University of Arkansas, Fayetteville
ScholarWorks@UARK

8-1-2013

B.R. Wells Rice Research Studies 2012

R. J. Norman
University of Arkansas, Fayetteville

K.A. K. Moldenhauer
University of Arkansas, Fayetteville

Follow this and additional works at: https://scholarworks.uark.edu/aaesser

Part of the Agricultural Science Commons, Agronomy and Crop Sciences Commons, Botany Commons, and the Horticulture Commons

Recommended Citation

Norman, R. J. and Moldenhauer, K.A. K., "B.R. Wells Rice Research Studies 2012" (2013). *Research Series*. 45.
https://scholarworks.uark.edu/aaesser/45

This Report is brought to you for free and open access by the Arkansas Agricultural Experiment Station at ScholarWorks@UARK. It has been accepted for inclusion in Research Series by an authorized administrator of ScholarWorks@UARK. For more information, please contact scholar@uark.edu, ccmiddle@uark.edu.

B.R. Wells

RICE RESEARCH STUDIES 2012

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

UofA
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION
August 2013
Research Series 609

This publication is available on the Internet at http://arkansasagnews.uark.edu/1356.htm

Cover Photo: Rice test plots at the Rice Research and Extension Center facilities, Stuttgart, Ark. Photo credit: University of Arkansas System Division of Agriculture.

Layout and editing by Marci A. Milus
Technical editing and cover design by Gail Halleck

Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture. Clarence E. Watson, Associate Vice-President for Agriculture–Research and Director, AAES. MG400CS5/CS6.
The University of Arkansas System Division of Agriculture follows a nondiscriminatory policy in programs and employment.
ISSN:1941-2177 CODEN:AKAMA6

B.R. Wells
RICE
Research Studies
2012

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

University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

Bobby R. Wells

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

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

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

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

FOREWORD

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

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

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

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agricultural Research Service. For further information about any author, contact Agricultural Communication Services, (479) 575-5647.

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.

The Arkansas Rice Research and Promotion Board

John Alter	DeWitt
Joe Christian	Jonesboro
Jay Coker	Stuttgart
Marvin Hare Jr.	Newport (Vice-Chairman)
Rich Hillman	Carlisle (Chairman)
Bryan Moery	Wynne (Secretary/Treasurer)
Roger Pohlner	Fisher
Mike Sullivan	Burdette
Wayne Wiggins	Jonesboro

CONTENTS

OVERVIEW AND VERIFICATION

BREEDING, GENETICS, AND PHYSIOLOGY

PEST MANAGEMENT: DISEASES

PEST MANAGEMENT: INSECTS

PEST MANAGEMENT: WEEDS

RICE CULTURE

RICE QUALITY AND PROCESSING

ECONOMICS

OVERVIEW AND VERIFICATION

2012 Rice Research Verification Program

L.A. Schmidt, R.S. Mazzanti, J.T. Hardke,
C.E. Wilson Jr., K.B Watkins, and T. Hristovska

ABSTRACT

The 2012 Rice Research Verification Program (RRVP) was conducted on 21 commercial rice fields across Arkansas. Counties participating in the program included Arkansas (3 fields), Chicot (2 fields), Clark, Clay, Conway, Craighead, Cross, Desha, Independence, Jackson, Jefferson, Lee, Lincoln, Phillips, Poinsett, Prairie, Randolph, and White for a total of 1,342 acres. Grain yield in the 2012 RRVP averaged 188 bu/acre ranging from 146 to 242 bu/acre. The 2012 RRVP average yield was 22 bu/acre greater than the estimated Arkansas state average yield of 166 bu/acre. The highest yielding field, Chicot 1 County, had a grain yield of 242 bu/acre. The lowest yielding fields were in White and Clark Counties and produced 146 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 51/70 (percent head rice/percent total white rice).

INTRODUCTION

In 1983, the University of Arkansas System Division of Agriculture Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize economic return. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service 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 Cooperative Extension Service 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, and 5) incorporate data from RRVP into Cooperative Extension Service educational programs at the county and state level. Since 1983, the RRVP has been conducted on 378 commercial rice fields in 33 rice-producing counties in Arkansas. Fields enrolled in the program have typically produced grain yields about 20 bu/acre greater than the state average yield. This increase in yield over the state average can be attributed mainly to timely implementation of intensive cultural management and integrated pest management practices.

