NEREC, grain yields of Diamond were 20 and 19 bu/acre greater than grain yields of CL153 at preflood N rates of 115 and 135 lb N/acre. Although not analyzed statistically, the higher preflood N rate resulted in grain yields that averaged 9 and 8 bu/acre greater than the lower preflood N rate at the NEREC and RREC, respectively.

Midseason N timing did not significantly impact grain yields, averaged across cultivars, at either preflood N rate at the NEREC (Table 3). The reasoning for the low impact of the midseason N application at the NEREC in 2017 is not well understood, but yields were consistently high regardless of midseason N application and preflood N rate, indicating generally sufficient N availability at the location, which may have reduced any impact of midseason N application. At the RREC, averaged across cultivars, midseason N application impacted grain yield at both preflood N rates. At the lower preflood N rate of 85 lb N/acre, no midseason N timing produced a significantly lower yield than the optimum single preflood treatment of 130 lb N/acre. Similarly, midseason N applications at BIE+7, BIE+14, and BIE+21 days resulted in greater grain yields than the control, while midseason N applications at BIE and BIE+28 days did not produce yields different than the control. When the preflood N rate was raised to 105 lb N/acre at the RREC, midseason N applications at BIE and BIE+7 days produced greater yields than the optimum single preflood application, while remaining midseason N application timings and the control did not differ from the single preflood N treatment. Grain yields from midseason N applications at BIE+14 and BIE+21 days did not differ significantly from applications made at BIE or BIE+7 days, but also did not differ from the single preflood N application. Midseason N applied at BIE+28 days, though not different from application at BIE+21 days, did not significantly impact grain yields relative to the control, indicating that applications made past BIE+21 days may not provide any significant benefit to the grain yield of rice.

Significance of Findings

Results of this study indicate, on the clay soil at the NEREC in 2017, midseason N application did not impact grain yields relative to the control (no midseason N) or the optimum single preflood application at either preflood N rate. On the silt-loam soil at the RREC, midseason N application produced a yield increase over the control when applied at BIE+7, BIE+14, or BIE+21 days at a preflood N rate of 85 lb N/acre. At the greater preflood N rate of 105 lb N/acre, midseason N applications from BIE to BIE+21 days increased grain yields over the control, while only applications made at BIE and BIE+7 days resulted in greater grain yields than the optimum single preflood N application. The general trend of midseason N application increasing grain yield when applied up to 21 days past BIE, which was observed in this study is consistent with previous studies (Norman et al., 2012; 2013a; 2014, Smartt et al., 2016). Although it was not included in previous studies, this study has provided evidence that delaying midseason N application past BIE+21 days may not provide a grain yield benefit. This indicates the midseason N application window is wider than previously thought and perhaps later than the current midseason N application recommendation, which is the time between BIE and 0.5-inch IE (Norman et al., 2013b). It is possible that yield increases resulting from later midseason N applications occur due to the greater ability of the rice plant to take up N as the plants grow larger, up to a point, as seen with applications made at BIE+28 days in this study, where the N may be taken up, but does not have sufficient time to result in a grain yield increase. Future research will help determine how late midseason N applications should occur in new cultivars and how wide the application time window is in order to optimize midseason N applications to produce greater grain yields. Results from this and previous studies have led to the new recommendation that the midseason N application should be applied no earlier than BIE and at least 3 weeks after the preflood N application; both of these conditions must be met to obtain the full grain yield benefit from the midseason N application.

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Literature Cited

Norman, R.J., T.L. Roberts, D.L Frizzell, N.A. Slaton, C.E. Wilson, Jr., and J.D. Branson. 2012. Response of two rice varieties to midseason nitrogen fertilizer application time. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2011. University of Arkansas Agricultural Experiment Station Research Series 600:215-219. Fayetteville.

Norman, R.J., J.T. Hardke, T.L. Roberts, N.A. Slaton, D.L. Frizzell, J.M. Wiggins, M.W. Duren and J.D. Branson. 2013a. Response of two rice varieties to midseason nitrogen fertilizer application time. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:232-236. Fayetteville.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013b. Soil Fertility. *In*: J.T. Hardke (ed.). Rice Production Handbook. University of Arkansas Division of Agriculture Cooperative Extension Service. MP192. Pp. 69-102. Little Rock.

Norman, R.J., J.T. Hardke, T.L. Roberts, N.A. Slaton, D.L. Frizzell, M.W. Duren and E. Castaneda-Gonzalez. 2014. Response of two rice varieties to midseason nitrogen fertilizer application timing. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station Research Series 617:303-310. Fayetteville.

Roberts, T.L. and J.T. Hardke. 2016. 2016 Recommended nitrogen rates and distribution for rice cultivars in Arkansas. Fact Sheet. University of Arkansas Division of Agriculture Cooperative Extension Service.

Smartt, A.D., R.J. Norman, J.T. Hardke, T.L. Roberts, N.A. Slaton, D.L. Frizzell, M.W. Duren, E. Castaneda-Gonzalez, and G.J. Lee. 2016. Response of two rice cultivars to midseason nitrogen fertilizer application timing. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2015. University of Arkansas Agricultural Experiment Station Research Series 634:319-325. Fayetteville.

Wilson, C.E., P.K. Bollich, and R.J. Norman. 1998. Nitrogen application timing effects on nitrogen efficiency of dry seeded rice. Soil Sci. Soc. Am. J. 62:959-964.

Table 1. Analysis of variance *P* values for rice grain yield as affected by rice cultivar, midseason N timing, and their interaction at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and Rice Research and Extension Center (RREC) during 2017.

	Location/ Preflood N Rate (lb N/acre)			
	NEREC		RREC	
Source	115	135	85	105
	P			
Cultivar	<0.0001	<0.0001	<0.0001	<0.001
Midseason N timing	0.5308	0.1564	0.0014	0.0002
Cult × msn timing	0.8281	0.3665	0.9131	0.5731

Table 2. Influence of rice cultivar, averaged across midseason N timing, on rice grain yield at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and the Rice Research and Extension Center (RREC) during 2017.

	Grain yield			
	Location/ Preflood N Rate (lb N/acre)			
	NEREC		RREC	
Cultivar	115	135	85	105
	(bu/acre)			
CL153	184 b†	192 b	170 b	178 b
Diamond	204 a	211 a	195 a	200 a
$LSD_{0.05}$‡	7.9	8.0	7.1	5.8

† Values in the same column followed by different letters are significantly different ($P < 0.05$).

‡ LSD = least significant difference.

Table 3. Influence of midseason (MS) N application timing, averaged across cultivars, on rice grain yield at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and the Rice Research and Extension Center (RREC) during 2017.

	Grain yield			
	Location/ Preflood N Rate (lb N/acre)			
	NEREC		RREC	
MS N Timing	**115**	**135**	**85**	**105**
	-------------------- (bu/acre) --------------------			
No MS N	190	199	166 c†	174 d
BIE‡	189	194	175 bc	197 a
BIE+7d	190	195	192 a	200 a
BIE+14d	198	203	193 a	195 ab
BIE+21d	200	206	187 ab	190 abc
BIE+28d	193	213	177 bc	182 cd
SPF§	199	199	185 ab	185 bcd
$LSD_{0.05}$¶	N.S.#	N.S.	13.2	10.8

† Values in the same column followed by different letters are significantly different ($P < 0.05$).
‡ BIE = beginning internode elongation.
§ SPF = Optimum single preflood N application of 160 lb N/acre at NEREC and 130 lb N/acre at RREC with no midseason N.
¶ LSD = least significant difference.
# N.S. = not significant at 0.05 alpha level.

Summary of Nitrogen Soil Test For Rice (N-STaR) Nitrogen Recommendations in Arkansas During 2017

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Abstract

Seeking to fine-tune nitrogen (N) application, increase economic returns, and decrease environmental N loss, some Arkansas farmers are slowly turning away from blanket N recommendations based on soil texture and cultivar by using Nitrogen Soil Test for Rice (N-STaR) to determine their field-specific N fertilizer rates. In 2010, scientists at the University of Arkansas correlated several years of direct steam distillation results (DSD) obtained from soil samples taken to an 18-inch depth to plot-scale N response trials across the state and developed a site-specific soil-based N test for Arkansas rice. After extensive field testing, N-STaR became available to the public for silt loam soils in 2012. The N-STaR has since been correlated for use on clay soils, using a 12-inch depth soil sample, both at small-plot and field scale validation, and has been offered to the public since 2013. To summarize the samples submitted to the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab for the 2017 growing year, samples were categorized by county and soil texture. Samples were received from 152 fields across 18 Arkansas counties, with Mississippi County and Arkansas County submitting the largest number of fields, 81 and 13 fields, respectively. The total samples received were from 54 silt loam fields and 98 clay fields. The N-STaR N rate recommendations for these samples were then compared to the producer's estimated N rate, the 2017 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas, and the standard Arkansas N rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. Each comparison was divided into three categories based on a decrease in the N rate recommendation, no change in recommended N rate, or an increase in the N rate recommendation. County was a significant factor when N-STaR called for a decreased N rate in the standard comparison ($P < 0.05$) and the cultivar recommendation comparison ($P < 0.01$) suggesting that some areas of the state may have higher residual-N not accounted for by these current N rate recommendation strategies. Soil texture was a significant factor when N-STaR called for a decreased N

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rate in the standard comparison ($P < 0.05$) and the cultivar recommendation comparison ($P < 0.001$), yet was also significant ($P < 0.001$) when N-STaR recommended an increase in N rate in the producer's estimated comparison. This further emphasizes the importance of correct soil texture classification and corresponding sampling methods.

Introduction

Nitrogen fertilizer rate recommendations for rice in Arkansas for years have been based on soil texture, cultivar selection, and the previous crop (Norman et al., 2013)—often resulting in over-fertilization which can decrease possible economic returns and increase environmental N loss (Khan et al., 2001). In hopes of finding a more field-based factor to drive N recommendations, scientists correlated several years of plant-available N estimates from direct steam distillation (DSD) results from 18-inch depth soil samples, equivalent to the rice rooting depth on a silt loam soil (Roberts et al., 2009) to plot-scale N response trials across the state and developed a site-specific, soil-based N test for Arkansas rice (Roberts et al., 2011).

Direct-seeded, delayed-flood rice production, with proper flood management, use of ammonium-based fertilizers, and best management practices, has a consistent N mineralization rate and one of the highest N-use efficiencies of any cropping system, therefore lending itself to a high correlation of mineralizable-N to yield response (Roberts et al., 2011). After extensive field testing, the Nitrogen Soil Test for Rice (N-STaR) became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas System Division of Agriculture's N-STaR Soil Testing Lab in Fayetteville, Arkansas. Later, researchers correlated DSD results from 12-inch depth soil samples to N response trials on clay soils (Fulford et al., 2013), and N-STaR rate recommendations became available for clay soils in 2013. Some Arkansas farmers are benefiting from this research by using N-STaR's field-specific N rates, but many continue to depend on soil texture, cultivar, previous crop, or routine management habits to guide N fertilizer rate decisions which may not always be the most profitable or environmentally sound practice.

Procedures

In an effort to summarize the effect of the N-STaR program in Arkansas, samples submitted to the N-STaR Soil Testing Lab for the 2017 growing year were categorized by county and soil texture. The N-STaR N fertilizer rate recommendations for these samples were then compared to the producer's estimated N rate supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2017 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas found in the 2017 Rice Farming for Profit publication (Hardke et al., 2017), or to the standard Arkansas N rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils and divided into three categories as follows: 1) those with a decrease in N fertilizer rate recommendation, 2) no change in recommended N rate, or 3) an increase in the N rate recommendation. The resulting data was analyzed using JMP 13 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($P = 0.05$).

Results and Discussion

Samples were received from 152 producer fields which represented 22 farmers across 18 Arkansas counties (Table 1). Mississippi and Arkansas Counties, ranked 12th and 6th in planted acres (USDA-FSA, 2017), evaluated the largest number of fields, with 81 and 13 fields, respectively. Three other counties, Clay, Jefferson, and Phillips, sent in samples for more than 10 fields while the remaining counties submitted samples for less than 5 fields. Only one farmer chose to submit samples during the post-harvest fall months when soil sampling conditions would have been more favorable. The only samples received during the early spring, before typical planting dates, were from Rice Research Verification fields collected by extension agents. The vast majority of samples were received during the typically wetter months of March and April after rice had been planted. Seven farmers sent samples for 5 or more fields while 10 farmers sent samples for just 1 field. However, one farmer submitted samples for 81 fields bringing the average number of samples submitted by farmer to 6.9 fields. There were 8 farmers who submitted samples in 2016 that also submitted samples in 2017. The samples received were from 54 silt loam fields and 98 clay fields.

Harvested rice acreage across Arkansas did decrease from 1.521 million acres in 2016 to 1.093 million acres in 2017 (USDA-FSA, 2017) mostly likely due to widespread, damaging spring floods occurring after most rice had been planted in combination with unfavorable replanting conditions. The N-STaR sample submission for 2017 of 152 fields (Table 1) mirrored this trend and resulted in a decrease of submitted fields from the 176 fields in 2016. Just as in previous years, sample submission by county did not reflect the planted acre estimates for 2017 with Poinsett and Lawrence counties having the highest estimates (USDA-FSA, 2017) yet only two fields from Lawrence County were submitted.

County and soil texture were found to be significant factors ($P < 0.05$) in the fields with a decrease in N fertilizer rate when the N-STaR recommendation was compared to Arkansas' standard N rate recommendation of 150 lb N/acre for silt loam soils and 180 lb N/acre for clay soils. This suggests that some areas of the state may be prone to N savings potential due to cropping systems and soil series (Fig. 1). County and soil texture were not significant in the fields where an increase in N rate was recommended by N-STaR, however it should be noted that there were no clay fields that resulted in an increased N rate in this comparison (Table 1). Of the fields in this comparison, there was a decrease in the N rate recommendation for 139 fields (91% of the 152 fields submitted) with an average decrease of 47 lb N/acre. No change in the N rate recommendation was found for three fields, while ten fields had an increase in the N rate recommendation (6.6%) with an average increase of 10.5 lb N/acre.

Five of the submitted fields had no estimated N rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the farmer's estimated N fertilizer rate. Of those compared, there was a decrease in the N rate recommendation for 94 fields (63.9% of the submitted fields) with an average decrease of 30.7 lb N/acre (Table 2). No change in the N rate recommendation was found for 9 fields, while 44 fields had an increase in the N rate recommendation (29.9%) with an average increase of 19.8 lb N/acre.

Soil texture was found to be a significant factor ($P < 0.001$) for the fields that resulted in an increase in the N fertilizer rate from the producer's estimate to the N-STaR N rate recommendation but was not significant in the fields that resulted in a decreased N rate. The difference in significance may be due to soil texture variability, soil texture classification errors, and the differences in sample depth and the N-STaR calculations for the two textures. The N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the farmer's correct classification of his field. County was not found to be a significant factor in this comparison for this particular year as in years past (Table 2).

When the N-STaR N fertilizer rate recommendation was compared to the 2017 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas (Hardke, et al., 2017), cultivar recommendations were adjusted for soil texture as recommended by adding 30 lb N/acre for rice grown on clay soils and then compared to the N rates determined by N-STaR. Eight fields failed to include cultivar on the N-STaR Sample Submission Sheet and were excluded from this comparison. There was a decrease in the N rate recommendation for 129 fields (89.6% of the 144 fields) with an average decrease of 46.3 lb N/acre (Table 3). No change in N rate recommendation was found for 4 fields, while 11 fields had an increase in N recommendation (7.6%) with an average increase of 10.9 lb N/acre. County ($P < 0.01$) and soil texture ($P < 0.001$) were significant factors in the fields exhibiting a decreased N-STaR recommended N rate, yet neither was significant when N-STaR called for an increased N rate. This suggests that N rates for some cultivars may be overestimated for certain areas of the state or soil textures.

Significance of Findings

These results continue to show the importance of the N-STaR program to Arkansas producers and can help target areas of the state that would most likely benefit from its incorporation. Standard N fertilizer rate recommendations for specific cultivars will continue to be good general estimates for N rates, but field-specific N rates continue to offer the best estimate of needed N fertilizer, regardless of soil texture or cultivar selection. Farmers are encouraged to consider taking N-STaR samples at the harvest of the previous crop when fields are typically in optimal conditions for soil sampling.

Acknowledgements

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Literature Cited

Fulford, A.M., T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson Jr., T.W. Walker, D.L. Frizzell, C.E. Greub, C.W. Rogers, S.M. Williamson, M.W. Duren, and J. Shafer. 2013. Evaluation of the Illinois Soil Nitrogen Test and the Nitrogen-Soil Test for Rice Grown on Clayey Soils. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.) B.R. Wells Rice Research Studies 2012. University of Arkansas Agricultural Experiment Station Research Series 609:204-212. Fayetteville.

Hardke, J.T., R. Baker, L. T. Barber, C. G. Henry, G. M. Lorenz, R. S. Mazzanti, R.J. Norman, J. K. Norsworthy, T.L. Roberts, B. C. Scott, N.A. Slaton, and Y. A. Wamishe. 2017. "2017 Rice Farming for Profit" University of Arkansas System Division of Agriculture Cooperative Extension Service. Accessed 12 Sept. 2017. Available at: http://www.uaex.edu/farm-ranch/crops-commercial-horticulture/rice/

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple soil test for detecting sites that are nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1751–1760.

Norman, R.J., N.A. Slaton, and T.L. Roberts. 2013. Soil Fertility. Pp. 69-101. In: J.T. Hardke (ed.). Arkansas rice production handbook. Misc. Publ. 192. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock.

Roberts, T.L., R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2009. Changes in alkaline hydrolyzable nitrogen distribution with soil depth: Implications for fertilizer correlation and calibration. Soil Sci. Soc. Am. J. 73:2143-2150.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton and C.E. Wilson, Jr. 2011. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1-12.

USDA-FSA. 2017. United States Department of Agriculture Farm Service Agency. 2017 acreage data as of Dec. 1, 2017. Accessed 7 Dec. 2017. Available at: https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard N rate recommendation, producer's estimated N rate, and the 2017 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas (Hardke et al., 2017) based on soil texture.

Soil texture	No. of fields submitted	Decreased N-STaR[a] recommendation: No. of fields	Decreased N-STaR[a] recommendation: Mean N decrease	Increased N-STaR recommendation: No. of fields	Increased N-STaR recommendation: Mean N increase	No change in recommendation
			(lb N/acre)		(lb N/acre)	
Standard soil texture						
Clay	98	98	54.1	-	-	-
Silt loam	54	41	30.1	10	10.5	3
Total	152	139	47.0	10	10.5	3
Producer estimate						
Clay	96	57	31.2	33	22.1	6
Silt loam	51	37	29.9	11	12.7	3
Total	147	94	30.7	44	19.8	9
Cultivar						
Clay	94	94	52.3	-	-	-
Silt loam	50	35	29.9	11	10.9	4
Total	144	129	46.2	11	10.9	4

[a] N-STaR = Nitrogen Soil Test for Rice.

Table 2. Distribution and change in N fertilizer rate compared to the producer's estimated N rate by county[a].

Soil texture	No. of fields submitted	Decreased N-STaR[b] recommendation: No. of fields	Decreased N-STaR[b] recommendation: Mean N decrease	Increased N-STaR recommendation: No. of fields	Increased N-STaR recommendation: Mean N increase	No change in recommendation
			(lb N/acre)		(lb N/acre)	
Arkansas	10	8	39.8	2	12.5	-
Clark	1	1	15	-	-	-
Clay	12	8	24.4	3	15	1
Crittenden	1	1	20	-	-	-
Desha	1	1	55	-	-	-
Greene	2	1	36	1	15	-
Jackson	1	-	-	-	-	-
Jefferson	11	10	44.5	-	-	1
Lawrence	2	2	47.5	-	-	-
Lee	1	-	-	-	-	1
Lincoln	2	1	60	1	5	
Lonoke	3	3	21.7	-	-	-
Mississippi	81	44	25.3	31	22.6	6
Phillips	11	7	27.9	4	11.3	-
Prairie	5	4	40	1	25	-
Pulaski	2	2	40	-	-	-
St. Francis	1	-	-	1	10	-
White	1	1	35	-	-	-
Total	147	94	30.7	44	19.8	9

[a] Five fields did not list an estimated N rate on their N-STaR Sample Submission Sheet and were excluded from the analysis.

[b] N-STaR = Nitrogen Soil Test for Rice.

Table 3. Distribution and change in N fertilizer rate by cultivar compared to the 2017 Recommended Nitrogen Rates and Distribution for Rice Cultivars (Hardke et al., 2017) in Arkansas[a].

		Decreased N-STaR[b] recommendation		Increased N-STaR recommendation		
Soil texture	No. of fields submitted	No. of fields	Mean N decrease	Number of fields	Mean N increase	No change in recommendation
			(lb N/acre)		(lb N/acre)	
CL 151	1	-	-	1	25	-
CL 172	1	1	20	-	-	-
CL 272	1	1	35	-	-	-
CLXL 745	10	9	31.14	1	15	-
Diamond	19	16	54.4	2	12.5	1
Jupiter	8	2	40	5	8	1
LaKast	1	1	15	-	-	-
Roy J	11	9	48. 3	1	5	1
Taggart	2	2	67.5	-	-	-
Titan	1	1	60	-	-	-
XL 753	89	87	46.4	1	10	1
Total	144	129	46.3	11	10.9	4

[a] Eight fields did not list a cultivar on their N-STaR Sample Submission Sheet and were excluded from the analysis.
[b] N-STaR = Nitrogen Soil Test for Rice.

Fig. 1. Number of fields submitted, percent and mean decrease and increase in Nitrogen Soil Test for Rice (N-STaR) N fertilizer rate recommendation (lb N/acre) by county compared to the standard N rate recommendation.

A Study on Discoloration and Microbial Growth Kinetics of Stored Rice from Plots Sprayed with Conventional Fungicide at the Crop Late Boot Stage

G.G. Atungulu[1] *and S. Shafiekhani*[1]

Abstract

Rice, like other cereal grains, is a biological material that is subject to changes in moisture content and to deterioration in response to change in environmental conditions. This study sought to clarify if conventionally practiced pre-harvest fungicide application on rice in the field has a significant impact on rice quality, especially kernel color, postharvest. Freshly harvested rough rice from commercial field plots with and without pre-harvest fungicide application were procured and stored at 4 moisture content (MC) levels (12.5%, 16%, 19% and 21%), and at 5 temperatures [50 °F (10 °C), 59 °F (15 °C), 68 °F (20 °C), 80.6 °F (27 °C), 104 °F (40 °C)] for 16 weeks, with samples taken every 2 weeks. The study showed that rice treated with fungicide can be stored at MC levels 12.5% and 16% and at temperatures of 50 °F and 59 °F for up to 16 weeks without showing any significant changes in discoloration and mold growth. A similar trend was observed for non-fungicide treated rice. On the other hand, when fungicide and non-fungicide rice were stored at higher MC (21%) and temperature (104 °F), a significant change in discoloration and mold growth was observed after 8 weeks. In order to maintain high quality rice and avoid high mold growth, it is crucial that rice is not stored at high MCs and temperatures.

Introduction

The long-term goal of this study is to provide science-based knowledge to inform improved regional and national food security and safety, especially for rice, through the control of foodborne hazards and to further evaluate and develop economical and adoptable control strategies that are aimed at reducing incidences of foodborne hazard(s) related to rice and to boost rice growers' returns (Atungulu et al., 2015).

One of the main factors contributing to spoilage of rice in storage is microbial development. Therefore, proper pre-harvest and post-harvest management of the rice is crucial to maintain the grain quality and safety (Maier, 1994; Grolleaud, 2001; Smith and

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Dilday, 2003). This study especially targeted answering questions raised by rice growers and processors who use on-farm, in-bin storage systems. The primary questions raised by these growers and processors pertain to the safe storage temperature and moisture content (MC) of rice to maintain milling yields and overall quality of processed rice.

The Federal Grain Inspection Service (FGIS) of the United States Department of Agriculture Grain Inspection, Packers and Stockyards Administration assigns grades to rice based on the number of discolored or otherwise unacceptable kernels in a sample. United States No. 1 grade milled rice may contain, at maximum, only one "heat-damaged" kernel per 1.1 lb (500-g) sample (USDA-FGIS, 2009). This low threshold can have a large impact on growers' or processors' profits if their rice exceeds the number of "heat-damaged" kernels permitted. To minimize the issues of rice discoloration, the trend among many rice growers in the U.S., in recent years, has been adoption of a recently introduced technology for on-farm, in-bin rice drying and storage. Kinetics of mold growth and rice quality deterioration, especially discoloration of kernels, have been reported for environmental condition and MCs regimes typical of the on-farm conditioning of rice in the in-bin storage systems in Arkansas (Atungulu et al., 2016; Siebenmorgen and Haydon, 2017). Surprisingly, even for some rice kernels with low MC at cool temperatures, some sort of discoloration would still be detectable. Also, variegated patterns of discoloration for kernels stored at the same temperature and MC conditions have been reported (Siebenmorgen and Haydon, 2017).

The specific objectives of this study were as follows: 1) determine links among mold growth and prevalence of rice kernel discoloration as observed during the grain storage; and 2) determine the extent to which conventionally practiced pre-harvest fungicide treatment of rice in the field impacts stored rice quality, especially on kernel color postharvest.

Procedures

Rice Samples

Hybrid long-grain rice cultivar RiceTec XL745 CL was used in this experiment. The rice was grown in 2016 in two commercial rice fields located in Pocahontas, Arkansas. In one of the rice fields, the rice was treated with fungicide Quilt-Xcel at the rate of 17 oz/acre sprayed during the late boot stage, henceforth reported as treated field/sample. The second rice field had no fungicide administered, henceforth reported as control field. The rice was harvested at 22% MC wet basis (all MCs in wet basis (w.b.) unless otherwise stated). Harvested rice from each lot (treated and control) were cleaned with a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.). Afterward the cleaned rice (treated and control) was divided into 4 sublots, each conditioned to MCs of 12.5%, 16%, 19%, and 21%. After conditioning the rice to the desired MC levels, the samples were immediately placed in individual well-labeled sealed quart-sized, glass containers and then transported to 5 separate temperature environments of 50 °F (10 °C), 59 °F (15 °C), 68 °F (20 °C), 80.6 °F (27 °C) and 104 °F (40 °C). The samples were stored for a period of 16 weeks and collected every 2 weeks except after week 12, when the rice samples were stored for a continuous period of 4 weeks.

Color Measurement

The color of the whole rice kernels was measured using an image analysis system (WinSEEDLE Pro 2005aTM, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). The sum of the areas of 7 discolored kernel descriptors was considered the total projected area. The software reported the area of each color classification and then the percentage of discoloration was calculated as the colored area divided by total projected area. All measurements were replicated.

Enumeration of Fungi Population on Stored Rice During Storage

The microbial isolation and counting process were conducted following the Association of Official Analytical Chemists (AOAC, 2002). A 0.02-lb (10-g) sample of rice was mixed with 3.04 ounce (90 mL) of sterilized phosphate-buffered dilution water in a sterile stomacher bag and masticated at 240 s and 0.5 stroke/s. A total of 5 fold serial dilutions for a particular treatment were used based on preliminary data. Successive dilutions were made by mixing 0.03 ounce (1 mL) of the mixture with 0.3 ounce (9 mL) of phosphate-buffered dilution water in a test tube and repeating the dilution until 10-5 dilution was made. The 3M Petrifilm Mold Count Plates (3M Microbiology Product, Minneapolis, Minn.) were used to enumerate mold counts following the manufacturers prescribed methods.

Results and Discussion

At 12.5% MC after 6 weeks of storage, discoloration increased in both fungicide and non-fungicide treated samples. However, it did not exceed 20% discoloration and trends appeared sufficiently linear over 16 weeks (Fig. 1). For rice stored at 16% MC and 80.6 °F, discoloration started to occur after 10 weeks. While, rice stored at 16% MC and 104 °F started to discolor after 6 weeks (17.3%) and increased significantly to 87.9% and 73% after 16 weeks for fungicide and non-fungicide treated samples, respectively. At high MC (21%), discoloration started after 2 weeks and continued to 99.1% and 96.5% after 16 weeks for fungicide and non-fungicide treated samples, respectively.

Based on Table 1, there was a significant difference in discoloration of high and low MC samples for fungicide treatments at a temperature of 104 °F. Similar trends were observed for non-fungicide treated samples. There was no significant difference in discoloration of high and low MC samples at temperatures of 50 °F, 59 °F, and 68 °F for fungicide and non-fungicide treated samples, except at 80.6 °F in high MC fungicide treated samples.

Based on Table 2, at 12.5% MC there were significant differences between mold counts (M) found on fungicide-treated rice stored at 104 °F (M = 4.85) and non-fungicide-treated rice stored at 68 °F (M = 5.58), 80.6 °F (M = 5.58), and 104 °F (M = 4.68). There were no significant differences between mold counts in fungicide- and non-fungicide-treated samples stored at 50 °F and 59 °F at 12.5% MC. At 16% MC, the mold count of non-fungicide treated samples fluctuated at different temperature ranges;

however, the mold count levels were consistent at temperature ranges of 50 °F to 80.6 °F for fungicide-treated samples. There were no significant differences between mold counts for fungicide- and non-fungicide-treated samples stored at 104 °F and 16% MC. At 19% MC, there were no significant differences between mold counts in fungicide-treated samples at 50 °F to 80.6 °F. However, in non-fungicide treated samples there were significant differences between mold counts at storage temperatures of 68 °F (M = 5.18) and 80.6 °F (M = 5.04). Moreover, at 104 °F and 19% MC there were significant differences between mold counts in fungicide- (M = 4.35) and non-fungicide- (M = 3.56) treated samples. At 21% MC, there were significant differences between mold counts in fungicide- and non-fungicide-treated samples when stored at 68 °F (M = 5.33) and 80.6 °F (M = 5.57). There were no significant differences between mold counts at 50 °F, 59 °F and 104 °F in both fungicide- and non-fungicide-treated samples at 21% MC.

Figure 2 shows that high growth of mold was not necessarily related to high discoloration in both fungicide- and non-fungicide-treated samples, especially at temperatures less than 80.6 °F. However, in the period leading to 10 weeks of storage at MC ≥ 19% and a temperature of 104 °F, discoloration increased with increase in mold counts. There was a consistent pattern of discoloration at low MCs and low temperatures. However, over the wide range of storage temperatures and MCs, there was no clear, direct relationship between discoloration and mold counts.

Low levels of rice discoloration were maintained at 50 °F and 59 °F for all MCs over the 16-week storage duration. The results suggested that cooling of rice may help to maintain the color of rice. At 21% MC, increase in rice discoloration started after 2 weeks and began getting severe after 4 weeks of storage for temperatures above 68 °F; thus, pointing to the potential of rice cooling treatments to permit short- to long-term storage management of grain.

While the scope of this study was not to elucidate the biochemical basis of the rice discoloration or the specific role of microorganisms in the process, such research would be useful to undertake in order to develop microbe-specific interventions to the rice discoloration problem. The interventions envisioned could be developing non-broadband fungicides which target specific microbes such as fusarium to discourage microbial induced discoloration, especially in some regimes of rice MC and storage temperatures.

Clearly, from this study, there might be a need to investigate more on the application timing of fungicides on rice, or altogether introduce post-harvest fungicide applications on rice if a significant impact on rice discoloration trends is to be expected post-harvest.

Significance of Findings

The findings from this study provide information which is helpful in understanding storage conditions necessary to avoid mold growth on rice in storage; such information is useful to guide management of on-farm, in-bin storage systems in order to avoid mold related quality deterioration of rice such as discoloration and mycotoxin contamination.

Acknowledgments

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Literature Cited

AOAC, Yeast and Mold Counts in Foods. 2002. In Yeast and Mold Counts in Foods, Association of Official Agricultural Chemists: Maryland U.S., Vol. 997.02.

Atungulu, G.G., H. Zhong, S. Thote, A. Okeyo, and A. Couch. 2015. Microbial prevalence on freshly-harvested long-grain pureline, hybrid, and Medium-grain rice cultivars. Appl. Engin. Agric. 31 (6):949-956.

Atungulu G.G., S. Thote, and S. Wilson. 2016. Storage of hybrid rough rice-consideration of microbial growth kinetics and prediction models. J. Stored Products Res. 9:235-244.

Grolleaud, M., 2001. Post-harvest losses: Discovering the full story overview of the phenomenon of losses during the post-harvest system. Rome, FAO.

Maier, D.E., 1994. Chilled aeration and storage of U.S. crops review. Proc. sixth Int. Working Conf. Stored-product Protec.-Volume 1.

Siebenmorgen, T. and K. Haydon. 2017. Impacts of delayed drying on discoloration and functionality of rice. Cereal Chemistry. http://dx.doi.org/10.1094/CCHEM-10-16-0257-R.

Smith, C. W. and R.H. Dilday. 2003. Rice: origin, history, technology, and production (Vol. 3): John Wiley and Sons Publisher.

USDA-FGIS. 2009. United States Department of Agriculure-Federal Grain Inspection Service. United States Standards for Rice. Washington, D.C., pp. 1-28.

Table 1. Mean values of discolored kernels stored at different temperatures for the rice with fungicide and non-fungicide treatments.

Moisture content level	Temperature (°F)	Fungicide	Non-Fungicide
	50	8.68 d,B†	7.81 c,B
	59	9.02 d,B	9.13 c,B
Low	68	8.71 d,B	8.13 c,B
(MC≤17%)	80.6	9.82 d,B	8.72 c,B
	104	23.12 b,A	19.47 b,A
	50	8.49 d,D	7.89 c,D
	59	9.65 d,D	7.96 c,D
High	68	10.76 cd,D	9.00 c,D
(MC≥17%)	80.6	15.24 c,C	9.57 c,D
	104	51.44 a,A	38.85 a,B

† Mean values differing by a lowercase letter are significantly different at α = 0.05 using Tukey's Honestly Significant Difference test for means at different treatments; mean values differing by an uppercase letter, across a row are significantly different at α = 0.05 using Tukey's Honestly Significant Difference test for means at different moisture contents (MC).

Table 2. Mean values of $\log_{10}$ CFU/g mold counts on rough rice stored at different temperatures for the rice with fungicide and non-fungicide treatments (1 g = 0.002 lb).

Variety	Temperature (°F)	MC = 12.5%	MC = 16%	MC = 19%	MC = 21%
	50	5.82 a†	5.82 a	5.74 a	5.96 a
	59	5.77 ab	5.64 ab	5.62 a	5.84 a
Fungicide	68	5.84 a	5.72 ab	5.83 a	5.33 d
	80.6	5.68 ab	5.62 ab	5.68 a	5.53 cd
	104	4.85 c	3.97 d	4.35 c	5.01 e
	50	5.79 a	5.65 ab	5.64 a	5.91 a
	59	5.75 ab	5.71 ab	5.68 a	5.85 a
Non-Fungicide	68	5.58 b	5.51 b	5.18 b	5.78 ab
	80.6	5.58 b	4.87 c	5.04 b	5.57 bc
	104	4.68 c	4.08 d	3.56 d	4.90 e

† Mean values differing by a lowercase letter are significantly different at α = 0.05 using Tukey's Honestly Significant Difference test for means at different moisture contents (MCs) in % wet basis; CFU means colony forming units.

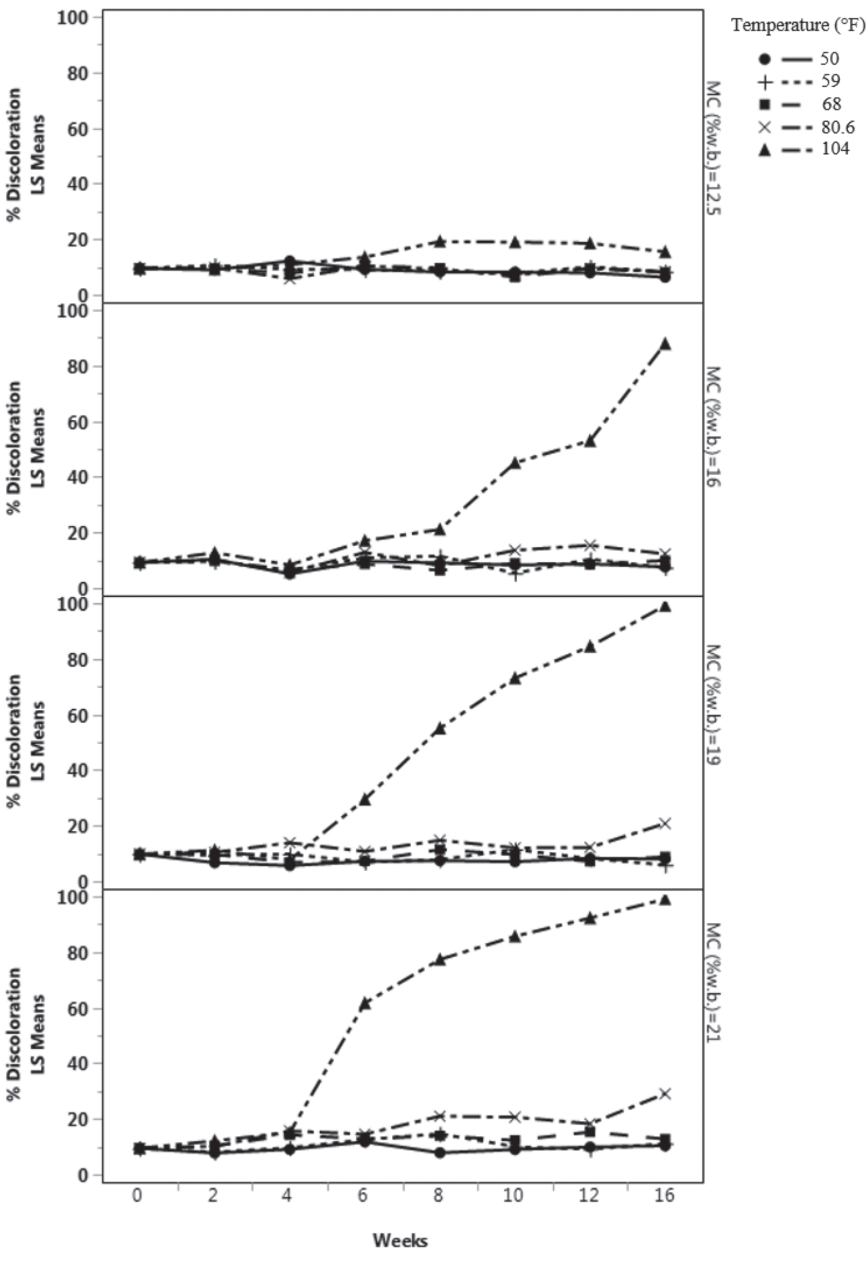
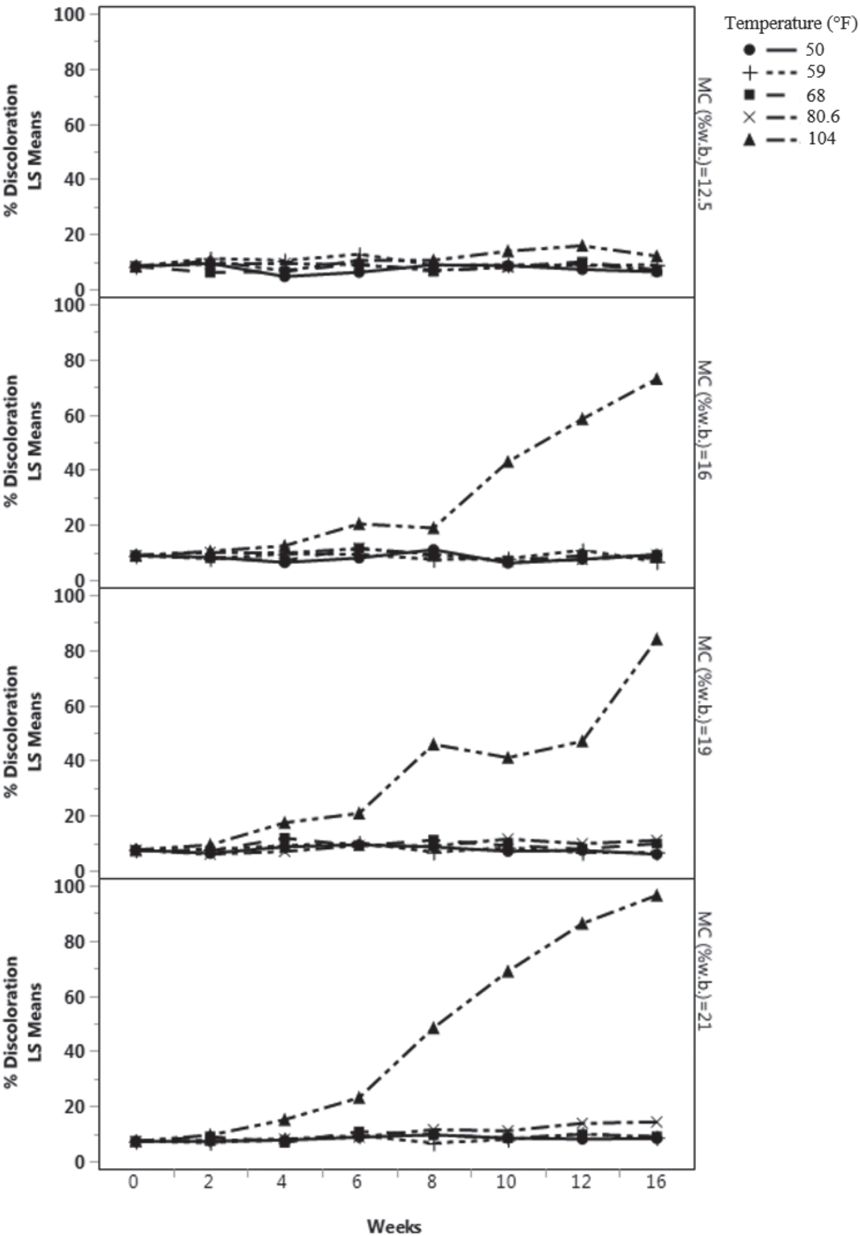


Fig. 1A. Effects of the indicated moisture contents (MCs) and temperatures on total discolored kernel area for fungicide treated rice during storage; LS = least squares.