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 Cooperative Extension Service recommendations in a timely manner from planting to harvest. A designated agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits to each field were made by the coordinator and county agents 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 infestations for possible pesticide applications.

An advisory committee, consisting of Extension specialists and university researchers with rice responsibilities, 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 2012 included Arkansas (3 fields), Chicot (2 fields), Clark, Clay, Conway, Craighead, Cross, Desha, Independence, Jackson, Jefferson, Lee, Lincoln, Phillips, Poinsett, Prairie, Randolph, and White. The 21 rice fields totaled 1,342 acres enrolled in the program. Nine cultivars were seeded [Clearfield (CL) CL111, CL151, CLXL729, CLXL745, Jupiter, Roy J, RiceTec XL723, RiceTec XL753, and Taggart] in the 21 fields and Cooperative Extension Service recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil-test results, variety, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on Cooperative Extension Service recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates of specific growth stages, grain yield, and milling yield.

RESULTS

Yield

The average RRVP yield was 188 bu/acre with a range of 146 to 242 bu/acre (Table 1). The RRVP average yield was 22 bu/acre greater than the estimated state average yield of 166 bu/acre. This difference has been observed many times since the program began, and can be attributed in part to intensive management practices and utilization of Cooperative Extension Service recommendations. The highest yielding field produced 242 bu/acre and was seeded with CL151 in Chicot 1 County. Eleven of the 21 fields exceeded 190 bu/acre. The lowest yielding fields produced 146 bu/acre and were seeded with Taggart and Francis in White and Clark Counties, respectively.

Milling data was recorded on all of the RRVP fields. A milling yield of 55/70 (percent head rice/percent total white rice) is considered the standard used by the rice milling industry. The average milling yield for the 21 fields was 51/70 with the highest milling yield of 60/72 occurring in Cross County with the variety CL151 (Table 1). The lowest milling yield was 24/61 and occurred in the Clark County field of Francis that experienced drought during grain fill.

Planting and Emergence

Planting began with fields in Craighead and Chicot 1 Counties on 28 March and ended with White County planted 1 May (Table 1). The majority of the RRVP fields were planted in April with an average seeding rate of 50 lb/acre. Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 11 days was required for emergence and stand density ranged from 4 to 28 plants/ft^2, with an average of 13 plants/ft^2. This wide range of stand densities can be explained partly by the difference in seeding rates recommended for conventional varieties and hybrids. In addition, the seeding rates in some fields were higher than average due to planting method and soil texture.

Fertilization

Nitrogen (N) recommendations were based on a combination of factors including soil texture, previous crop, and variety requirements (Table 2). Nitrogen rates may appear high in some fields with a clay soil texture where rice was the previous crop. These factors increase the N requirements of rice significantly compared to a silt loam soil where soybeans were the previous crop.

Ammonium sulfate (21-0-0-24) was applied in some fields at the 2- to 3-lf stage as a management tool to speed plant height development and shorten the time required to reach the flood stage or to correct sulfur deficiencies (Table 2). Ammonium sulfate was applied at a rate of 100 to 150 lb/acre in Arkansas 1, Arkansas 3, Chicot 1, Chicot 2, Clay, Desha, Jefferson, and Prairie Counties.

Phosphorus (P), potassium (K), and zinc (Zn) were applied based on soil-test results (Table 2). Phosphorus and/or K and Zn were applied preplant in most of the fields. Phosphorus was applied to Arkansas 1, Arkansas 2, Arkansas 3, Chicot 1, Chicot 2, Clark, Clay, Craighead, Independence, Jackson, Lee, Lincoln, Phillips, Poinsett, Prairie and White Counties. In three fields (Arkansas 3, Chicot 1, and Lincoln), P was applied in the form of diammonium phosphate (DAP; 18-46-0). Zinc was applied as a seed treatment in fields with hybrid rice varieties at a rate of 0.5 lb Zn/60 lb seed. The average cost of fertilizer across all fields was $167.82 (Table 3), which was $23.19 more than in 2011.