(B)

Fig. 1(B). Effects of the indicated moisture contents (MCs) and temperatures on total discolored kernel area for non-fungicide treated rice during storage; LS = least squares.

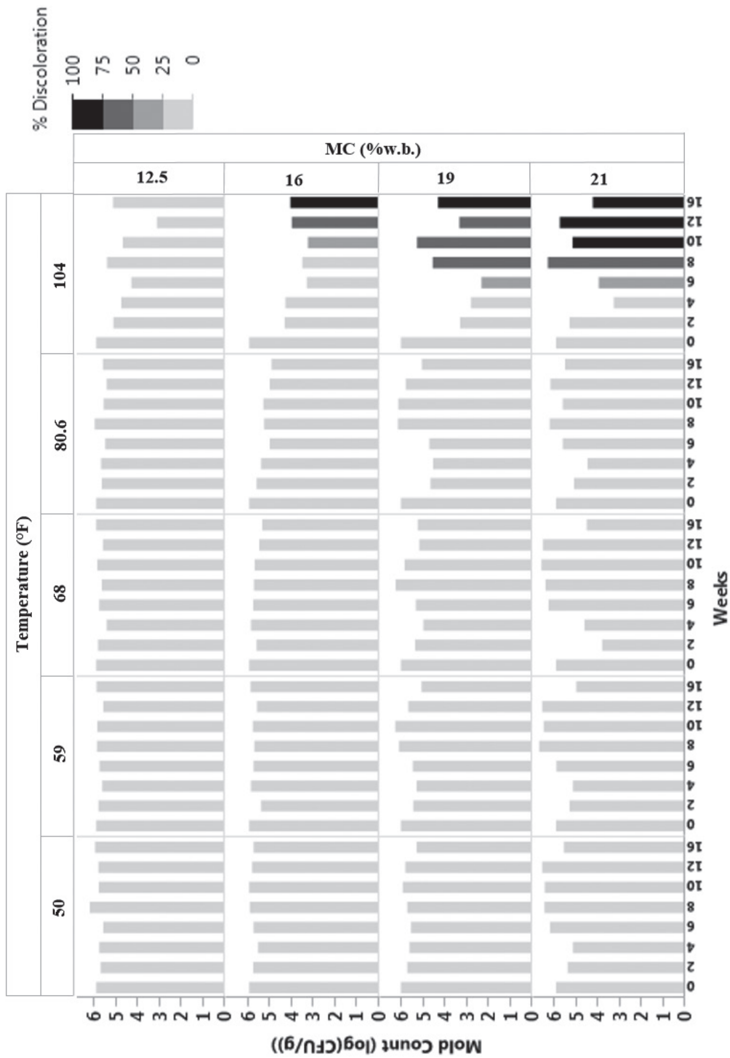


Fig. 2. Discoloration detected over a storage period of 16 weeks for rough rice moisture contents = 12.5%, 16%, 19%, 21% and temperatures = 50 °F, 59 °F, 68 °F, 80.6 °F, 104 °F versus mold counts (log_{10} CFU/g); CFU means colony forming units (1 g = 0.002 lb).

Impact of Drying Deep Beds of Rice with Microwave set at 915 MHz Frequency on the Rice Milling Yields

G.G. Atungulu[1] and D.L. Smith[1]

Abstract

This study investigates the feasibility of achieving one-pass drying of high moisture content (MC) rice with microwaves (MWs) set at 915 MHz. Medium-grain rough rice at initial MC of 23% wet basis (w.b.) was dried using a MW dryer set to transmit energy at power levels 284.35, 568.69 and 853.04 BTU/minute (5, 10, and 15 kW) for 4, 6, and 8 minutes for rice bed thicknesses of 1.97, 3.94 and 5.91 in. (5, 10 and 15 cm). Increasing MW specific energy up to 386.93 BTU/lb-grain (900 kJ/kg-grain) resulted in increasing rice final surface temperature (FST) and drying rate which together had the effect of lowering the milled rice yield (MRY) and head rice yield (HRY). There was a statistically significant disparity in HRYs across the studied rice bed thicknesses. The highest HRYs were observed (64.5%) in the 3.94 to 5.91 in. (top) layer (10 to 15 cm). The 0 to 1.97 in. (bottom) (5 cm) and the 3.94 to 5.91 in. (middle) (5 to 10 cm) layers had statistically similar mean HRYs that were both lower than the top layer.

Introduction

Rice kernel fissuring as a result of temperature and moisture content (MC) gradients negatively impacts the rice milling yield which, in large part, is quantified by the head rice yield (HRY) (USDA-GIPSA, 2010; Kunze, 1979). The presence of fissures on a rice kernel makes it more susceptible to breakage during subsequent hulling and milling processes, thus reducing the HRY (Ban, 1971; Kunze and Choudhury, 1972; Kunze, 1979). Head rice yield is the current standard in the rice industry to measure rice milling quality and is defined as the weight percentage of rough rice that remains as head rice (kernels that are at least three-fourths of the original kernel length) after complete milling. Preventing HRY reduction during drying is very critical and bears significant economic importance to the rice industry (Cnossen and Siebenmorgen, 2000). Under ideal conditions, a perfect HRY recovery would be about 70% of the total rough rice produced after the rice hulls and bran are removed. However, with current conventional rice drying methods, HRY recovery averages only about 58%, and can

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be even lower depending on other pre-harvest and post-harvest factors (USDA, 2014; Atungulu et al., 2016).

In this study, the effects of increasing microwave (MW) specific energy to dry rice beds of multiple thicknesses with a 915 MHz industrial MW system on rice milling yields and drying characteristics were investigated. Insight on disparities, if any, that exist across the rice bed layers in terms of surface temperatures, drying rates, milled rice yields (MRYs) and milled rice quality are important to inform design and operation of a commercially viable MW drying process which could benefit the rice industry. Hence, the specific objectives of this research were to investigate the implications of the following: 1) increasing MW specific energy on rice milling characteristics such as MRY and HRY; 2) increasing MW specific energy on the rice drying characteristics such as the final surface temperature, final moisture content, and rice drying rate; and 3) increasing rice bed layer thicknesses on the rice milling and drying characteristics.

Procedures

Rice Samples

Freshly harvested, medium-grain rice samples (cv. Jupiter) at initial MC of 23.5% wet basis (w.b.) were used in this study. The samples were cleaned using a dockage equipment (MCi Kicker Dockage Tester, Mid-Continent Industries Inc., Newton, Kan.). The equipment used a series of small sized sieves to provide a fast, accurate and consistent way of separating shrunken, broken, scalped material, broken kernels, splits and dust from rice. The cleaned rice was stored in a laboratory cold room set at 39.2 °F (4 °C). At the beginning of the experiments, the samples were retrieved from the cold room and allowed to equilibrate at room conditions (77 °F, 25 °C) overnight before conducting any experiments. The MCs of the samples reported in this study were determined using an AM 5200 Grain Moisture Tester (PERTEN Instruments, Hägersten, Sweden) which was calibrated using the American Society of Agricultural and Biological Engineers (ASABE) standard (Jindal and Siebenmorgen, 1987). The MC of each sample was measured by placing 0.03 lb (15 g) duplicate samples into a conduction oven (Shellblue, Sheldon Mfg., Inc., Cornelius, Ore.) set at 266 °F (130 °C) for 24 h, followed by cooling in a desiccator for at least one-half hour (Jindal and Siebenmorgen, 1987). All reported MCs are on wet basis, unless otherwise stated.

Microwave Equipment

An industrial microwave system (AMTek, Applied Microwaves Technology Inc., Cedar Rapids, Iowa) was used in this study. The system (Fig. 1a) consists of a transmitter, a wave guide, and the microwave heating zone (oven) and operates at a frequency of 915 MHz. The transmitter is a high-powered vacuum tube that works as a self-excited microwave oscillator. It is used to convert high-voltage electric energy to MW radiation. The waveguide consists of a rectangular metal tube through which the electromagnetic field propagates lengthwise. It is used to couple microwave power from the magnetron into the lab oven. The lab oven is the internal cavity of the microwave that provides uniform temperatures throughout while in use.

Experimental Design

The experimental conditions were determined based on a feasibility study. It was determined that MW treatments over 343.94 BTU/lb-grain (800 kJ/kg-grain) result in the rice burning and popping. Consequently for this research, specific energies above 343.94 BTU/lb-grain (800 kJ/kg-grain) were omitted. Microwave treatments were done in batch with power levels of levels of 284.35, 568.69, and 853.04 BTU/minute (5, 10 and 15 kW) and heating durations of 4, 6, and 8 minutes for rice beds of thicknesses 1.97, 3.94, and 5.91 in. (5, 10, and 15 cm) which translates to loading masses of 6.61, 13.23, and 19.84 lb (3, 6 and 9 kg). The experimental design is shown in Table 1.

Microwave Treatments

The implications of MW intensity and heating duration on treatments of rice beds of different thicknesses (1.97, 3.94 and 5.91 in.) were studied. For each layer, a sample of 6.61 lb (3 kg) rice was massed out and placed into the MW blind trays (Fig. 1b) for the treatment. Each tray was stackable allowing for a total of up to 13.23 lb (9 kg) of rice to be treated at once. The outsides of the trays were made of polypropylene with a Teflon-coated fiberglass mesh at the bottom to hold the samples. The trays with rice samples were set in the oven on the belt and treated at various power levels and durations (Table 1). The temperature of rice during MW heating was measured using fiber optic temperature sensors (OMEGA Engineering, INC., Stamford, Conn. 06907). After MW treatments, the samples were separated by layer then transferred immediately after to glass jars and sealed air tight. A HOBO sensor (Onset Computer Corporation, Bourne, Mass.) was placed in the jars to determine the changes in temperature and relative humidity inside the jars. The jars were placed in an environmental chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 140 °F (60 °C) and relative humidity of 65%. The rice was tempered for 4 h. After the tempering, the rice was spread uniformly on individual trays, transferred to an equilibrium moisture content (EMC) chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 77 °F (25 °C) and relative humidity of 65%.

Drying Rate Calculation

Drying rate is defined by the loss of moisture from the wet solid per unit time. A general equation (Eq. 1) was used to estimate drying rates:

Eq. (1)

$$\boldsymbol{Drying\ rate} = \left(\frac{\boldsymbol{lb.water\ removed}}{\boldsymbol{second}}\right) = \frac{(\boldsymbol{m_w - m_d})}{\boldsymbol{t}}$$

where, m_w = Mass of rice before drying, m_d = Mass of rice after drying, and t = heating duration (s).

Rice Milling

Triplicate, 0.33 lb (0.15 kg) subsamples of rough rice, obtained from each sample dried to 12.5% MC, were dehulled using a laboratory huller (Satake Rice Machine, Satake Engineering Co., Ltd., Tokyo, Japan), milled for 30 s using a laboratory mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas) and aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). The MRY was calculated as the mass proportion of rough rice that remains including head rice and broken, after milling. Head rice was then separated from broken kernels using a double tray sizing machine (Grainman Machinery Manufacturing Corp., Miami, Fla.). Head rice is considered as kernels that remain at least three-fourths of the original kernel length after complete milling (USDA-GIPSA, 2010). The HRY was calculated as the mass proportion of rough rice that remains as head rice after complete milling.

Statistical Analysis

Statistical analyses were performed with statistical software JMP v. 11.0.0 (SAS Institute, Inc., Cary, N.C.). A one-way fixed effects analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test were performed to determine significant differences within and among samples. The F ratio statistic was used to test the hypothesis that the response means are significantly different from one another. A larger F ratio indicates a decreased likelihood that the observed difference in treatment means is due to chance. A small P-value (≤ 0.05) indicates strong evidence against the null hypothesis. All tests were considered to be significant when $P < 0.05$.

Results and Discussion

Microwave Specific Energy Versus Milled Rice Yield and Head Rice Yield

Control samples constituted medium-grain rough rice (cv. CL721) at initial MC of 23% (w.b.) that were not treated with MW but gently dried to a MC of 12.5% w.b. in an EMC chamber (Platinous chamber, ESPEC North America, Inc. Hudsonville, Mich.) set at a temperature of 77 °F (25 °C) and relative humidity of 65%. The least square means of the control MRY and HRY were 70.4% and 63.1%, and standard deviations were 3.0% and 4.4%, respectively.

The effect of increasing MW specific energy was found to be significant for both the MRY ($P < 0.0010$; F-Ratio of 3.5734) and HRY ($P < 0.0001$; F-Ratio of 15.9472) responses. It should be noted that the MRY response had a much smaller F ratio with reference to the HRY response. This indicates that the HRY response was more sensitive to the effects of increasing MW specific energy than the MRY.

The effect of increasing MW specific energy was determined to have statistically significant effects on the MRY. As MW specific energy increased, the MRY increased to a peak response at 128.98 BTU/lb-grain (300 kJ/kg-grain) after which the MRY decreased. At this specific energy, rice samples had least square means of 79.3% and standard deviation of 2.3%. It should be noted, however, that the MRY for rice samples treated with MW were statistically similar or higher than the MRY of control samples gently dried with natural air.

The effect of increasing MW specific energy was determined to have statistically significant effects on the HRY (Fig. 2). As MW specific energy increased, the HRY increased to a peak response at 128.98 BTU/lb-grain (300 kJ/kg-grain); at this specific energy, rice samples had least square means of 67.9% and standard deviation of 3.1%. The HRY increased to reach a peak response at the specific energy of 128.98 BTU/lb-grain (300 kJ/kg-grain) after which the HRY decreased. The reduction can be attributed to the increasing specific energy.

Implications of Rice Bed Thickness Variation

The effects of increasing MW specific energy and rice bed layer thickness (1.97, 3.94 and 5.91 in., which are also denoted by layer numbers 1, 2 and 3) were determined for the MRY and HRY. Data suggest that increasing rice bed layer thickness was only significant for the HRY ($P = 0.02873$) response as indicated by the corresponding *P*-value. Based on statistical analyses, summarized effects table showed that the *P* values corresponding to increasing MW specific energy on the MRY and HRY were 0.0014 and 0.02873 respectively; the *P* values corresponding to increasing rice bed layer thickness on the MRY and HRY were 0.9352 and 0.01399, respectively.

Tukey's HSD test was done to identify where the differences were and are indicated on the graph (Fig. 3). Increasing the rice bed layer thickness resulted in a disparity in responses among layers. The top layer (Layer 3) had MRY higher than the middle (Layer 2) and bottom layers (Layer 1). At the top layer, the samples had MRY with a least square mean of 73.0% and standard deviations of 0.7%. The bottom layer had MRY higher than the middle layer. In rice beds of 5.91 in. thickness, it was observed that middle rice bed layers tended to reach higher surface temperatures compared to the top and bottom layers which resulted in lower MRY. Top layers experienced evaporative cooling resulting in lower surface temperatures and, thus, higher MRY. It should be noted that there was no statistical difference in MRY between the rice bed layers.

As for the HRY, increase of the rice bed layer thickness resulted in a disparity in responses between layers (Fig. 3). The top layer (Layer 3) had HRY higher than the middle (Layer 2) and bottom layers (Layer 1). At this layer, the samples had HRY with a least square mean of 64.5% and standard deviations of 0.7%. The bottom and middle layers had statistically similar mean HRYs that were lower than the top layer.

Microwave Specific Energy Versus Final Moisture Content and Drying Rate

The implications of MW specific energy on the rice final moisture content (FMC) and drying rate were determined and are displayed in Figure 4. The effect of increasing MW specific energy was found to be statistically significant for both the FMC ($P < 0.0001$; F-Ratio of 98.1859) and drying rate ($P < 0.0001$; F-Ratio of 17.2607) responses.

The FMC decreased with increasing specific energy. The lowest FMCs were seen at the specific energy of 343.94 BTU/lb-grain (800 kJ/kg-grain). The responses of FMC had a least mean square of 13.5% and a standard deviation of 1.0%.

The effect of increasing specific energy was found to be statistically significant ($P > 0.0001$) on the drying rate response. The drying rate increased with increasing specific energy until a slight drop at the specific energy of 343.94 BTU/lb-grain (800 kJ/kg-grain). At this specific energy, the response of drying rate had a least square mean of 0.0015 lb-H_2O (0.0007 kg-H_2O) removed per second and standard deviation of 0.0002 lb-H_2O (0.0001 kg-H_2O) removed per second.

Implications of Rice Bed Thickness Variation on Final Surface Temperature, Final Moisture Content and Drying Rate

It was determined that the effects of increasing MW specific energy ($P < 0.0001$; F-Ratio of 3200.77) and rice bed layer thickness ($P < 0.0001$; F-Ratio of 474.39) both have a statistically significant effect on the final surface temperature (FST) which decreased with increasing specific energy. The highest FST was seen at the specific energy of 343.94 BTU/lb-grain (800 kJ/kg-grain). At this specific energy, the response of FST had least square means of 252.5 °F (122.5 °C) and standard deviation of 41.9 °F (5.5 °C); as indicated by the higher F ratio and lower *P*-value, it was determined that increasing MW specific energy had an effect on rice FST.

Figures 5 and 6 show the effect of increasing heating duration and specific energy, respectively, on the surface temperature of rice bed layers 1, 2 and 3. If the 5.91 in. (15 cm) rice bed was placed on an *x*-*y* plane, layer 1 would represent the 0 to 1.97 in. (0 to 5 cm) layer, layer 2 would represent the 1.97 to 3.94 in. (5 to 10 cm) layer, and layer 3 would represent the 3.94 to 5.91 in. (10 to 15 cm) layer

The factor of rice bed thicknesses (up to 5.91 in.) was not significant for the drying rate and FMC responses ($P = 0.15$ and $P = 0.57$). Increasing the rice bed layer thickness did not result in any changes in FMC, FST, or drying rate and there was no disparity in these responses between any of the layers.

Implications of Final Moisture Content, Final Surface Temperature and Drying Rate on Milled Rice Quality

Analyses were conducted to determine the implications of the FMC, FST and drying rate effects on the MRY and HRY. Table 2 list the model effects (*P*-values) for the FMC, FST and drying rate effects for the MRY and HRY responses.

For the response of MRY, of the 3 factors analyzed, it was determined that FMC had the most effect ($P = 0.0089$). This means that the effect of decreasing FMC leads to a significant decrease in MRY. The effects of FST and drying rate did not have any significant statistical effect on the MRY as indicated by their *P*-values.

For the response of HRY, of the 3 factors analyzed, it was determined that FMC has the most effect on HRY ($P < 0.0001$) (Table 2). This means that the effect of decreasing FMC leads to a significant decrease in HRY. The effects of FST also had a significant (P = 0.0451) effect on the HRY. Increasing FST resulted in significantly lower HRY. This result was corroborated by Wadsworth (1993), who postulated that increased surface temperatures are correlated with decreases in HRY. Drying rate did not have any significant (P = 0.8856) effect on the HRY. It should be noted, however, that the HRY for rice samples treated with MW were statistically similar or higher than the HRY of control samples gently dried with natural air.