Weed Control

Command was utilized in 14 of the 21 fields for early-season grass control (Table 3). Facet was applied early post-emergence in 13 fields (Arkansas 2, Chicot 1, Chicot 2, Clark, Clay, Conway, Independence, Jackson, Jefferson, Lee, Lincoln, Poinsett, and Randolph Counties). Two fields (Conway and Cross) did not utilize a herbicide for pre-emergence weed control. Eight fields (Arkansas 1, Arkansas 3, Chicot 1, Chicot 2, Cross, Desha, Phillips and Prairie) were seeded in Clearfield cultivars (Table 1) and Newpath and Clearpath were applied for control of red rice and other weeds (Table 3). All of the fields required a post-emergence herbicide application for grass weed control.

Disease Control

Sixteen fields had a seed treatment containing a fungicide (Table 4). Foliar fungicides were applied to nine of the fields in 2012 for control of sheath blight and/or kernel smut prevention. Quilt Xcel or Stratego were used to control sheath blight and/or provide kernel smut prevention with rates determined based on variety, growth stage, climate, disease incidence/severity, and disease history.

Insect Control

Ten fields (Chicot 1, Clay, Conway, Craighead, Desha, Independence, Jackson, Lee, Phillips and Randolph Counties) had an insecticide seed treatment containing Cruiser insecticide and one field, Arkansas 1, had a Nipsit Inside insecticide seed treatment (Table 4). The Clark County field was treated for control of chinch bugs in seedling rice. Four fields (Arkansas 1, Conway, Cross, and Desha Counties) were treated for rice stink bugs in 2012.

Irrigation

Well water was used to irrigate 13 of the 21 fields in the 2012 RRVP while the remaining fields were irrigated with surface water. Three fields (Chicot 2, Conway, and Desha Counties) were zero-grade and five fields (Clay, Craighead, Lee, Prairie, and Randolph Counties) used multiple inlet (MI) irrigation either by utilizing irrigation tubing or by having multiple risers or water sources. Flow meters were used in eight of the fields to record water usage throughout the growing season (Table 5). The average of all irrigation methods used was 30 acre-inches, which was the value utilized for fields without flow meters. The difference in water used was due in part to rainfall amounts which ranged from 3.00 to 18.30 inches. Typically, a 25% reduction in water use is seen when using MI irrigation.

Economic Analysis

This section provides information on production costs and returns for the 2012 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 21 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's 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 2012 Crop Enterprise Budgets published by the University of Arkansas System Division of Agriculture Cooperative Extension Service and information provided by the producer cooperators. 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 range from $495.29/acre for Cross County to $801.97/acre for Lincoln County, while operating costs per bushel range from $2.42/bu for Conway County to $4.56/bu for Lincoln County. Total costs per acre (operating plus fixed) range from $565.42/acre for Cross County to $908.77/acre for Lincoln County; and total costs per bushel range from $2.92/bu for Conway County to $5.16/bu for Lincoln County. Returns above operating costs range from $177.71/acre for Clark County to $1,239.21/acre for Independence County; and returns above total costs range from $84.25/acre for Clark County to $1,141.64/acre for Independence County.

A summary of yield, rice price, revenues, and expenses by type for each RRVP field is presented in Table 7. The average rice yield for the 2012 RRVP was 188 bu/acres but ranged from 146 bu/acre for Clark and White Counties to 242 bu/acre for Chicot 1 County. The Arkansas average long-grain cash price for the 2012 RRVP was estimated from 22 August through 26 October daily price quotes to be $6.26/bu. The RRVP had two fields planted in medium-grain varieties (Independence and Poinsett). The average medium-grain price contracted in Arkansas was estimated to be $6.40/bu and represented the average long-grain price plus an average medium-grain premium of $0.13/bu. The average medium-grain premium was estimated based on the average difference in Arkansas milled rice value between medium-grain and long-grain rice obtained from the Arkansas Weekly Grain Review for the period 28 August through 30 October converted to a rough rice equivalent. A premium or discount was given to each field based on the milling yield measured for each field and standard milling yields of 55/70 for long-grain rice and 58/69 for medium-grain rice. Broken rice was assumed to have 70% of whole price value. If milling yield was higher than the standard, a premium was made while a discount was given for milling less than standard. Estimated long-grain prices adjusted for milling yield varied from $4.77/bu in Clark County to $6.94/bu in Jefferson County. Medium-grain prices adjusted for milling yield were $6.43/bu in Poinsett County to $6.66/bu in Independence County. The average operating expense for the 21 RRVP fields was $637.61/acre.

Fertilizers accounted for the largest share of operating expenses on average (26.3%) followed by post-harvest expenses (17.8%), pesticides (12.9%), seed (12.2%), and irrigation energy costs (10.3%) (Table 8). Although seed's share of operating expenses was 12.2% across the 21 fields, its average cost and share of operating expenses varied depending on whether a Clearfield hybrid was used ($148.47/acre; 23.9% of operating expenses), a non-Clearfield hybrid was used ($110.28/acre; 17.4% of operating expenses), a Clearfield variety was used ($53.59/acre; 7.7% of operating expenses) or a non-Clearfield non-hybrid variety was used ($34.75/acre; 5.6% of operating expenses). Arkansas 1 was the only field to have a second crop (ratoon). After harvesting the regular rice crop in August, the ratoon crop was harvested in early October and yielded 30 bu/acre. The only costs associated with the ratoon crop were harvesting costs amounting to $90.38/acre or $3.01/bu (operating plus fixed). Returns above total costs for the ratooned rice were $112.19/acre.

The average return above operating expenses for the 21 fields was $556.56/acre and ranged from $177.71/acre for Clark County to $1,239.21/acre for Independence County (Table 7). The average return above total specified expenses for the 21 fields was $464.22/acre and ranged from $84.25/acre for Clark County to $1,141.64/acre for Independence County. Table 8 provides selected variable input costs for each field and includes a further breakdown of pesticides costs for herbicides, insecticides, and fungicides. Table 8 also lists the specific rice varieties grown on each RRVP field.

DISCUSSION

Field Summaries

The Arkansas 1 County field was located across from the Rice Research and Extension Center on Hwy 130 E. near Stuttgart, Ark. The 51-acre field was a Dewitt silt loam soil and the previous crop was soybean. RiceTec CLXL745 seed was planted 30 March at 22 lb/acre. The seed was treated with Nipsit Inside insecticide seed treatment in addition to the company's standard seed treatment. The rice emerged on 10 April with a stand density of 8 plants/ft^2. A preplant fertilizer rate of 21-30-60-10-24 (N-P_2O_5-K_2O-Zn-S) lb/acre was applied according to soil-sample recommendations. Newpath herbicide was applied pre-emergence and Clearpath and Permit were applied as post-emergence herbicides. Both herbicide applications provided adequate weed control. The field was weed free throughout the year and a deep flood was maintained. Irrigation amounts were 20 acre-inches with rainfall amounts totaling 10 inches. Urea was applied based on N-ST*R (Nitrogen-Soil Test for Rice) soil-test recommendations at 270 lb/acre preflood followed by 70 lb/acre at the late boot stage. Stratego fungicide was applied for control of sheath blight and for prevention of kernel smut and false smut. Karate insecticide was applied for control of above threshold levels of rice stink bug. The field was harvested on 10 August and yielded 199 bu/acre. The average harvest moisture was 19%. The milling yield was 51/70.

The Arkansas County 2 field was located just northeast of Reydell. The field was 96 acres of a Dewitt silt loam. Conventional tillage practices were used to prepare the field for planting. On 29 March, the field was planted in Roy J at a seeding rate of 67 lb/acre. The rice emerged on 7 April with a stand density of 14 plants/ft^2. Command and League herbicides were used pre-emergence followed by SuperWham, Facet, and Aim applied post-emergence. Favorable spring rains properly activated the pre-emergence herbicides which provided long-lasting control of early season grasses and broadleaves. Preplant fertilizer was applied at 0-50-120-10-0 lb/acre. Nitrogen was applied according to N-ST*R recommendations at 200 lb/acre preflood followed by 100 lb/acre at mid-season. The contour field had several levees throughout the field and the irrigation source was surface water which provided a deep flood throughout the growing season. Tilt fungicide was applied for prevention of kernel smut and false smut. Although sheath blight was detected in the field, a fungicide was never applied for control of this disease because it failed to reach treatment threshold levels. The field was harvested on 29 August and yielded 197 bu/acre with a milling yield of 55/72.