Significance of Findings

Increasing specific energy caused increases in rice FST and drying rate. Conversely, increasing specific energy caused decreases in rice FMC, HRY, and MRY. There was a statistically significant ($P < 0.05$) disparity in HRY as a result of increasing rice bed thicknesses. Highest HRYs were observed at the top, followed by the middle and bottom layer in thick rice beds. However, increasing rice bed thicknesses up to 5.91 in., did not result in any significant changes in the rice FMC or drying rate, and there was no disparity in these responses among any of the rice bed layers. Increasing FST and drying rates and decreasing FMC resulted in significantly ($P < 0.05$) lower MRY and HRY.

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Literature Cited

Atungulu, G., D. Smith, S. Wilson, H. Zhong, S. Sadaka, and S. Rogers. (2016). Assessment of One –Pass Drying of Rough Rice with an Industrial Microwave System on Milling Quality. Applied Engineering in Agriculture, 32(3):417-429.

Ban, T. (1971).Rice cracking in high rate drying. Japanese Agric. Res. Quarterly, 6, 113–116.

Cnossen, A.G. and T.J. Siebenmorgen. (2000). The glass transition temperature concept in rice drying and tempering: Effect on milling quality. Trans. ASAE-Amer. Soc. Agric. Eng. 43(6):1661-1668.

Jindal, V. K. and T.J. Siebenmorgen. (1987). Effects of oven drying temperature and drying time on rough rice moisture content determination. Trans. ASAE, 30(4):1185-1192. http://dx.doi.org/10.13031/2013.30542

Kunze, O.R. (1979). Fissuring of the rice grain after heated air-drying. Transactions of the ASAE, 22:1197–1202, 1207.

Kunze, O.R. and M.S.U. Choudhury. (1972). Moisture adsorption related to the tensile strength of rice. Cereal Chem. 49:684–696.

USDA-NASS. 2014. United States Department of Agriculture National Agricultural Statistics Service. Crop and stocks report. Retrieved from http://www.nass.usda.gov/

USDA-GIPSA. 2010. United States Department of Agriculture Grain Inspection, Packers and Stockyards Administration. Grain inspection handbook-Book, Chapter 3, Washington, p. 13.

Wadsworth, J.I. 1993. Microwave-vacuum drying. Food Science and Technology. New York-Marcel Dekker, 299-299.

Table 1. Rice bed thicknesses, microwave power levels and heating durations used in the rice drying experiments.

Rice bed thickness	Microwave power	Heating duration
in. (cm)	BTU/min (kW)	(min)
1.97 (5)	284.35 (5)	4
1.97 (5)	284.35 (5)	6
1.97 (5)	284.35 (5)	8
1.97 (5)	568.69 (10)	4
3.94 (10)	284.35 (5)	4
3.94 (10)	284.35 (5)	6
3.94 (10)	284.35 (5)	8
3.94 (10)	568.69 (10)	4
3.94 (10)	568.69 (10)	6
3.94 (10)	568.69 (10)	8
3.94 (10)	853.04 (15)	4
5.91 (15)	284.35 (5)	4
5.91 (15)	284.35 (5)	6
5.91 (15)	284.35 (5)	8
5.91 (15)	568.69 (10)	4
5.91 (15)	568.69 (10)	6
5.91 (15)	568.69 (10)	8
5.91 (15)	853.04 (15)	4
5.91 (15)	853.04 (15)	6
5.91 (15)	853.04 (15)	8

Table 2. Effect summary table showing *P*-values to illustrate the effects of rice final moisture content, final surface temperature and drying rate on the milled rice yield and head rice yield responses.

	Response *P*-Value		
Source	Final moisture content	Final surface temperature	Drying rate
	(%)	(° C)	(kg/s)
Milled Rice Yield	0.0089	0.5613	0.8145
Head Rice Yield	0.0000	0.0451	0.8856

Fig. 1a. Diagram of microwave system showing the transmitter (1), heating zone (2), wave guide (3), conveyor belt (4), and control panel (5).

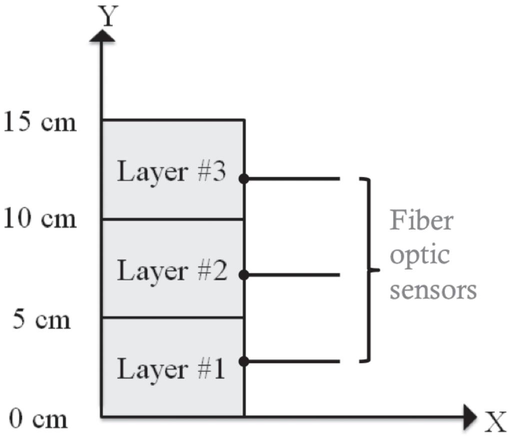

Fig. 1b. Schematic diagram of stackable microwave blind trays fitted with fiber optic cables in each layer, 1.97, 3.94 and 5.91 in. (5, 10 and 15 cm).

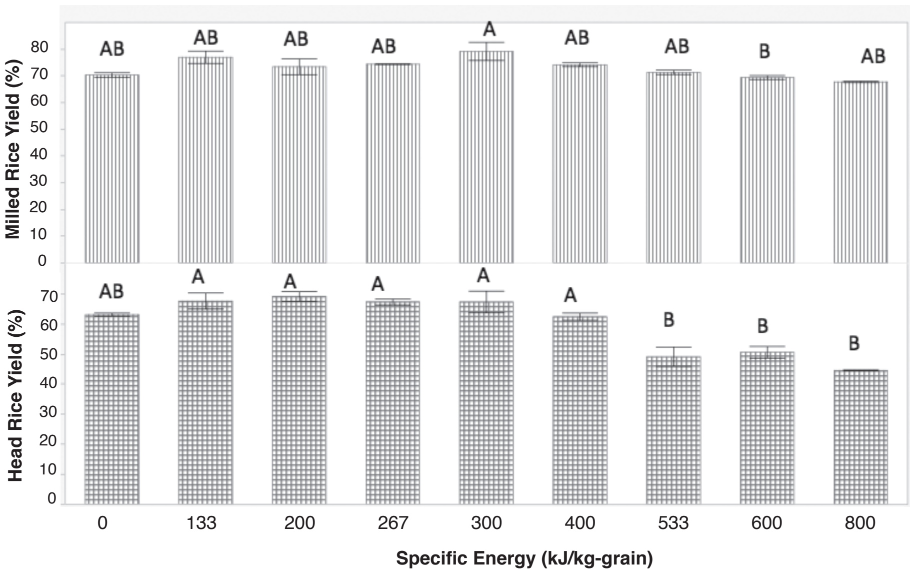

Fig. 2. Effect of increasing microwave specific energy on the milled rice yield (MRY) and head rice yield (HRY) of medium grain rice. Means with the same type of letters are not significantly different at α = 0.05. 1 kJ/kg = 0.429923 Btu/lb; 1 Btu/lb = 2.326 kJ/kg.

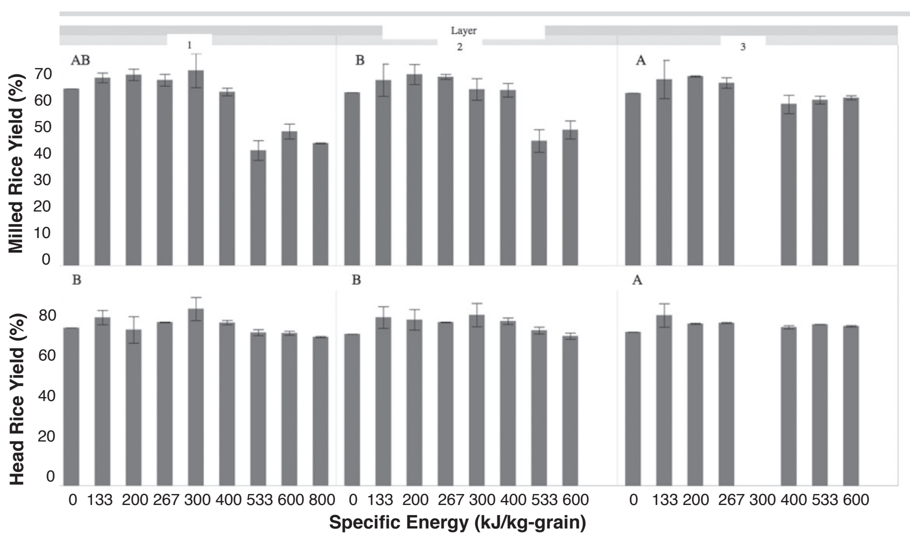

Fig. 3. Effect of increasing microwave specific energy and rice bed thicknesses on the milled rice yield and head rice yield of medium grain rice. Means with the same type of letters are not significantly different at α = 0.05. Layer 1 corresponds to the 0 to 1.97 in. (bottom) layer, Layer 2 corresponds to the 1.97 to 3.94 in. (middle) layer and Layer 3 corresponds to the 3.94 to 5.91 in. (top) layer. 1 kJ/kg = 0.429923 Btu/lb; 1 Btu/lb = 2.326 kJ/kg.

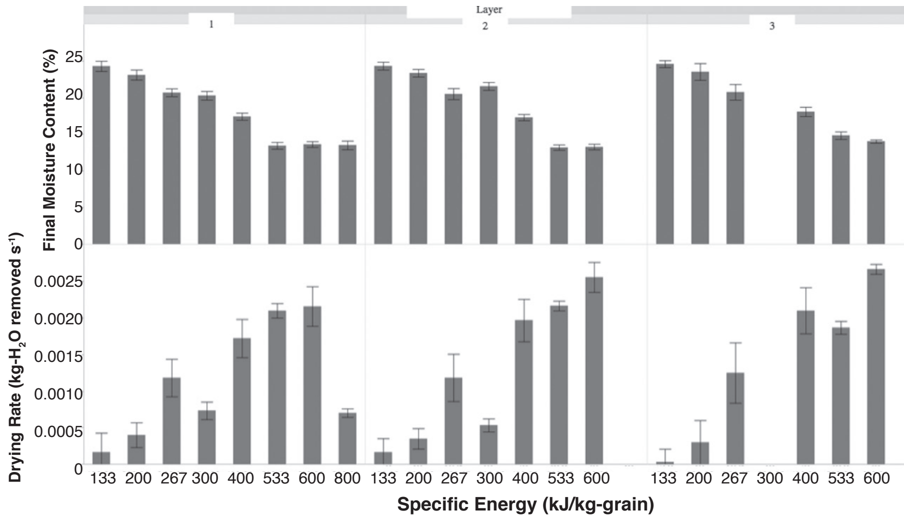

Fig. 4. Effect of increasing microwave specific energy on the final percent moisture content (wet basis, w.b.) and drying rate of medium grain rice. Means with the same type of letters are not significantly different at α = 0.05. Layer 1 corresponds to the 0 to 1.97 in. (bottom layer), Layer 2 corresponds to the 1.97 to 3.94 in. (middle layer), and Layer 3 corresponds to the 3.94 to 5.91 in. (top) layer. 1 kJ/kg = 0.429923 Btu/lb; 1 Btu/lb = 2.326 kJ/kg; 1 kg = 2.205 lb.

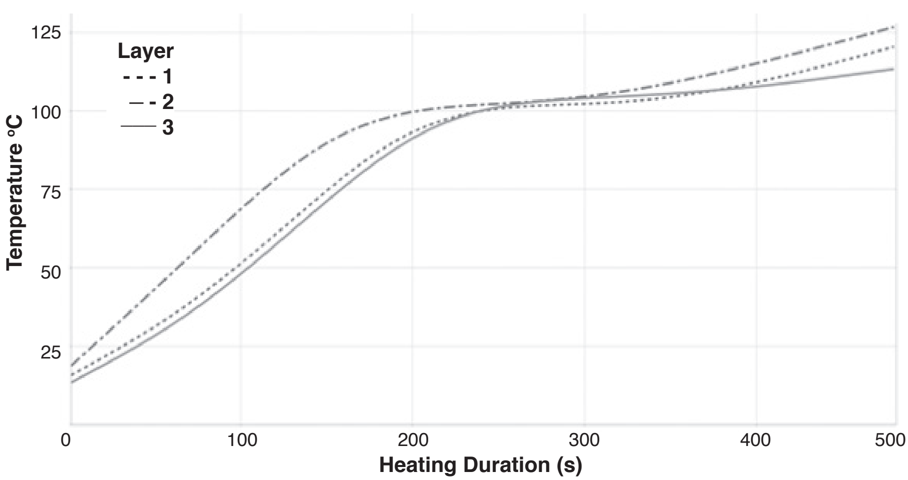

Fig. 5. Effect of increasing microwave heating duration on the surface temperature of rice layers in a 15 cm thick rice bed (supplied microwave power = 10 kW; duration of heating = 8 min). Layer 1 corresponds to the 0 to 1.97 in. (bottom) layer, Layer 2 corresponds to the 1.97 to 3.94 in. (middle) layer and Layer 3 corresponds to the 3.94 to 5.91 in. (top) layer. °F = °C * 9/5 + 3; °C = (°F - 32) * 5/9.

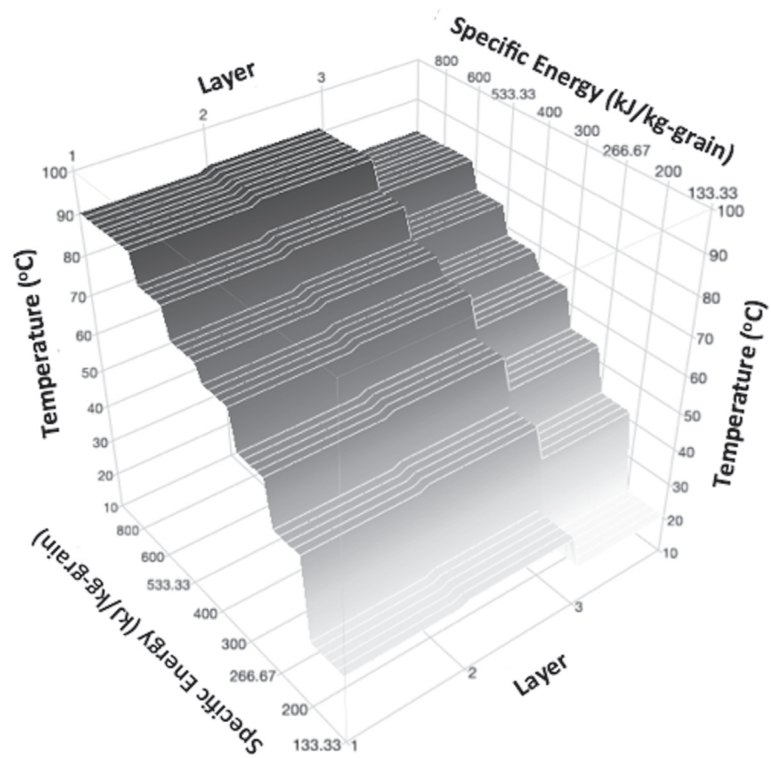

Fig. 6. Effect of increasing microwave specific energy on the surface temperatures of rice layers in a 15 cm rice bed. Layer 1 corresponds to the 0 to 1.97 in. (bottom) layer, Layer 2 corresponds to the 1.97 to 3.94 in. (middle) layer and Layer 3 corresponds to the 3.94 to 5.91 in. (top) layer. 1 kJ/kg = 0.429923 Btu/lb; 1 Btu/lb = 2.326 kJ/kg. °F = °C * 9/5 + 3; °C = (°F - 32) * 5/9.

Fissure Detection in Rough Rice Kernels using X-Ray Imaging

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Abstract

X-ray imaging can be used to detect fissures in rough rice kernels owing to the ability of X-rays to penetrate hulls, allowing visualization of internal kernel structure. In this study, the fissure detection capability of an X-ray system was evaluated and the relationship between the head rice yield (HRY) of a sample, as measured through laboratory milling, and the percentage of fissured rough rice kernels in that sample was determined. Long-grain rice lots were dried using heated air for five drying durations to produce different degrees of fissuring, and then milled to determine HRY. A strong linear correlation (R^2 = 0.95) between HRY and the percentage of fissured rough rice kernels after drying was observed. This correlation confirms the substantial impact that kernel fissures have on milling yields. Overall, these findings show the effectiveness of X-ray imaging in rough rice fissure detection, which could allow for in-situ drying research that may provide a better understanding of kernel fissuring kinetics.

Introduction

Fissures in rice kernels are fractures of the endosperm that can either be perpendicular to the long axis of the kernel (Kunze and Calderwood, 2004) or in no specific alignment (Bautista et al., 2000). During milling, rice kernels tend to break at the fissure sites. The resulting kernels that are less than three-fourths of an intact kernel are referred to as brokens; the remaining kernels are referred to as head rice. Head rice yield (HRY) is defined as the mass percentage of rough rice that remains as head rice after milling (USDA, 2009). Brokens have a reduced commercial value, typically between 60% and 80% of the value of head rice (Siebenmorgen et al., 2008). Therefore, minimizing kernel fissuring is an important goal of the rice industry.

Grainscopes have been used as a method of fissure detection due to low cost and portability. However, to use a grainscope, the hulls have to be removed from kernels, which is a time-consuming process. Additionally, fissured kernels will often break apart during dehulling, even when dehulling by hand. It is thus appropriate to determine if using an X-ray system to detect fissures in rough rice is as reliable as using a grainscope to detect fissures in brown rice. If viable, X-ray imaging could allow fissures to be observed in rough rice during the drying process and hence provide information on fissuring kinetics.

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Currently, laboratory milling is the only method used for measuring HRY, yet, there is an increasing demand for a method that can more rapidly estimate this parameter. The goal of this research was to evaluate X-ray imaging as a method for fissure detection in rough rice kernels and to establish a relationship between the percentage of fissured kernels in a rough rice sample and the sample HRY.

Procedures

Fifteen rough rice samples, comprising long-grain cultivars grown in Arkansas, were harvested at moisture contents (MCs) ranging from 16% to 24% from Keiser, Pocahontas, and Harrisburg, Ark (Table 1). All samples were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn.) In order to create samples with a range of fissured kernels, rough rice from each cultivar lot was dried for varying durations. From each 2015 cultivar lot, four 200-g sublots were each dried using air at 140 ºF (60 ºC), 10% relative humidity (RH) for two drying durations: 30 min for 2 of the sublots and 60 min for the other 2 sublots. Similarly, from each 2016 cultivar lot, four 200-g sublots were dried for two drying durations: 20 min for 2 of the sublots, and 40 min for the other two sublots. Additionally from 2016, one sub-lot was selected in which no heated air drying was conducted. The drying air conditions were maintained by an environmental chamber (ESL 4CA Platinous Temperature and Humidity Chamber, Espec, Hudsonville, Mich.). One of the 2 sublots from each drying duration was tempered in a sealed bag at 140 ºF (60 ºC) for 2 h immediately after drying and before cooling; whereas the other sublot was cooled immediately after drying by exposing the kernels to air at room temperature 70 ± 4 ºF (21 ± 2 ºC). These drying/post-drying treatments (Fig. 1) are known to produce drastically different degrees of fissuring, and consequently, a range of HRYs. Thereafter, all 70 sublots were slowly dried to a MC of 12.5 ± 0.5% in a climate-controlled chamber (79 ºF, 56% RH) regulated by a stand-alone conditioner (5580A, Parameter Generation and Control, Black Mountain, N.C.).

Fissures can readily occur due to the drying process. It was relevant to determine how the X-ray system and the grainscope compared in detecting moisture desorption fissures. For each sublot from each cultivar lot that had been exposed to the various drying and post-drying treatments and then conditioned to 12.5% MC, a 100-kernel sample was selected and divided into 5, 20-kernel subsamples. For each of the 20-kernel sub-samples, fissures were detected by spreading the rough rice kernels on an acrylic sample shelf and introducing the kernels to an X-ray system (UltraFocus 60, Faxitron Bioptics LLC., Tucson, Ariz.) at 3X magnification. Imaging was then conducted at 32 KeV energy, 0.34 mA current, and 5.5 s exposure duration. All the images were then saved to be used for analysis. Then each of the 20-kernel rough rice subsamples was dehulled by hand. The resulting brown rice kernels were then presented to first the X-ray system and then the grainscope for enumerating fissures by both instruments (Fig. 1).

Also from each sublot from each cultivar lot that had been exposed to the various drying and post-drying treatments and then conditioned to 12.5% MC, a 200-g subsample was selected from which a 150-g rough rice sample was milled to determine HRY.