The Arkansas 3 County field was 120 acres of a Dewitt silt loam and located just south of DeWitt. The field was seeded with 56 lb/acre of CL151 on 10 April. Glyphosate and Command herbicides were used for burndown and pre-emergence weed control. The field emerged on 23 April with a stand density of 14 plants/ft^2. Clearpath and Permit Plus herbicides, followed by an application of Beyond herbicide, were used for post-emergence weed control. The herbicide applications provided good control of both grasses and broadleaves. Preplant fertilizer applied was 18-46-90-10 lb/acre. Ammonium sulfate was applied at 100 lb/acre to ensure uniform stand establishment. Multiple inlet irrigation was used with six risers on the east side of the field. The field maintained an adequate flood throughout the season. Results from soil samples analyzed using the N-ST*R system recommended 200 lb/acre of preflood urea followed by 100 lb/acre applied mid-season. Quilt Xcel and Tilt fungicides were used for sheath blight control and kernel smut prevention. The field was harvested 28 August and yielded 180 bu/acre with a milling yield of 51/72.

The Chicot 1 County field was located northeast of Lake Village. The field was 50 acres of a Sharkey clay that had been left fallow for 50 years while used as a cow pasture. On 28 March, CL151 seed, treated with CruiserMaxx Rice, was planted at 55 lb/acre. Field emergence was recorded on 12 April with a stand density of 16 plants/ft^2. Two sequential applications of Touchdown herbicide were used as a burndown. Clearpath and League herbicides followed by Facet and Newpath herbicides were used for post-emergence weed control. Despite the presence of acetolactate synthase (ALS)-resistant barnyardgrass in neighboring fields, herbicide treatments were effective throughout the season. Preplant fertilizer was applied at 21-18-46-0-24 lb/acre. The N-ST*R program played a crucial role in determining N fertilization for this field since it had been left fallow for 50 years. N-ST*R recommendations were to apply 130 lb/acre of urea preflood (half the standard recommended rate) followed by a mid-season urea application of 100 lb/acre. The straight levee field utilized 43.5 irrigated acre-inches of water which is about 10 inches above average. Rainfall amounts in this field were one of the highest in the state at 14.7 inches for the season. Quilt Xcel and Bumper fungicides were used for sheath blight control and kernel smut prevention. The field was harvested 21 August with a RRVP record yield of 242 bu/acre and milling yield of 51/70. Sooty mold was detected on one end of the field which may have been an indication that the N rate used was still greater than needed for that area of the field. However, no lodging occurred in this field, which was one of the grower's main concerns.

The Chicot 2 County field was located between Eudora and Parkdale off Hwy. 8. The field was 47 acres of zero grade Perry clay and the previous crop was soybean. The variety was CL111 planted on 1 April at a rate of 50 lb/acre. Emergence date was 12 April with a stand density of 12 plants/ft^2. No insecticide seed treatments were used, so rice water weevil traps were spread throughout the field to monitor for this pest. After checking traps every few days throughout the early season there was no infestation of rice water weevil detected. Newpath and glyphosate herbicides were applied as a pre-emergence burndown application. Newpath followed by Facet and Permit herbicides were applied post-emergence. The field was free from grass and broadleaf weeds throughout the season. Preplant fertilizer applied was at 21-18-46-0-24 lb/acre. The irrigation source was surface water with 18 acre-inches recorded. Rainfall amounts in this field were well above normal at 15.3 inches for the season and an adequate flood was maintained throughout the year. Based on standard fertilizer recommendations, urea was applied preflood at 300 lb/acre with 100 lb/acre applied at mid-season. Quilt Xcel fungicide was applied for sheath blight control. The field was harvested 21 August with a yield of 183 bu/acre and a milling yield of 53/71.

Clark County was one of the later planted fields in the RRVP. The zero-grade field was located northwest of Arkadelphia on the Ouachita River. Chicken litter was applied in early spring at 1 ton (60-60-70)/acre. The field was conventionally tilled with a previous crop of corn. The field was 73 acres and the soil type was a Gurdon silt loam. The field was seeded with Francis on 12 April at a rate of 70 lb/acre. The rice emerged on 27 April with an average stand count of 9 plants/ft^2. Glyphosate and Command herbicides were used as burndown and pre-emergence applications, respectively. Facet and Permit Plus herbicides applied post-emergence provided good weed control. Karate insecticide was applied for chinch bug control on seedling rice. Urea fertilizer was applied preflood according to N-ST*R recommendations at 240 lb/acre followed by a mid-season application of 100 lb/acre. This field utilized surface water irrigation from the Ouachita River. Unfortunately, extreme heat and drought conditions led to record-low water levels on the river and eventually water levels became so low that the producer was no longer able to irrigate. This occurred at the same time rice reached the heading stage, causing severe yield loss and poor milling quality. The field was harvested on 6 October. The yield was 146 bu/acre with a milling yield of 24/61.

The precision-graded Clay County field was located west of Corning on a Knobel silt loam soil. The field was 79 acres and the previous crop produced on the field was soybeans. In March, conventional tillage practices were used for field preparation and a preplant fertilizer based on soil-test analysis was applied at a rate of 0-30-60 lb/acre. On 10 April, CruiserMaxx Rice-treated RiceTec XL753 rice seed was drill-seeded at a rate of 24 lb/acre. Command herbicide was applied pre-emergence following planting.

Emergence of the rice in the field was observed on 22 April and consisted of 8 plants/ft^2. Prior to the tillering stage, a suspected Newpath herbicide drift affected approximately one third of the field. Recovery was slow and once Newpath symptoms began to cease, 100 lb/acre of ammonium sulfate was applied and the field was flushed to help the rice that had been set back. Weeds not controlled or breaking through the Command herbicide application were treated with a combination of Facet and Riceshot, which resulted in good overall weed control for the remainder of the season. Preflood urea at 200 lb/acre was applied 13 June and multiple-inlet flood irrigation was started the same day to initiate permanent flood. Flood levels were maintained well throughout the year despite the hot and dry weather conditions. Below threshold levels of rice diseases and rice stink bug were observed throughout the season, therefore, neither fungicides nor insecticides were recommended on the field. The recommended boot application of 67 lb/acre of urea to hybrid rice was applied on 8 July. The field endured several rain systems following maturity, but less than approximately 1% of the field experienced any lodging. Harvest began 20 September and the yield for the field was 196 bu/acre and the milling yield was 49/70.

The zero-graded Conway County field was 53 acres and located southwest of Morrilton on a Dardanelle silt loam soil. The previous crop planted in the field was rice. Conventional tillage was practiced on the field in late winter to early spring. RiceTec XL753 with CruiserMaxx Rice seed treatment was drill-seeded on 23 April at rate of 19.5 lb/acre (target was 22 lb/acre). Field emergence was observed on 5 May and consisted of 8 plants/ft^2. A post-emergence application of Facet, Permit, and Command for broadleaf and grass control was applied 12 May. Weed control and crop growth were good throughout the tillering stage due to the above average temperatures experienced in the region. Preflood urea (150 lb/acre) and ammonium sulfate (100 lb/acre) were applied 17 May and a permanent flood was established 20 May. The field held a deep flood throughout the entire season following permanent flood establishment. A Clincher herbicide application was applied to approximately 17 acres after flood establishment for control of barnyardgrass in areas where herbicide application was difficult, such as under highline electric wires running through the field and along the field edge. On 22 June, a single mid-season urea application (100 lb/acre) replaced the recommended boot application to hybrid rice due to the appearance of N deficiency symptoms in the rice. Low disease incidence was observed in the field and no fungicide was recommended, although a few panicles were confirmed to have bacterial panicle blight later in the season. Once rice reached the heading stage, the field was scouted routinely for rice stink bugs. Populations reached threshold levels by the second week of scouting, and an early-morning application of Kendo (lambda-cyhalothrin) was applied 3 days later on 27 July and provided good control of the rice stink bug population. Very sporadic heading was observed in the field, though this observation may have been influenced by the common presence of volunteer rice from the previous season. Pumping ceased 15 August and the field was drained 22 August. Harvest began 4 September and the field yielded 211 bu/acre despite the high population of later maturing volunteer rice present. The milling yield for the field was 51/69.