These 150-g milling samples were taken from each of the 4 sublots of the 5 cultivar lots harvested in 2015 and from each of the 5 sublots of the 10 cultivar lots harvested in 2016; thus, a total of 70 HRY determinations were made. Of these 70 combinations, 47 were randomly selected and used in deriving an equation relating fissured kernel percentage to HRY; the remaining 23 were used for validating the ability of the derived equation to predict HRY.

Results and Discussion

Figure 2 shows the fissure detection comparison in dried brown rice kernels between the X-ray system and the grainscope. The slope of 1.04 implies that the two approaches produced similar fissure counts. This, along with the root mean square error (RMSE) of 8 percentage points, which is equivalent to 1-2 kernels per 20-kernel subsample, indicates that there were marginal differences between the X-ray and grainscope methods of fissure detection in brown rice kernels. There is a general trend, however, showing that the X-ray system detected slightly more fissured kernels than the grainscope, as indicated by the slope of the fitted line, which is >1. This trend may be due in part to the different operating principles of an X-ray system and a grainscope; an X-ray system uses ionizing radiation whereas a grainscope uses visible light and thus, a slight variation in kernel orientation when using a grainscope could make a fissure(s) non-detectable by the human eye.

Figure 3 compares the fissure detection capabilities of the X-ray system using rough rice and the grainscope using brown rice. Figure 3 shows a slope of 1.03, which implies that the two approaches produced similar fissure counts with few cases where there were great deviations from the fitted line. As was the trend in Fig. 2 using brown rice kernels, Fig. 3 indicates a trend that the X-ray system detected more fissured rough rice kernels than was detected in brown rice kernels using a grainscope. At fissured kernel percentages <20%, the data points fit closer to the fitted line than when the fissured kernel percentages were >20%. This trend implies that the two instruments have more similar fissure detection capabilities in samples having fewer fissures (<20%) than in heavily fissured (>20%) samples.

Figure 4 shows the relationship between HRY and the percentage of fissured rough rice kernels detected in dried samples using the X-ray system. The plot shows that HRY is a linear function of the percentage of fissured kernels with a correlation coefficient (R) of -0.97. These findings corroborate those of Iguaz et al. (2006) and Siebenmorgen et al. (2007) wherein reduction in HRY was observed with increase in percentage of fissured brown rice kernels observed using a fissure inspection box and a grainscope, respectively.

The coefficient of determination (R^2) (Fig. 4) implies that 95% of the variability in HRYs can be attributed to the percentage of fissured rough rice kernels in a dried sample. The remaining variability in HRYs may be explained by other factors such as kernel maturity (Lu and Siebenmorgen, 1995), chalkiness (Bautista et al., 2010), and insect damage (Arthur et al., 2012). Immature, chalky, and insect-damaged kernels are known to be mechanically weaker than completely sound kernels and are likely to break during milling. Breakage from these kernels would further reduce HRY more than fissured kernels alone would.

Validation of the prediction equation shown in Fig. 4 was conducted using a validation data set that comprised 23 rice sub-lots. The predicted HRYs were then compared to the HRYs determined through laboratory milling. The comparison (Fig. 5) indicates that the equation provided satisfactory HRY predictions.

Significance of Findings

This study confirmed that fissured kernel percentage is a key factor determining HRY. While other kernel imperfections can play varying roles in reducing HRY, the equation is deemed useful in providing rapid estimates of expected HRY without having to mill a rough rice sample.

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Literature Cited

Arthur, F.H., G.O. Ondier, and T.J. Siebenmorgen. (2012). Impact of *Rhyzopertha dominica* (F.) on quality parameters of milled rice. J. Stored Prod. Res., 48, 137-142.

Bautista, R.C., T.J. Siebenmorgen, and P.A. Counce. (2010). Rice kernel chalkiness and milling quality relationship of selected cultivars. *In:* R. J. Norman and K.A.K. Moldenhauer (eds). B.R. Wells Arkansas Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:220-229. Fayetteville.

Bautista, R. C., T.J. Siebenmorgen, and J.W. Fendley. (2000). Fissure formation characterization in rice kernels during drying using video microscopy. *In:* R. J. Norman and K.A.K. Moldenhauer (eds). B.R. Wells Arkansas Rice Research Studies 1999. University of Arkansas Agricultural Experiment Station Research Series Research Series 476:325-330. Fayetteville.

Iguaz, A., M. Rodriguez, and P. Virseda. (2006). Influence of handling and processing of rough rice on fissures and head rice yields. J. Food Eng. 77(4):803-809.

Kunze, O.R. and D.L. Calderwood. (2004). Chapter 9: Rough rice drying-moisture adsorption and desorption. *In*: E.T. Champagne (ed.), Rice: Chemistry and technology (pp. 223-268). St. Paul, Minn.: AACC Int.

Lu, R. and T.J. Siebenmorgen. (1995). Correlation of head rice yield to selected physical and mechanical properties of rice kernels. Trans. ASAE, 38(3):889-894.

Siebenmorgen, T. J., R.C. Bautista, and P.A. Counce. (2007). Optimal harvest

moisture contents for maximizing milling quality of long- and medium-grain rice cultivars. Appl. Eng. Agric., 23(4):517-527.
Siebenmorgen, T. J., N.T. Cooper, R.C. Bautista, P.A. Counce, E. Wailes, and K.B. Watkins. (2008). Estimating the economic value of rice (*Oryza sativa* L.) as a function of harvest moisture content. Appl. Eng. Agric., 24(3):359-369.
USDA. (2009). United States Standards for Rice: 27 November 2009. Washington, D.C.: USDA, Grain Inspection, Packers and Stockyard Administration. Retrieved from www.gipsa.usda.gov

Table 1. Summary of harvested rice samples.

Year	Location	Cultivar	Harvest MC[a] (%, wet basis)
2015	Keiser, Ark	LaKast	18.2
	Keiser, Ark	XL753(a)	17.0
	Keiser, Ark	CL152	20.8
	Pocahontas, Ark	XL760	20.0
	Pocahontas, Ark	XL753(b)	19.0
2016	Harrisburg, Ark	Aura115	15.9
	Harrisburg, Ark	Cheniere	18.2
	Harrisburg, Ark	CL151	17.9
	Harrisburg, Ark	CLXP766	17.5
	Harrisburg, Ark	XL753	16.6
	Harrisburg, Ark	CLXL745	19.9
	Harrisburg, Ark	CL111	17.0
	Harrisburg, Ark	XL760	16.4
	Harrisburg, Ark	XL723	19.2
	Keiser, Ark	Roy J	23.6

[a] MC = moisture contents.

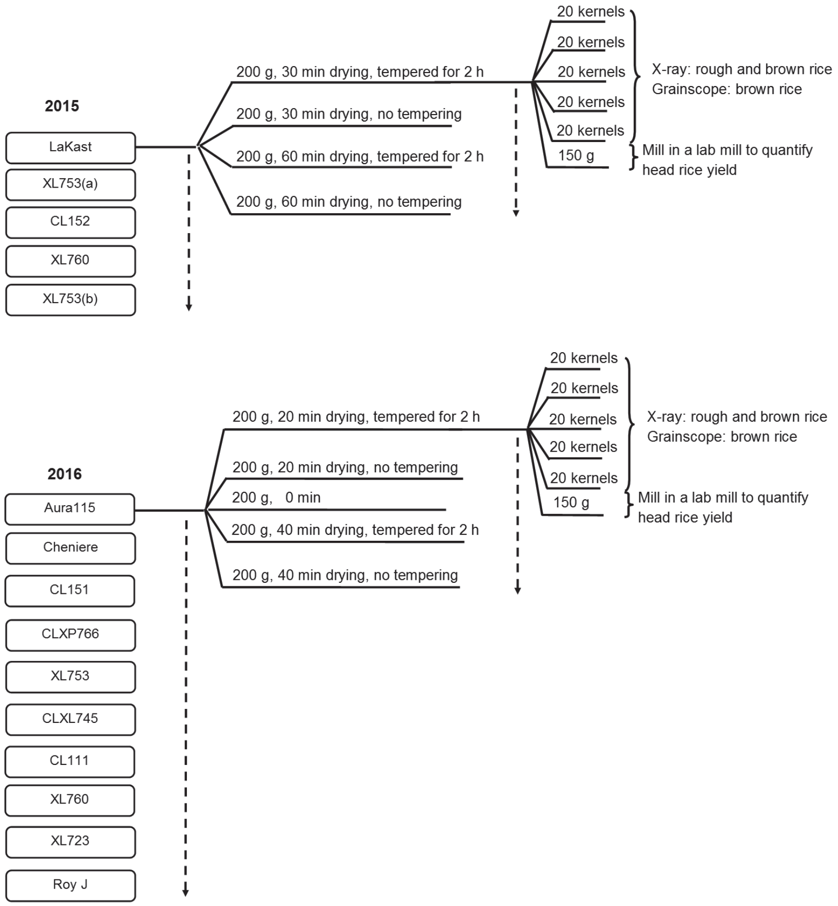

Fig. 1. Layout of the experimental procedure for creating a set of samples from the 2015 and 2016 cultivar lots (Table 1) with greatly different levels of kernel fissuring. This sample set was subsequently used for fissure detection in dried kernels using an X-ray system and a grainscope then milled in laboratory mill to determine head rice yield.

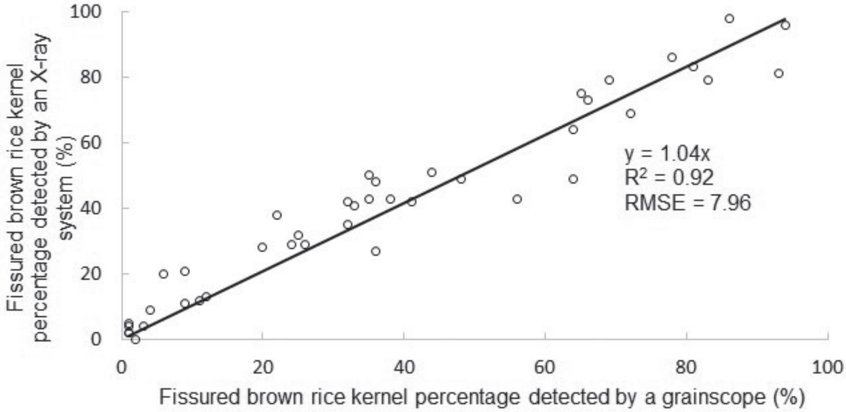

Fig. 2. Comparison between fissure detection capabilities of an X-ray system and a grainscope using dried brown rice kernels. Most fissures were created by varying degrees of drying severity and post-drying treatments. The R^2 is the coefficient of determination and RMSE is the root mean square error.

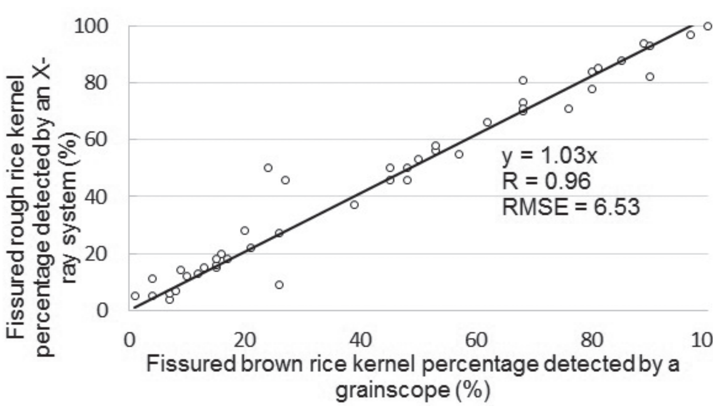

Fig. 3. Comparison between fissure detection capabilities of an X-ray system using dried rough rice kernels and a grainscope using dried brown rice kernels. Most fissures were created by varying degrees of drying severity and post-drying treatments. The R^2 is the coefficient of determination and RMSE is the root mean square error.

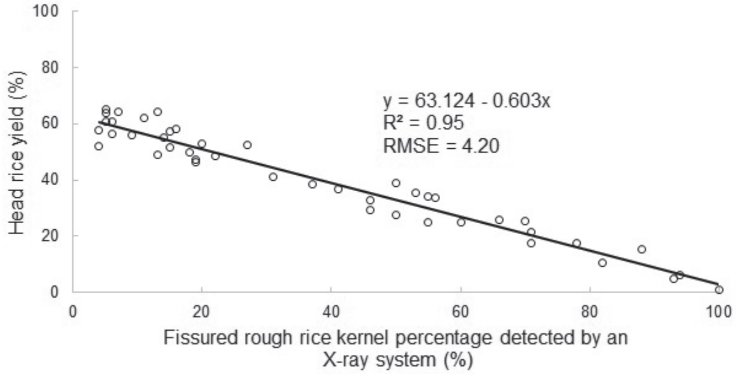

Fig. 4. Correlation between head rice yield and fissured rough rice kernel percentage detected by an X-ray system. The R^2 is the coefficient of determination and RMSE is the root mean square error.

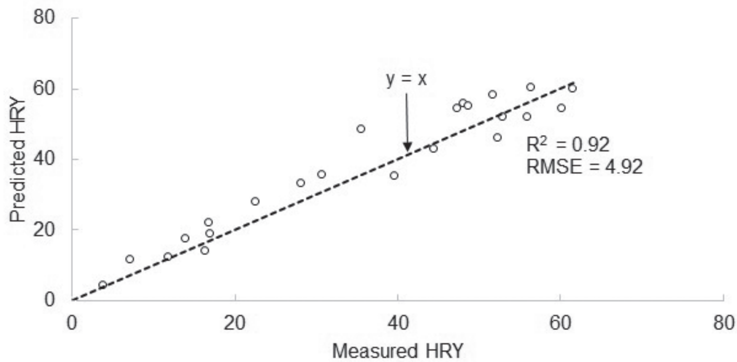

Fig. 5. Head rice yield (HRY) predicted using the equation *y* = 63.124-0.603*x* vs HRY determined through laboratory milling for the 23 sub lots allocated as a validation set. The R^2 is the coefficient of determination and RMSE is the root mean square error.

Consequence of Surface Water Use and Efficient Irrigation Practice Adoption on Economic Returns and Groundwater Conservation

K. Kovacs[1], A. Durand-Morat[1], and Q. Huang[1]

Abstract

The use of surface water from off-farm canals or on-farm reservoirs to supplement groundwater for irrigation, as well as the use of efficient irrigation practices, raises economic returns but does not necessarily lead to groundwater conservation. The intended rise in the aquifer volume with these irrigation investments does not occur unless the off-farm water is available at a sufficiently low price and the irrigation practices are adequately efficient to shift the source of irrigation away from groundwater. Overdraft of groundwater continues with the use of surface water and efficient practices because the crops become more irrigation intensive.

Introduction

Investment in the development of surface water storage for irrigation can be expensive in comparison to investment in greater irrigation efficiency through irrigation-scheduling devices and pressurized irrigation systems, but the return from these investments have to be weighed against the costs (Schaible and Aillery, 2012). Ample surface water in the off-season that can be cheaply stored and easily transported to farms may be preferred to costly improvements in irrigation efficiency. The physical characteristics of the land also affect the suitability of irrigation system investments (Caswell and Zilberman, 1986). Gravity systems are better when fields have flatter slopes and soils with low infiltration rates, while pressurized systems have an advantage on irregular shaped fields with steeper slopes and soils with high infiltration rates. An agricultural landscape above an abundant aquifer with significant natural recharge may not need any investments in irrigation so long as groundwater pumping is cheap. Increases in irrigation-intensive crop acreage though will likely make some irrigation investment necessary.

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Procedures

A spatial model tracks groundwater use and crop mix over three decades to determine how conjunctive surface water use, efficient irrigation practices, and water conservation policies affect the economic returns and conservation of the aquifer. The crops involved include irrigated rice, soybean, corn, cotton, non-irrigated sorghum and soybean, and double cropped irrigated soybean with winter wheat. To evaluate the availability of off-farm water use and irrigation practice adoption on land, reservoir, and groundwater use, and economic returns, the baseline—which assumes no off-farm and reservoir water use and no irrigation practice adoption (No OFW-No Res-No IP)—is compared to the results of the technology and policy scenarios, for off-farm water price of $125/acre-ft.

The technology scenarios are: i) off-farm water only (OFW-No Res-No IP); ii) off-farm and reservoir water only (OFW-Res-No IP); iii) off-farm and irrigation practice adoption only (OFW-No Res-IP); and iv) off-farm and reservoir water use and irrigation practice adoption (OFW-Res-IP). The irrigation practice options are conventional (furrow for crops other than rice and flood for rice), center pivot, computerized poly pipe-hole selection, surge, land leveling, alternate wet-dry, and multiple-inlet. The groundwater conservation policy options are a reservoir construction cost share and a land-leveling cost share, which are 65% and 60%, respectively, based on the Natural Resource Conservation Service (NRCS) rates (NRCS, 2015).

Results and Discussion

At $125/acre-ft for off-farm water, off-farm water provides 47,000 acre-ft or 4% of total water use in 2043 without reservoirs, and no acre-feet when reservoirs are used (Table 1). When groundwater is the sole irrigation source, rice acreage by 2043 is estimated at 214,400 acres or 19% of the total land used. The acreage of rice compared to the baseline without off-farm water expands by 1% without reservoirs and by 19.3% with reservoirs, and the amount of land in irrigated soybeans and irrigated corn increases by 1% and 6% without reservoirs and by 1% and 7% with reservoirs. The land in non-irrigated sorghum falls by 13% without reservoirs and by 26% with reservoirs.

The adoption of irrigation practices increases the share of irrigated crops on the landscape to over 90% of the total land use (Table 2). Rice acreage expands to almost half of the total land used in 2043, and there is no difference in rice acreage with and without reservoirs. All rice and cotton acreage is expected to adopt some form of water-saving irrigation practice. The use of irrigation practices means that the land in soybeans and corn falls, but the use of reservoirs keeps the acreage in those crops from falling as much. With irrigation practice adoption, the land in non-irrigated sorghum falls by 72% without reservoirs and by 77% with reservoirs.

Without off-farm water, reservoirs, and irrigation practices, the model projects that the volume of the aquifer will decrease to 57.7 million acre-ft by 2043 (Table 1). With off-farm water, the 2043 aquifer falls to 57.5 or 57.6 million acre-ft with and without reservoir, respectively, because the acreage of irrigated crops increases when reservoirs and off-farm water provides a backstop water source. The off-farm water availability at the price of $125/acre-ft raises economic returns by 1% and 2%, with and without reservoirs, respectively. The use of reservoirs with the off-farm water increases the economic returns and the volume of the aquifer.

The adoption of irrigation practices significantly raises the aquifer volume by 5% to 60.7 million acre-feet even as irrigation-intensive rice acreage expands by more than a 100% (Table 2). This is primarily because each acre of rice uses less irrigation water than before with the adoption of the efficient zero-grade land leveling. The use of the irrigation practices and the availability of off-farm water makes economic returns rise by 51% without reservoirs and 52% with reservoirs. These findings demonstrate the value of encouraging efficient irrigation practice adoption as well as surface water infrastructure.

Table 3 presents the influence of water conservation policies when off-farm water and reservoir water are available (OFW-Res-IP). The reservoir cost share program contributes to doubling the reservoir acreage from 11,000 to 22,000 acres, and the aquifer rises by 3.9 million acre-feet. It also changes land use in favor of irrigated crops, most notably cotton, at the expense of non-irrigated sorghum. The program costs the government $159 million and improves farm returns by $82 million, meaning there is a cost to society of the reservoir policy of $77 million. Dividing the cost to society by the 3.9 million acre-ft of groundwater saved implies a cost of $19.9/acre-ft. The cost-share on land leveling leads to an expansion of irrigated crops, most notably cotton, a modest expansion of total water use supported by reservoir and groundwater, and a lower aquifer. Hence at high off-farm water prices, the cost share on land-leveling exerts changes in water use that are a cost to society without any increase in the aquifer.

Significance of Findings

Estimating the demand for surface water and the adoption of efficient irrigation practices is useful to agricultural producers and policy makers gauging whether these investments increase economic returns and conserve the aquifer. The current research finds that the rise in the acreage irrigation intensive crops raises economic returns by about 1% without efficient irrigation practices, but this also means a higher rate of groundwater overdraft. The price of surface water from either on- or off-farm sources needs to be less than $75/acre-ft to generate a shift away from groundwater as the crops become more irrigation intensive. An excellent approach to encouraging economic growth and aquifer conservation is to lower the price of surface water from off- or on-farm sources.

Efficient irrigation practices allow high value crops to be grown at a lower cost and with less burden on the aquifer. Encouraging the adoption of irrigation practices may be better for aquifer conservation than the development of surface water infrastructure, but this hinges on how efficiently these practices reduce the water applied. Also, policy makers should promote the complementary use of surface water and irrigation practices because this furthers economic and conservation goals.

Acknowledgments

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Literature Cited

Caswell, M., and D. Zilberman. 1986. The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology. Amer. J. Agric. Econ. 68:798-811.

NRCS. 2015. Natural Resources Conservation Service, Arkansas. 2015 EQIP Conservation Practices and Payment Rates. Accessed August 2015. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ar/home/?cid=STELPRDB 1240703

Schaible, G.D. and M.P. Aillery. 2012. Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands. Economic Information Bulletin Number 99. Economic Research Service, United States Department of Agriculture, Washington, D.C. (September). http://www.ers.usda.gov/media/884158/eib99.pdf

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Table 1. Impact of reservoir construction on land and water use, and economic returns in 2043.

Land use	NO OFW NO RES NO IP[a]	Off-farm water price: OFW - NO RES - NO IP	Off-farm water price: OFW - RES - NO IP
(acres)		-------------($125/acre-ft)-------------	
Rice - conventional irrigation	214,400	216,700	255,800
Irrigated soybeans - conventional irrigation	126,100	126,800	127,100
Irrigated corn - conventional irrigation	379,800	402,200	406,600
Irrigated cotton - conventional irrigation	94,844	97,360	97,943
Double crop soybean/wheat - conventional irrigation	11,600	23,234	5866
Non-irrigated sorghum	314,400	274,900	233,400
Reservoirs		0	14,353
Water use (1000 acre-ft/year)			
Annual water use	1145	1186	1275
Annual reservoir water use	0	0	115
Annual groundwater use	1145	1139	1160
Annual off-farm water use	0	47	0
Aquifer	57,720	57,570	57,630
30 year farm net returns (million $)	**4469**	**4500**	**4546**

[a] OFW: Off-farm water; RES: reservoirs; IP: irrigation practices.

Table 2. Impact of irrigation practices on land and water use, and economic returns in 2043.

Land use	NO OFW NO RES NO IP[a]	Off-farm water price	
		OFW - NO RES – IP	OFW – RES – IP
(acres)		--------------($125/acre-ft)--------------	
Rice - conventional irrigation	214,400	0	0
Rice - IP		560,200	560,500
Irrigated soybeans - conventional irrigation	126,100	49,823	50,177
Irrigated corn - conventional irrigation	379,800	313,300	317,500
Irrigated corn - IP		19,200	13,000
Irrigated cotton - conventional irrigation	94,844	0	0
Irrigated cotton - IP		105,200	111,200
Double crop soybean/wheat - conventional irrigation	11,600	5937	4808
Non-irrigated sorghum	314,400	87,410	72,793
Reservoirs		0	11,133
Water use (1000 acre-ft/year)			
Annual water use	1145	1137	1141
Annual reservoir water use	0	0	91
Annual groundwater use	1145	1040	1050
Annual off-farm water use	0	97	0
Aquifer	57,720	60,730	60,700
30 year farm net returns (million $)	**4469**	**6748**	**6783**

[a] OFW: Off-farm water; RES: reservoirs; IP: irrigation practices.

Table 3. Water conservation policies influence on reservoir construction, aquifer capacity, and economic returns by 2043.

	Off-farm water price		
Land use	**OFW-RES-IP**[a]	**CS RES**[b]	**CS LL**[c]
(acres)	-------------------($125/acre-ft)-------------------		
Rice – IP	560,500	561,300	560,800
Irrigated soybeans - conventional irrigation	50,177	50,143	50,177
Irrigated corn - conventional irrigation	317,500	329,300	324,500
Irrigated corn – IP	13,000	3400	5500
Irrigated cotton - IP	111,200	120,000	118,400
Double crop soybean/wheat - conventional irrigation	4808	3413	2331
Non-irrigated sorghum	72,793	51,525	68,099
Reservoirs	11,133	22,099	11,326
Water use (1000 acre-ft/year)			
Annual water use	1141	1152	1146
Annual reservoir water use	91	182	92
Annual groundwater use	1050	970	1054
Annual off-farm water use	0	0	0
Aquifer	60,700	64,580	60,660
30 year farm net returns (million $) [d]	6783	6866	6851
30 year government revenue (million $)	--	-159.4	-67.5
Groundwater conservation cost ($/acre-ft) [e]	--	19.9	No ground-water conserved

[a] OFW: Off-farm water; RES: reservoirs; IP: irrigation practices.
[b] The cost share is 65% for irrigation reservoir construction (NRCS, 2014).
[c] The cost share is 60% for land leveling (NRCS, 2014).
[d] The farm net returns include the payments to or receipts from the government because of the policy.
[e] Groundwater conservation cost is calculated as the policy cost (which is the farm net returns in the baseline less the farm net returns plus government revenue for each policy scenario) divided by the change in aquifer level between the policy option and the baseline.

World and United States Rice Baseline Outlook, 2017-2027

E.J. Wailes[1], E.C. Chavez[1], and Alvaro Durand-Morat[1]

Abstract

International rice prices stabilized during the second half of 2017 as ample supplies and active competition to supply the unexpected demand from Bangladesh and Sri Lanka prevailed in the global rice market. Thai rice prices became more competitive with those of Vietnam. In nominal terms, the average global rice projected price increases steadily at 2.2% annually over the next decade, as net global trade grows at 1.9% over the same period. India and Thailand remain the top global rice exporters; and the People's Republic of China (PRC) and Nigeria remain the major global rice importers. Global growth in trade over the next decade reflects expansion in export shipments from India, Vietnam, Myanmar, Thailand, and Cambodia; and the strong import growth in Western African countries and the Middle East. The U.S., which ships nearly half of its total rice output to the international market, has long been the fifth largest rice exporter in world, but Myanmar in this baseline becomes fifth largest owing to its expected strong expansion in production over the next decade. The 0.8% annual growth in global rice production comes mainly from yield improvements as expansion in area remains limited. We project adequate global rice supplies in the baseline period. Population growth remains the primary driver of growth in rice consumption as per capita use continues to decline. Global rice stocks are projected to decline by 0.4%/year, as growth in total consumption slightly exceeds that of total global output.

Introduction

This document contains baseline rice projections from the Arkansas Global Rice Economics Program (AGREP) at the University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness in Fayetteville. The purpose of this outlook is not to predict, but to present the current state and the expected directions of the global rice economy over the next decade. We provide probability ranges for projections of key variables.

Over the next decade, India, Thailand, Vietnam, Pakistan, and Myanmar are projected to be the top rice exporters, accounting for more than 80% of net trade. Thailand

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regained its position as the largest exporter of rice in 2016/2017 as it recovered from the controversial and costly paddy pledging program implemented in 2011 and discontinued in 2014 (Wailes and Chavez, 2013). The program was replaced with subsidized credit and inputs to farmers (USA Rice Federation, 2014); and a limited support program for fragrant and glutinous rice (USDA-FAS, 2014). The Thai government has disposed of its excessive edible old stocks. India is projected to expand exports over the baseline, replacing Thailand as the new leader in global rice trade.

Procedures

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework that covers 66 rice producing- and consuming- countries/regions developed and maintained by AGREP.

Most of the details and the theoretical structure and the general equations of the Arkansas Global Rice Model, with the exception of the newly added countries, can be found in the online documentation by Wailes and Chavez (2011). The historical rice data comes from USDA-FAS (2018) and USDA-ERS (2018); and the macro data comes from IHS Global Insight provided by FAPRI-Missouri (2018). The baseline projections are grounded in a series of assumptions as of January 2018 about the general economy, agricultural policies, weather, and technological change. The basic assumptions include the following: continuation of existing policies; current projections of macroeconomic variables; no new World Trade Organization (WTO) trade reforms; and average normal weather conditions.

In light of the volatility of the global rice economy, stochastic estimates of selected variables using 300 random draws are included in this report to provide a better understanding of the probable distribution of future outcomes (Figs. 1 through 5). The stochastic estimates establish the likely upper and lower bounds for selected key variables, which serve as indications of inherent risks associated with the rice economy.

Results and Discussion[2]

International rice prices have stabilized during the second half of 2017 as ample supplies and active competition prevailed in the global rice market despite the occurrence of unexpected import demand from Bangladesh and Sri Lanka during the same period. Prices strengthened back again in January 2018 due to the growing import demand from Indonesia; and eased by mid-February 2018; but remain above $410/metric ton (mt) for long grain quotes from the main Asian exporters. Over the next decade, the average global rice price is projected to increase steadily at 2.2% annually, as total global net trade grows at 1.9% over the same period. Major rice-deficit countries continue to import as domestic production falls short of domestic demand despite

[2] Although complete baseline projections for supply and demand variables are generated for all 66 countries/regions covered by AGRM, only selected variables are included in this report due to space consideration.

efforts and expressed desire to attain self-sufficiency. The average international long-grain rice reference price increases from $400/mt (2015-2017 average) to $489/mt in 2027. Over the same period, the international medium-grain rice prices are projected to remain high and relatively steady, ranging between $735/mt (2015-2017 average) and $763/mt (Table 1), as demand for medium-grain trade remains stable and small relative to long-grain rice.

The Western Hemisphere prices remain substantially higher—with average margins to Asian prices expanding to as high as $183/mt in 2017 (AGRM projection), a level deemed to be unsustainable. These margins are expected to narrow steadily over the baseline, reaching $99 in 2022 and $58 by 2027 (Table 1), as competition between Asian and Western Hemisphere rice is expected to grow in markets such as Iraq, Nigeria, and Latin America.

Over the projection period, India and the People's Republic of China (PRC) will continue to account for the bulk of the global rice economy. On average, the two countries combined are projected to account for nearly 36% of the world population from 2017-2027. Over the same period, they will have an average combined share of close to 45% of world rice area harvested, 51% of total milled rice production, 49% of total rice consumption, and 79% of world rice stocks.

Global rice output continues to expand over the next decade, driven by the use of higher-yielding varieties and hybrids and other improved production technologies—in line with self-sufficiency programs of major rice-consuming countries. World production increases by nearly 40 million metric tons (mmt) over the next decade, equivalent to an annual growth of 0.8%; and reaching 520.5 mmt in 2027 with 0.6% of gain coming from yield improvement and the rest from increases in area harvested (Table 2).

By volume, about 34% of the expected growth in global rice output over the next 10 years will come from India; 45% from 7 countries including Bangladesh, Thailand, Vietnam, Myanmar, the Philippines, Indonesia, and Cambodia; and 21% from the 15-member Economic Community of West African States (ECOWAS). However, rice output in PRC declines by a total of 6.3 mmt, and those of Japan and South Korea decline by 1.0 mmt combined, over the same period. Total U.S. rice production, on the other hand, is projected to increase by a total of nearly 963 thousand mt [31 million hundred weight (cwt)] over the same period, equivalent to 1.4% annual growth, which comes mainly from yield improvement (Table 3).

Over the next decade, expansion of world rice demand will be driven mainly by population, in conjunction with other demographic factors. In some Asian countries where rice is an inferior good and food staple, rising incomes continue to dampen per capita rice demand. These countries include Japan, Taiwan, PRC, and South Korea. Demographic trends also weaken rice demand, as aging populations and focus on health shift preferences away from carbohydrates from rice and towards protein-based diets. Over the baseline, global rice consumption is projected to increase by 47.6 mmt reaching 521.8 mmt in 2027, equivalent to an annual growth of just under 1.0%, with global population growth of 1.1%/year projected to be offset partly by a 0.14% decline in average world rice consumption per capita (Table 2).

About 24% of the total growth in consumption is accounted for by India; 54% by 5 additional countries including Bangladesh, PRC, Nigeria, the Philippines, and Indonesia; 17% by ECOWAS; and the rest by other countries. The U.S. total rice consumption increases by 470 thousand mt (15.0 million cwt) over the same period, reaching 4.3 mmt (136.1 million cwt) in 2027 or an annual growth of 1.2%; of which 0.9% comes from population growth and 0.3% from higher per capita use. Global rice stocks-to-use ratio is projected to decline slightly over the same period, from about 0.23 in 2017 to 0.20 in 2027, reflecting the relatively faster growth in total consumption than that of the total global output. One of the important uncertainties of this baseline is what the PRC will do over the projection period with its large quantity of rice stocks. Production subsidies have contributed to excessive production. Should the PRC begin to liquidate its surplus stocks, there will be significant downward pressure on international long-grain prices.

Net global rice trade expands 1.9%/year over the same period, reaching 46.6 mmt in 2027 well above the three-year (2015-2017) average of 38.6 mmt (Table 1). On the exporters' side, the significant investment in production and processing capacity in the Mekong Delta in Vietnam, Cambodia and Myanmar bodes well for increasing their role as important rice suppliers over the next decade. As low-cost producers, these countries are poised geographically to supply the relatively steady Chinese rice import market. The productivity gains from hybrids and the research generated by the Global Rice Science Partnership (GRiSP) are expected to have positive impacts on Asian and African rice economies over the same period.

Thailand's rice prices have become more closely aligned with its competitors (e.g., Vietnam). However, India is projected to surpass Thailand as the largest exporter during the baseline period.

For the U.S., total rice exports increase by 240 thousand mt or 6.0 million hundredweight (mil. cwt) over the next decade, reaching 3.7 mmt (or 115 mil. cwt) in 2027; and total imports are flat around 24 mil. cwt. The U.S. relies increasingly on trade agreements to lock in preferences for its rice exports. (See Table 3 for U.S. data in English units).

Cambodia's exports are projected to grow at 4.9% per year, reaching 2.0 mmt in 2027 up from 1.2 mmt (2015-2017 average) as both area and yield growth increases production above consumption growth. Myanmar's exports, on the other hand, are projected to expand from 2.4 mmt (2015-2017 average) to 3.7 mmt in 2027, supported by yield-based growth in production.

Rice imports have been steadily concentrating in the last several years. For instance, the share of the 5 largest rice importers increased from 17% in 2006/07 to 27% in 2016/17. However, we project this trend to ease during the projected period. While China remains an important major rice importer over the next decade, its imports are relatively flat around its Tariff Rate Quota (TRQ) level as it maintains large rice stocks. Nearly 75% of the volume growth in global imports over the same period will come from Africa, with the 15-member ECOWAS accounting for 59% of the growth in African imports. In general, expansion in imports is associated with a combination of relatively high population growth and lagging production growth relative to expansion of consumption.

Significance of Findings

Understanding the market and policy forces that drive the global rice market are beneficial for Arkansas rice producers and other stakeholders. This is especially true because Arkansas is the top rice-producing state in the U.S. accounting for nearly 48% of the country's rice output (2015-2017 average); and about half of Arkansas annual rice crop is exported. Market prices received by the Arkansas rice producers are primarily determined by the dynamics that play out in international rice trade. These include changes in rice production and consumption patterns, the economics of alternative crops, domestic and international rice trade policies, as well as the general macroeconomic environment under which global rice trade is transacted. While the results presented in this outlook are not predictions, they can be considered as a synthesis of the combined impacts of these factors; and serve to indicate what could happen over the next decade and serve as a baseline reference for further analysis. The estimates are intended for use by government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders that conduct medium- and long-term planning that includes rice in their work.

Acknowledgments

The authors wish to thank the University of Arkansas System Division of Agriculture for its support; as well as the Arkansas rice farmers who provided support through the Rice Research and Promotion Board, which provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model. Funding is also provided by the USDA, NIFA, Hatch/Multi-State Project ARK02426. The model was updated twice in 2017 and once in January 2018 in collaboration with FAPRI-Missouri which provided the major portion of the funds for the global rice modeling program of AGREP. The most recent enhancement of the AGRM includes: updating and re-estimating the submodels for 3 African countries; and adding original submodels for 5 new African countries. The expanded AGRM now covers 66 countries/regions.

Literature Cited

FAPRI-Missouri. 2018. Food and Agricultural Policy Research Institute. U.S. Baseline Outlook: Projections for Agricultural and Biofuel Markets. March 2018. FAPRI-MU Report #01-18.

USA Rice Federation. 2014. Comments Regarding the 2015 National Trade Estimate Report on Foreign Trade Barriers. October 28, 2014. Accessed 10 January 2017. http://www.usarice.com/docs/default-source/trade-policy/usa-rice-nte-2015-submission.pdf?sfvrsn=2

USDA-ERS. 2018. United States Department of Agriculture-Economic Research Service. Rice Outlook. RCS-18A (by Nathan Childs), January 17, 2018. Accessed 18 January 2018. http://usda.mannlib.cornell.edu/usda/ers/RCS//2010s/2018/RCS-01-17-2018.pdf

USDA-FAS. 2018. United States Department of Agriculture-Foreign Agricultural Service. Production, Supply, and Distribution (PSD) Online. Accessed 14 January 2018. https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery

USDA-FAS. 2014. United States Department of Agriculture-Foreign Agricultural Service. Thailand Grain and Feed Update, October 2014. Gain Report No. TH4104. Accessed 10 January 2017. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Update_Bangkok_Thailand_10-31-2014.pdf

USDA-FAS. 2018. United States Department of Agriculture-Foreign Agricultural Service. Thailand Grain and Feed Update, January 2018. Gain Report No. TH8020. Accessed 13 February 2018. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Update_Bangkok_Thailand_1-26-2018.pdf

Wailes, E.J. and E.C. Chavez. 2011. 2011 Updated Arkansas Global Rice Model. University of Arkansas Department of Agricultural Economics and Agribusiness, Division of Agriculture Staff Paper 2011-01. http://ageconsearch.umn.edu/handle/102650

Wailes, E.J. and E.C. Chavez. 2013. World Rice Outlook: International Rice Baseline Projections, 2012-2022. *In*: R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2013. University of Arkansas Agricultural Experiment Station, Research Series 609:401-417. http://arkansasagnews.uark.edu/609-coverfront.pdf

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Table 1. World rice total trade by country and

Country	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	2020/ 2021	2021/ 2022
	-------	-------	-------	-------	-------	-------
Net exporters						
Argentina	466	441	415	411	469	499
Australia	45	230	131	124	119	140
Cambodia	1130	1426	1273	1296	1328	1374
Lao PDR	-50	-9	-101	-84	-67	-55
Egypt	-50	4	-15	-18	-4	-6
India	11,219	11,528	11,409	11,533	11,459	12,219
Myanmar (Burma)	3090	2723	2772	2899	2964	3032
Pakistan	3590	3723	3577	3528	3438	3417
Thailand	11,000	9,935	9,924	10,150	10,651	10,652
United States	2959	2389	2512	2524	2637	2719
Uruguay	975	896	873	851	843	856
Vietnam	5900	5983	6156	6156	6237	6298
Brazil	-50	-27	-23	163	236	206
Paraguay	498	522	656	654	666	685
Total net exports[a]	40,722	39,764	39,559	40,186	40,975	42,038
Net importers						
Bangladesh	70	2504	1960	1796	1613	1565
People's Republic of China	4495	4127	4240	4184	4180	4162
Brunei Darussalam	50	49	50	51	53	54
Cameroon	550	536	568	584	595	608
Canada	361	376	390	400	410	420
China – Hong Kong	345	344	351	358	363	369
Colombia	143	143	179	169	168	174
Cote d'Ivoire	1270	1494	1501	1528	1599	1589
European Union-28	1514	1535	1587	1618	1646	1675
Ghana	590	535	648	652	670	687
Guinea	645	569	619	641	615	613
Indonesia	280	737	729	848	863	865
Iran	1600	1479	1664	1663	1667	1742
Iraq	1050	1123	1161	1215	1260	1302
Japan	630	627	627	627	627	627
Kenya	650	651	648	656	715	766
Liberia	310	292	332	341	347	360
Malaysia	955	849	1138	1015	1034	1033
Mali	100	72	276	279	292	336
Mexico	782	754	732	760	770	784
Mozambique	715	731	735	760	789	831
Nigeria	2500	2812	2757	2902	3147	3292
Philippines	1100	1308	679	1041	1276	1399
Saudi Arabia	1400	1451	1571	1632	1672	1736
Senegal	990	1027	1012	1006	1029	1069

international reference prices, 2016-2027.

2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand metric tons)--					
523	541	565	585	595	609
155	172	184	191	192	185
1478	1612	1674	1802	1858	1997
-39	-14	11	45	81	109
-3	1	4	6	8	11
12,413	12,659	12,748	12,772	12,851	12,902
3085	3247	3386	3476	3570	3676
3390	3393	3454	3497	3536	3552
10,801	11,168	11,131	11,108	11,124	11,247
2784	2786	2816	2845	2877	2900
867	880	892	916	940	955
6457	6551	6648	6730	6827	7014
223	219	287	392	514	573
708	729	744	772	810	850
42,843	43,943	44,545	45,137	45,782	46,581
1570	1427	1488	1557	1618	1573
4166	4188	4211	4226	4235	4253
54	55	55	55	56	56
622	629	639	678	711	749
429	437	442	447	454	462
375	379	382	386	390	395
176	170	169	175	181	188
1598	1623	1664	1632	1606	1624
1705	1726	1736	1747	1751	1762
688	704	714	729	693	680
606	623	678	733	791	854
848	887	787	724	719	622
1790	1899	1936	1909	1958	1965
1344	1385	1428	1469	1511	1555
627	627	627	627	627	627
779	834	835	873	885	917
371	375	371	372	379	388
1035	1037	1034	1024	1021	1012
365	366	352	343	376	414
796	805	815	821	826	834
873	932	980	1015	1051	1087
3385	3502	3570	3641	3664	3778
1461	1522	1548	1487	1465	1526
1797	1849	1876	1900	1925	1951
1113	1151	1192	1229	1272	1322

continued

Table 1. Continued.

Country	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	2020/ 2021	2021/ 2022
	----	----	----	----	----	----
Net importers (continued)						
Sierra Leone	350	134	111	114	116	128
Singapore	300	321	317	318	323	329
South Africa	862	835	906	921	942	953
South Korea	401	409	409	409	409	409
Taiwan	56	56	56	56	56	56
Tanzania	200	228	338	390	429	502
Turkey	243	301	319	312	316	313
Other Africa	2582	2374	2450	2539	2612	2698
Other Americas	661	386	733	807	843	914
Other Asia	4219	4405	3818	3615	3485	3501
Other Europe	130	141	143	150	155	156
Other Oceania	45	46	47	47	48	49
Ecowas 7	1727	1866	1896	1953	2014	2101
Madagascar	330	512	95	128	140	152
Malawi	15	18	20	25	27	28
Zambia	10	15	16	15	17	17
Rwanda	40	43	39	42	45	48
Uganda	80	84	91	115	130	139
Cuba	524	550	585	565	556	554
Costa Rica	155	178	145	144	145	147
Dominican Republic	31	14	55	29	26	30
Guatemala	97	113	120	123	127	131
Honduras	145	153	162	164	166	170
Nicaragua	88	56	72	74	76	77
Panama	60	71	67	66	69	71
Chile	136	144	137	139	144	146
Peru	260	253	230	166	117	138
Residual	3880	-67	26	32	39	25
Total net imports	40,722	39,764	39,559	40,186	40,975	42,038
Prices	----	----	----	----	----	----
International rice reference price	394	402	388	394	403	409
U.S. FOB Gulf Ports	488	584	527	515	515	518
U.S. No. 2 Medium FOB[b] Calif.	611	826	794	785	774	777
Real international rice reference price (2015/17=100)	394	391	372	370	368	364

[a] Total net exports are the sum of all positive net exports and negative net imports.
[b] FOB = free on board.

2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand metric tons)----------					
116	118	119	124	131	141
332	333	331	329	328	329
949	969	951	979	993	1018
409	409	409	409	409	409
56	56	56	56	56	56
570	602	627	629	640	671
294	312	323	331	334	340
2764	2846	2866	2992	3066	3155
937	978	996	1010	1030	1059
3517	3716	3744	3818	3910	4012
156	159	159	161	161	163
49	50	50	51	52	52
2174	2246	2340	2412	2490	2580
166	180	194	204	211	216
30	31	31	31	32	32
18	19	19	19	19	19
49	50	51	49	47	46
147	152	151	141	125	108
555	554	539	525	517	514
149	151	152	153	153	154
28	30	32	31	29	27
135	138	141	145	148	152
175	180	183	185	188	192
79	80	80	79	79	80
71	72	71	70	69	68
148	151	153	156	160	164
183	223	246	253	245	230
17	7	0	0	-6	-3
42,843	43,943	44,545	45,137	45,782	46,581
(U.S. dollars/metric tons)----------					
413	422	445	467	481	489
513	519	531	543	547	547
765	761	762	764	767	763
359	358	368	377	379	376

Table 2. World rice supply and utilization,

Variable		**2016/ 2017**	**2017/ 2018**	**2018/ 2019**	**2019/ 2020**	**2020/ 2021**
	(units)[a]	-------	-------	-------	-------	-------
Area harvested	(1000 ha)	160,822	160,444	161,726	161,558	161,542
Yield	(mt/ha)	3.03	3.01	3.04	3.05	3.07
		-------	-------	-------	-------	-------
Production	(1000 mt)	487,078	482,201	490,855	492,155	495,176
Beginning stocks	(1000 mt)	132,632	138,112	140,773	144,496	145,388
Domestic supply	(1000 mt)	619,710	620,313	631,628	636,651	640,563
		-------	-------	-------	-------	-------
Consumption	(1000 mt)	476,898	479,596	487,383	491,270	495,200
Ending stocks	(1000 mt)	138,112	140,773	144,496	145,388	145,129
Domestic use	(1000 mt)	615,010	620,369	631,879	636,658	640,329
Total trade	(1000 mt)	46,005	45,628	45,374	45,771	46,489
Per capita use	(kg)	64.0	63.7	64.0	63.9	63.7
Percent stocks-to-use	(%)	22.5	22.7	22.9	22.8	22.7
Population growth	(%)	1.1	1.1	1.1	1.1	1.0
Real GDP growth	(%)	2.5	3.2	3.3	3.2	3.0

[a] Metric ton (mt), hectare (ha), and kilogram (kg).

Table 3. Detailed U.S. rice supply and utilization,

Variable		**2016/ 2017**	**2017/ 2018**	**2018/ 2019**	**2019/ 2020**	**2020/ 2021**
	(units)					
Yield (rough basis)	(lb/acre)	7237.5	7506.3	7789.9	7845.2	7912.7
Total harvested area	(thous. acres)	3097.0	2374.0	2633.9	2619.1	2640.1
Supply (rough basis)	(mil. cwt)[b]	294.1	248.9	259.0	265.2	274.2
Production	(mil. cwt)	224.1	178.2	205.2	205.5	208.9
Beginning stocks	(mil. cwt)	46.5	45.9	29.1	35.5	41.6
Imports	(mil. cwt)	23.5	24.8	24.7	24.3	23.7
Domestic use (rough basis)	(mil. cwt)	131.4	119.7	119.7	119.9	121.5
Food	(mil. cwt)	104.6	107.9	109.2	110.4	111.4
Seed	(US$/cwt)[c]	2.0	2.9	3.2	3.2	3.3
Brewing	(US$/cwt)	19.5	19.2	19.5	19.6	19.7
Residual	(US$/cwt)	5.3	-10.3	-12.3	-13.3	-12.9
Exports	(US$/cwt)	116.6	100.1	103.8	103.8	106.8
Total use	(US$/cwt)	248.0	219.8	223.5	223.6	228.3
Ending stocks	(mil. cwt)	45.9	29.1	35.5	41.6	45.9

and macro data, 2016-2027.

2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
(thousand hectares)						
161,800	161,997	162,165	162,255	162,534	162,702	162,948
3.09	3.10	3.12	3.14	3.15	3.17	3.19
(mt/ha)						
499,285	502,695	506,353	509,652	512,382	516,564	520,535
145,129	144,101	142,395	140,013	137,688	134,957	133,137
644,414	646,797	648,748	649,664	650,070	651,521	653,673
(thousand metric tons)						
499,657	504,157	508,458	511,692	514,771	518,181	521,788
144,101	142,395	140,013	137,688	134,957	133,137	131,675
643,758	646,552	648,471	649,380	649,728	651,318	653,463
47,581	48,376	49,461	49,966	50,422	50,914	51,621
63.6	63.6	63.5	63.3	63.1	62.9	62.8
22.4	22.0	21.6	21.2	20.8	20.4	20.2
1.0	1.0	1.0	1.0	0.9	0.9	0.9
3.1	3.1	3.1	3.1	3.1	3.0	3.0

and macro data, 2016-2017.

2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
7994.9	8061.5	8140.1	8217.0	8294.0	8363.3	8434.3
2659.5	2672.2	2670.9	2679.9	2685.8	2701.9	2713.0
282.2	289.3	293.7	297.7	301.5	306.0	310.2
212.6	215.4	217.4	220.2	222.8	226.0	228.8
45.9	50.0	52.2	53.3	54.5	55.9	57.3
23.7	23.8	24.0	24.2	24.2	24.2	24.1
122.9	125.5	128.6	130.3	131.9	134.0	136.1
113.1	115.0	117.0	118.9	120.8	122.7	124.6
3.3	3.3	3.3	3.3	3.3	3.3	3.4
19.8	19.9	20.0	20.0	20.1	20.1	20.2
-13.3	-12.7	-11.6	-12.0	-12.3	-12.2	-12.0
109.3	111.5	111.8	112.9	113.8	114.8	115.4
232.2	237.0	240.4	243.1	245.7	248.7	251.5
50.0	52.2	53.3	54.5	55.9	57.3	58.7

continued

Table 3. continued.

Variable	(units)	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	2020/ 2021
Prices						
Loan rate	(US$/cwt)	6.50	6.50	6.50	6.50	6.50
Season ave. farm price	(US$/cwt)	10.40	12.55	11.31	11.46	11.62
Long grain farm price	(US$/cwt)	9.64	11.73	10.69	10.64	10.79
Medium grain farm price	(US$/cwt)	12.90	14.97	13.92	13.99	14.19
Japonica farm price	(US$/cwt)	13.70	15.81	14.73	14.79	14.99
Southern medium-grain farm price	(US$/cwt)	10.10	11.93	11.15	11.19	11.36
Reference prices						
Long-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00
Southern medium-grain farm price	(US$/cwt)	14.00	14.00	14.00	14.00	14.00
Japonica	(US$/cwt)	16.10	16.10	16.10	16.10	16.10
Export price, FOB[a] Houston (U.S. No. 2)	(US$/cwt)	22.14	26.49	23.92	23.37	23.35
Medium-grain price, FOB Calif. (U.S. No. 2)	(US$/cwt)	27.71	37.46	36.01	35.62	35.10
Program payment	(mil. US$)	3.8	2.3	3.1	3.1	2.9
Average world price	(US$/cwt)	9.2	9.6	9.4	9.3	9.4
Income factors						
Production market value	(mil. US$)	2349.4	2259.8	2369.1	2374.0	2446.6
Program payment	(mil. US$)	859.7	402.7	631.7	633.8	599.7
Total income	(mil. US$)	3209.1	2662.5	3000.7	3007.8	3046.4
Market returns above variable cost	(US$/ac)	264.3	443.3	386.6	381.6	335.4
Total returns above variable cost	(US$/ac)	541.9	612.9	626.4	623.6	335.4
Per capita use	(lb)	40.59	36.74	36.43	36.20	36.40
Stocks-to-use ratio	(%)	0.19	0.13	0.16	0.19	0.20
Population growth	(%)	0.69	0.69	0.80	0.80	0.79
Real GDP growth	(%)	1.49	2.25	2.66	2.56	2.05

[a] FOB = free on board.
[b] Million hundred weight (mil cwt).
[c] U.S. dollars/hundred weight (US$/cwt).

2021/ 2022	2022/ 2023	2023/ 2024	2024/ 2025	2025/ 2026	2026/ 2027	2027/ 2028
6.50	6.50	6.50	6.50	6.50	6.50	6.50
11.71	11.39	11.55	11.90	12.30	12.48	12.52
10.87	10.57	10.72	11.05	11.41	11.58	11.61
14.32	13.92	14.11	14.55	15.04	15.27	15.32
15.11	14.69	14.90	15.37	15.87	16.12	16.17
11.45	11.12	11.28	11.66	12.06	12.26	12.30
14.00	14.00	14.00	14.00	14.00	14.00	14.00
14.00	14.00	14.00	14.00	14.00	14.00	14.00
16.10	16.10	16.10	16.10	16.10	16.10	16.10
23.52	23.25	23.56	24.08	24.61	24.82	24.83
35.22	34.70	34.52	34.55	34.68	34.81	34.59
2.7	3.0	2.8	2.4	2.0	1.8	1.8
9.4	9.4	9.6	9.9	10.3	10.5	10.6
2509.9	2474.0	2530.5	2641.9	2759.5	2841.9	2885.7
578.9	648.3	612.9	534.3	449.1	408.4	401.6
3088.8	3122.3	3143.4	3176.1	3208.6	3250.2	3287.3
335.1	301.1	307.7	331.2	359.2	371.5	372.0
335.1	301.1	307.7	331.2	359.2	371.5	372.0
36.53	37.03	37.66	37.86	38.05	38.38	38.71
0.22	0.22	0.22	0.22	0.23	0.23	0.23
0.78	0.77	0.76	0.74	0.73	0.72	0.70
1.82	1.97	1.94	1.91	1.84	1.81	1.78

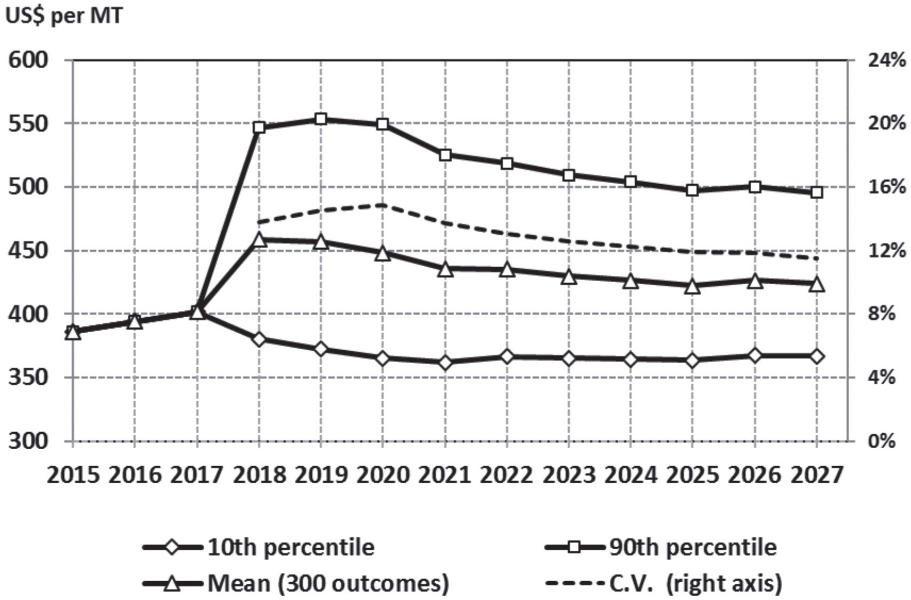

Fig. 1. Stochastic projections of long-grain rice international reference price [U.S. dollars/metric ton (US$/MT)], 2015-2027.

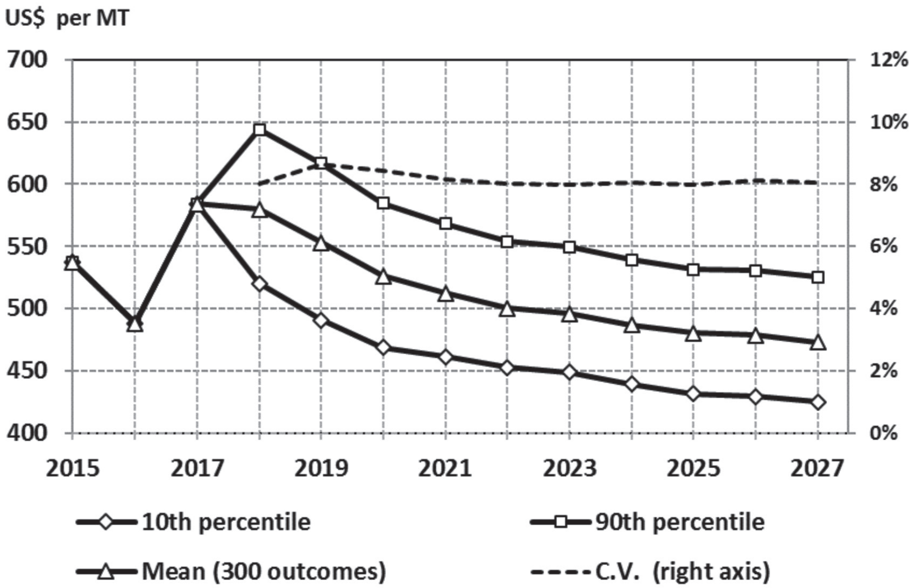

Fig. 2. Stochastic projections of U.S. long-grain rice export price, free on board export price [U.S. dollars/metric ton (US$/mt)], 2015-2027.

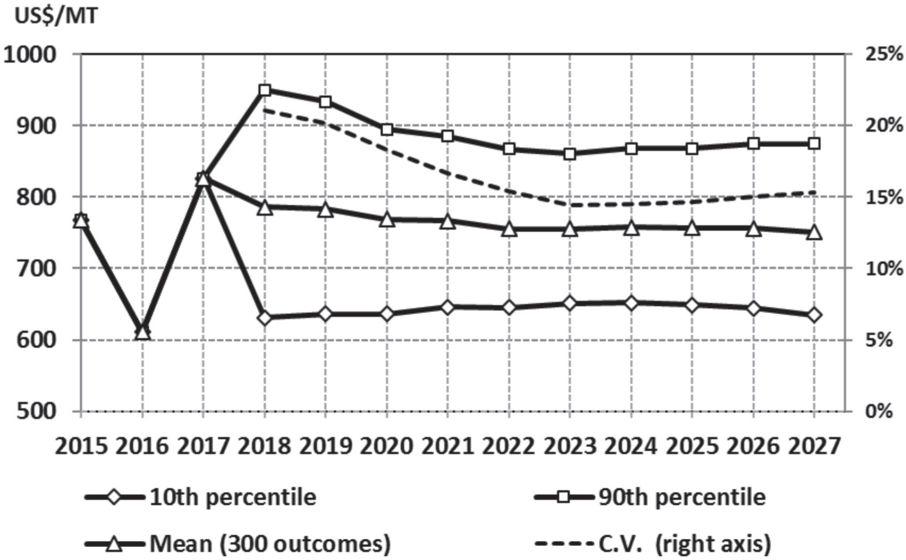

Fig. 3. Stochastic projections of medium-grain rice mill price, free on board California U.S. dollars/metric ton (US$/mt)], 2015 -2027.

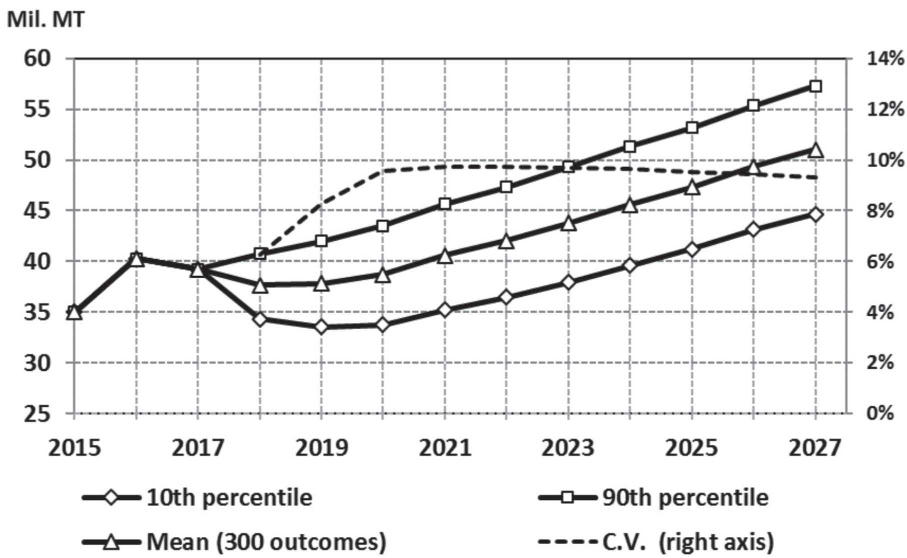

Fig. 4. Stochastic projections of world rice net trade [million metric tons (Mil./MT)], 2015-2027.

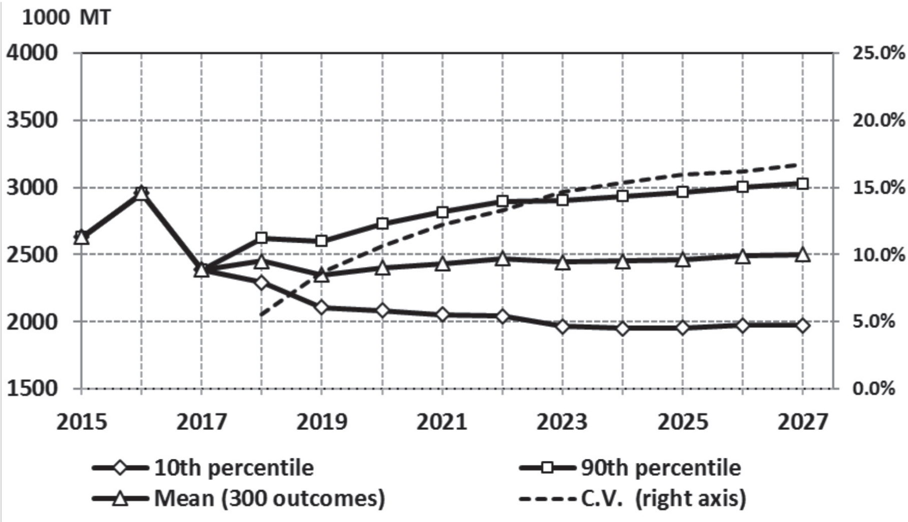

Fig. 5. Stochastic projections of U.S. rice net exports [metric ton (MT)], 2015-2027.

Commodity Program Analysis of Arkansas Representative Farms, 2016-2023

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Abstract

Current commodity programs, authorized in Title 1 of the Agricultural Act of 2014 (also known as the 2014 Farm Act) will expire in 2018. New legislation will replace the 2014 farm bill. This study assesses the adequacy of the Price Loss Coverage (PLC) program and payment limit provisions of current law, if they are extended in the new farm bill. The analysis includes 5 representative Arkansas farms. We project the production and financial characteristics of these farms for 2017 to 2023. We evaluate the adequacy of government commodity support from the reference price of the PLC relative to costs of production. Except for peanuts, the current level of PLC supports are not adequate to cover costs of production for rice, soybeans, corn, and cotton. Payment limit provisions of the current farm bill, if extended, will also adversely affect Arkansas crop farms.

Introduction

In this study, we focus on the financial status of 5 representative Arkansas crop farms in Stuttgart, Wynne, McGehee, Mississippi County, and Hoxie for the 7-year period starting from 2017 through 2023, which covers the last 2 years of the current farm bill and the expected 5 years (2019-2023) of a new farm bill. We evaluate the adequacy of commodity program support for the primary Arkansas crops. We also examine the likelihood that payment limit provisions in the current farm bill will adversely impact Arkansas crop farms. Projected prices and costs generate estimates of future Arkansas net cash farm income and the role of commodity support programs in sustaining these farms.

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Procedures

The 5 representative farms are based on financial data files made available by the Texas A&M Agricultural and Food Policy Center (AFPC, 2017). The AFPC develops and maintains data to analyze 94 representative crop, dairy, and livestock operations in major production areas in 29 states with a stated purpose of projecting the economic viability of these farms. Baseline data are developed through ongoing cooperation with panels of agricultural producers in the selected states (Richardson et al., 2017). The 5 Arkansas farms covered in this paper are included in the AFPC portfolio of representative farms. The 2016 data for Arkansas farms were developed with panels of farmers and with the participation of the Arkansas research and extension personnel. This data was extended for the years 2017-2023 based on currently available information specific to the state; most notably prices and various costs including input costs, drying costs, and the costs of machinery and equipment. The updated input cost projections are based on the August 2017 baseline of the Food and Agricultural Policy Research Institute (FAPRI/University of Missouri).

Results and Discussion

Farm Descriptions

The basics for each of the 5 farms in terms of acreage and crop mix are presented in Tables 1 through 5. The Stuttgart farm includes a total of 3240 acres comprised of 45% long-grain rice, 45% soybeans, and 10% corn. The Wynne farm operates 2500 acres equally split between long-grain rice and irrigated soybeans. The McGehee farm is the largest of the 5 farms with a total of 6500 acres with 60% planted to full-season soybeans, 30% to corn and 10% to long-grain rice. The Mississippi County farm produces on 5000 acres with 50% irrigated cotton/cottonseed, 20% soybeans, 20% peanuts, and 10% corn. The Hoxie farm has 4000 acres with 51% long-grain rice, 30.6% irrigated soybeans, 9% MG rice, 6.3% corn, and 3.1% non-irrigated soybeans. Each farm has acreage allocated by percent owned, percent cash rented, and percent share-rented. By subtracting out landlord share, we calculate the effective base and planted acres that generates the revenue and costs for the farm operator.

Two key issues are of concern to Arkansas crop producers with respect to the development of the Commodity Title in the 2018 Farm Bill. The first issue is whether reference prices associated with the Price Loss Coverage (PLC) program can provide adequate support should market prices continue to be weak, resulting in net cash farm income losses. The second issue relates to the fact that most Arkansas crop farms are relatively large compared to mid-west farms and that the payment limit provisions in the commodity title are not sufficient to sustain Arkansas farms when the farm economy is weak.

Baseline Costs of Production Relative to Reference Prices

Arkansas producers are expected to enroll heavily in the PLC in the next farm bill. While many Arkansas soybean and corn producers enrolled in the Agriculture Risk Coverage-County (ARC-Co) program in 2014, historical prices relative to projected prices suggest that the ARC-Co program will not provide adequate commodity program support over the next farm bill. This is because the support levels are based on a moving 5-year average of historical prices and county yields; and over the next 5 years, the ARC-Co support formula will use the recent set of low farm prices as a base.

Therefore, the concern of Arkansas producers is whether the reference price support in the PLC program will help them survive financially, should market prices continue to remain low over the next farm bill period. To examine this question we compared the estimated costs of production by commodity on a per unit basis for the representative Arkansas farms. Table 6 provides a summary of the projected weighted average costs of production for the 2016-2018 and 2019-2023 periods. Reference prices of the PLC are then estimated as a percent of these cost estimates.

Table 6 also provides the current actual and effective reference price in the 2014 farm bill. Actual reference prices in the 2014 farm bill apply to only 85% of base acres enrolled in the program. For example, a $14/hundred weight (cwt) reference price for rice is effectively an $11.90/cwt. for all base acre production. In addition, sequestration reduces this payment further by 6.8% of the actual reference price or by $0.81/cwt. Therefore, the effective PLC support level for base program production is $11.09/cwt. compared to the legislated PLC reference price of $14/cwt. In Table 6, Arkansas representative costs of production are estimated as a percent of the legislated actual and effective reference prices. Additional discounts on the effectiveness of the support level could also include the fact that payments are made on program base yields rather than actual yields. However, given the year-to-year variability of actual yields, we have not included this discount into the effective reference price estimate.

The results highlight that, except for peanuts, current actual or effective reference prices are not sufficient for any of the major Arkansas crops relative to estimated costs of production. For rice, a $14.00/cwt reference price only covers 91% of the average per hundred weight cost of rice for the 2019-2023 period. If one accounts for the effective support only being $11.09, then coverage is only 72%. The results are even worse for Arkansas soybeans and corn as the estimates in Table 6 show.

Impacts of Government Program Payment Limit on Arkansas Representative Farms

The Commodity Title of the farm bill establishes the payment limit of $125,000 for an individual and $250,000 for a two-entity enterprise, typically a married couple. Additional entities are eligible subject to rules of being “actively engaged in farming.” In the analysis of Arkansas representative farms, we have estimated the probability that a two-entity farming operation would be constrained by the $250,000 payment limit. To make these estimates, we have used the FAPRI projected prices and county projected yields to estimate the farm operator’s commodity payments. We also simulate for the 5 Arkansas representative farms their farm operations 500 times for each year from 2017 to 2023 using random draws of prices and yields to estimate the probability of payments exceeding the $250,000 payment limit. These random prices and yields are based on historical variation observed in the respective Arkansas county where each representative farm is located.

Table 7 and figs. 1 and 2 show the relevant results for each farm. The Hoxie farm, with the highest percent of rice production, is estimated to be adversely impacted by the $250,000 payment limit for the 2019 to 2023 crop years. There is also a high probability that given variation in prices and yields, this farm will be subject to payment limit levels at least 50% of the time out to 2023. The McGehee and Stuttgart farms are also likely to be adversely impacted 50% to 60% of the time for the 2019-2023 crop years. For the Mississippi County farm, with the new seed cotton PLC program, payments limits will be met 100% of the time over the 2019-2023 period. The Wynne farm is not likely to face payment limits except in 2021 and 2022.

Table 7 also provides estimates of total cash receipts and net cash farm income. All farms except the Mississippi County farm experience at least one year when cash receipts, plus government commodity payments, are not sufficient to avoid losses in net cash farm income. Without the commodity program, Arkansas crop farms would experience significant financial stress.

Significance of Findings

This study highlights the inadequacy of reference prices for key Arkansas crops, given the likely cost projections for each of the five representative farms. It also indicates that because of the size of Arkansas crop farms, program payments are more likely to be constrained by the payment limit rules in the current farm bill legislation. Low commodity prices and rising costs over the 2019-2023 time period suggests that the farm bill commodity program will continue to be important in sustaining the economic viability of Arkansas crop farms.

Acknowledgments

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Literature Cited

AFPC. 2017. Texas A&M Agricultural and Food Policy Center. Various reports on representative farms.

Richardson, J.W., J.L. Outlaw, G.M. Knapek, J.M. Raulston, B.K. Herbst, D.P. Anderson, and S.L. Klose. 2017. Representative Farms Economic Outlook for the January 2017 FAPRI/AFPC Baseline. AFPC Briefing Paper 17-1, March 2017. Accessed 26 February 2018. https://www.afpc.tamu.edu/research/publications/files/685/BP_17-1.pdf

Table 1. Stuttgart Arkansas representative farm acreage and crop allocation.

Particulars	Long-grain rice	Soybean	Corn	Total
Planted acres	1458.0	1458.0	324.0	3240.0
Base acres	1620.0	1296.0	0.0	2916.0
PLC[a] payment yield	65.3	47.2	0.0	
Percent cropland owned	20.0%	20.0%	20.0%	
Percent cropland cash-rented	32.1%	32.1%	32.1%	
Percent cropland share-rented	47.9%	47.9%	47.9%	
Net percent production[b]	90.4%	90.4%	90.4%	
Effective base acres	1464.8	1171.8	0.0	2636.6
Effective planted acres	1318.3	1318.3	293.0	2929.6

[a] PLC = price loss coverage.
[b] Net percent production = (% cropland share rented × (1-% landlord's share in production)) + (% cropland owned)+(% cropland cash rented).

Table 2. Wynne Arkansas representative farm acreage and crop allocation.

Particulars	Long-grain rice	Irrigated soybean	Total
Planted acres	1250.0	1250.0	2500.0
Base acres	1250.0	1250.0	2500.0
PLC[a] payment yield	66.3	36.4	
Percent cropland owned	50.0%	50.0%	
Percent cropland cash-rented	25.0%	25.0%	
Percent cropland share-rented	25.0%	25.0%	
Net percent production[b]	93.8%	93.8%	
Effective base acres	1171.9	1171.9	2343.8
Effective planted acres	1171.9	1171.9	2343.8

[a] PLC = price loss coverage.
[b] Net percent production = (% cropland share rented × (1-% landlord's share in production)) + (% cropland owned)+(% cropland cash rented).

Table 3. McGehee Arkansas representative farm acreage and crop allocation.

Particulars	Long-grain rice	Full-season soybeans	Corn	Total
Planted acres	650.0	3900.0	1950.0	6500.0
Base acres	2263.8	3475.8	617.4	6357.0
PLC[a] payment yield	55.0	39.8	126.3	
Percent cropland owned	18.5%	18.5%	18.5%	
Percent cropland cash-rented	20.4%	20.4%	20.4%	
Percent cropland share-rented	61.2%	61.2%	61.2%	
Net percent production[b]	84.7%	84.7%	84.7%	
Effective base acres	1917.7	2944.4	523.0	5385.1
Effective planted acres	550.6	3303.8	1651.9	5506.3

[a] PLC = price loss coverage.
[b] Net percent production = (% cropland share rented × (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 4. Mississippi County Arkansas representative farm acreage and crop allocation.

Particulars	Irrigated cotton	Irrigated cotton seed	Soybeans	Peanuts	Corn	Total
Planted acres	2500.0	2500.0	1000.0	1000.0	500.0	5000.0
Base acres	0.0	0.0	999.9	999.9	500.0	2499.8
PLC[a] payment yield	0.0	0.0	21.0	1.4	112.0	
Percent cropland owned	20.0%	20.0%	20.0%	20.0%	20.0%	
Percent cropland cash-rented	16.0%	16.0%	16.0%	16.0%	16.0%	
Percent cropland share-rented	64.0%	64.0%	64.0%	64.0%	64.0%	
Net percent production[b]	84.0%	84.0%	84.0%	84.0%	84.0%	
Effective base acres	0.0	0.0	839.9	839.9	420.0	2099.8
Effective planted acres	2100.0	0.0	840.0	840.0	420.0	4200.0

[a] PLC = price loss coverage.

[b] Net percent production = (% cropland share rented × (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 5. Hoxie Arkansas representative farm acreage and crop allocation.

Particulars	Medium-grain rice	Long-grain rice	Irrigated soybeans	Non-irrigated soybeans	Corn	Total
Planted acres	360.0	2040.0	1225.0	125.0	250.0	4000.0
Base acres	360.0	2040.0	1225.0	125.0	250.0	4000.0
PLC[a] payment yield	67.5	67.5	37.0	37.0	101.9	
Percent cropland owned	25.0%	25.0%	25.0%	25.0%	25.0%	
Percent cropland cash-rented	25.0%	25.0%	25.0%	25.0%	25.0%	
Percent cropland share-rented	50.0%	50.0%	50.0%	50.0%	50.0%	
Net percent production[b]	87.5%	87.5%	87.5%	87.5%	87.5%	
Effective base acres	315.0	1785.0	1071.9	109.4	218.8	3500.0
Effective planted acres	315.0	1785.0	1071.9	109.4	218.8	3500.0

[a] PLC = price loss coverage.

[b] Net percent production = (% cropland share rented × (1-% landlord's share in production)) + (% cropland owned) + (% cropland cash rented).

Table 6. Comparison of price loss coverage actual reference (Ref) prices and effective reference prices (ERef) to Arkansas crop cost of production estimates.

Crop	Reference price		2016–2018 average			2019–2023 average		
	Actual	Effective	Cost Estimate	Ref % Cost	ERef % Cost	Cost Estimate	Ref % Cost	ERef % Cost
Rice $/cwt	$14.00	$11.09	$13.36	105%	83%	$15.33	91%	72%
Soybeans $/bu	$8.40	$6.65	$11.69	72%	57%	$12.68	66%	52%
Corn $/bu	$3.70	$2.93	$4.87	76%	60%	$5.16	72%	57%
Cotton $/lb	$0.367	$0.287	$0.364	101%	79%	$0.378	97%	76%
Peanuts $/ton	$535.00	$423.83	$242.5	221%	175%	$247.8	216%	171%

Table 7. Payments without limits compared to two-entity limit of $250,000 for Arkansas representative farms, total cash receipts and net cash farm income.

Farm	Program payment	2017	2018	2019	2020	2021	2022	2023
Hoxie	Payment w/o limit ($1000)	212.9	235.8	327.4	330.3	328.3	324.5	322.6
	Prob. reaching 250K limit	48%	51%	64%	66%	66%	66%	66%
	Total cash receipts ($1000)	2421.1	2503.1	2431.6	2447.9	2458.9	2479.4	2496.2
	Net cash farm income ($ 1000)	-57.0	62.6	-78.0	-225.1	-334.2	-417.4	-479.2
McGehee	Payment w/o limit ($1000)	162.9	206.4	286.6	289.1	287.4	284.1	282.4
	Prob. reaching 250K limit	35%	44%	58%	57%	58%	57%	58%
	Total cash receipts ($1000)	4156.8	4464.1	4600.8	4700.0	4736.2	4789.3	4855.1
	Net cash farm income ($ 1000)	-15.9	328.4	356.4	206.4	38.2	-65.4	-141.2
Mississippi County	Payment w/o limit ($1000)[a]	205.6	155.8	366.4	541.8	428.7	363.8	389.8
	Prob. reaching 250K limit	0%	0%	100%	100%	100%	100%	100%
	Total cash receipts ($1000)	3828.8	3915.8	4096.1	4171.6	4224.8	4289.8	4341.5
	Net cash farm income ($ 1000)	1121.7	1184.7	1304.6	1283.1	1256.8	1244.3	1222.9
Stuttgart	Payment w/o limit ($1000)	173.3	187.0	259.7	262.0	260.5	257.4	255.9
	Prob. reaching 250K limit	37%	43%	56%	57%	57%	59%	58%
	Total cash receipts ($1000)	2297.0	2332.8	2317.3	2335.0	2342.5	2352.9	2367.4
	Net cash farm income ($1000)	222.0	298.1	229.8	113.8	22.6	-53.9	-115.4
Wynne	Payment w/o limit ($1000)	122	163.1	143.4	107.7	268.4	268.4	67.7
	Prob. reaching 250K limit	25%	32%	26%	20%	57%	57%	14%
	Total cash receipts ($1000)	1624.6	1662.6	1683.3	1719.5	1640.7	1648.0	1770.2
	Net cash farm income ($ 1000)	205.1	265.9	236.6	174.0	18.8	-19.4	49.6

[a] Seed cotton payments calculated using 100% of generic base acres in the price loss coverage (PLC).

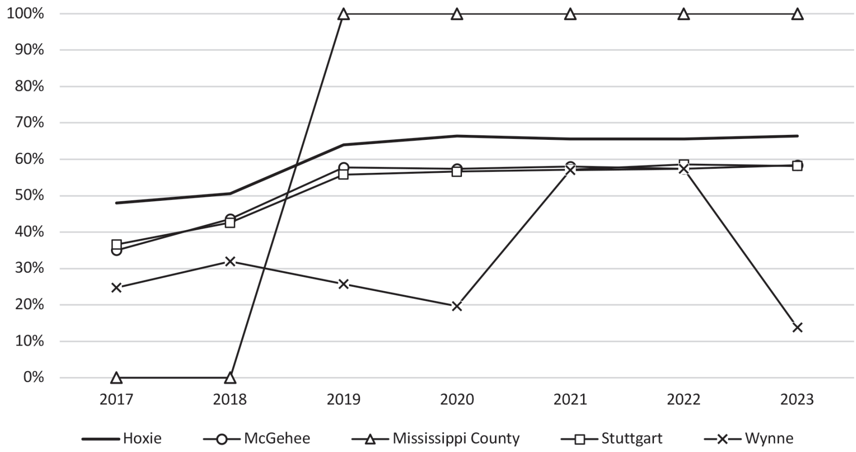

Fig. 1. Probability of Arkansas representative farms reaching the $250,000 commodity payment limit, 2017-2023.

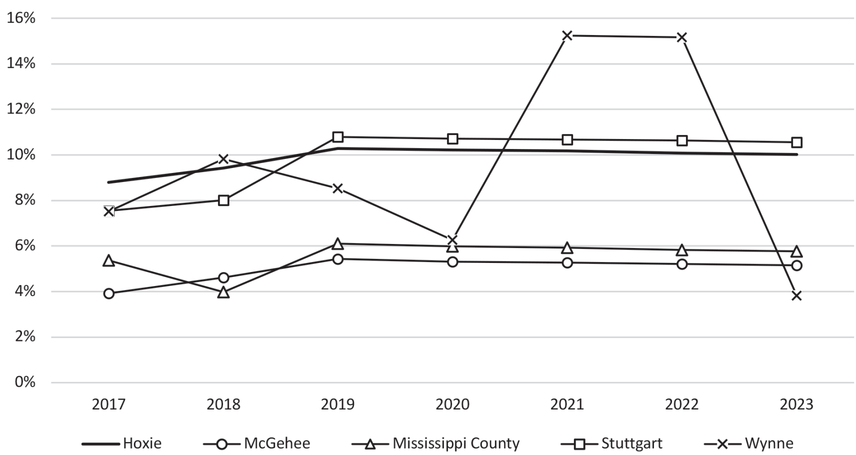

Fig. 2. Commodity program payments as a percentage of total cash receipts for Arkansas representative farms, 2017-2023.

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