The precision-graded, 58-acre field in Craighead County was located on the western edge of Lake City on a Sharkey clay soil. Soybean was planted the previous year at this location. Field preparation involved conventional tillage techniques and blended fertilizer was applied at a rate of 10-60-120 lb/acre in March prior to planting based on soil-test analysis. On 28 March, Roy J rice, treated with CruiserMaxx Rice and Release, was drill-seeded at a 100 lb/acre rate. League and Roundup herbicides were applied to the field following planting to control newly emerged weeds and to provide broadleaf residual control. Emergence of the rice was observed on 2 April with stand counts of 21 rice plants/ft^2. To address the grass and broadleaf weed emergence in the field, Prowl and RiceBeaux were applied 13 April. Preflood urea at a rate of 200 lb/acre was applied 11 May with a permanent flood being established shortly afterward. Maintaining an adequate flood level was a challenge due to the hot and dry conditions experienced this year, but the use of multiple inlet irrigation helped address this issue. Barnyardgrass remained present in the field after the flood was established, but a herbicide treatment was not utilized due to the low density of barnyardgrass and the field's proximity to Lake City. No fungicide or insecticide treatments were recommended on the field due to low rice disease and insect incidence. Mid-season urea at 100 lb/acre was applied 4 June in a single application and the rice continued to develop normally throughout the remainder of season. The field was drained 8 August and sodium chlorate was applied 22 August to desiccate green foliage and harvest was started a day later due to summer heat enhancing sodium chlorate activity. The field yielded 196 bu/acre and was one of the highest yields in the program. The milling yield was 52/69.

The precision-graded field in Cross County was 127 acres and located east of Crowley's Ridge near the community of Coldwater. The soil type for this location was an Alligator clay and the field had rice planted the previous year. Conventional tillage was practiced in early April and then the field was drill-seeded on 20 April at a rate of 50 lb/acre using CL151 seed treated with Apron, Maxim, and Release. The grain-drill spacing was 10 inches and, although not recommended, had to be used due to farm equipment logistics. Past research has indicated this drill spacing is not optimum for rice performance. Stand establishment was very inconsistent throughout the field and was attributed to the use of an ultra-low seeding rate, drought conditions, and clay soil texture (ultra-low seeding rate was not recommended). Initial emergence occurred 14 days after planting. The field was flushed twice in order to achieve an average stand of 11 plants/ft^2 at 28 days after planting. Despite the low average stand count for this variety, it was determined that the field had a sufficient stand to continue production. Clearpath herbicide was applied post-emergence on 11 May for control of barnyardgrass and broadleaf weeds. An additional herbicide application was required to achieve adequate grass control; therefore, Newpath and Command herbicides were applied preflood on 6 June. Command was included for improved residual control of sprangletop species. One day later, 300 lb/acre of preflood urea was applied and a permanent flood was initiated on 10 June. On 23 June, around mid-season, Blazer herbicide was applied to 40 acres of the field to control a large population of hemp sesbania. Two days later, on 25 June, a single mid-season application of 100 lb/acre of urea was applied to the -field with rice ranging in growth stage from late tillering to 0.5-inch internode elongation. The variability in rice plant development throughout the field was due to an elongated period of emergence after planting. While disease pressure was initially low, later in the season treatment levels of sheath blight were detected resulting in an application of Stratego fungicide on 11 July. Rice stink bugs were observed prior to heading on escaped barnyardgrass plants. After the field reached the heading stage, scouting indicated rice stink bug populations to be above threshold; therefore, Mustang Max was applied on 8 August for their control. Adequate flood levels were maintained throughout the season. On 30 August, the field was drained in preparation for Tropical Storm Isaac. Harvest was initiated on 19 September and ran into early October due to harsh field conditions created by frequent rainfall following Tropical Storm Isaac. However, the field experienced only minor lodging during this period. The yield was 162 bu/acre. The producer and Division of Agriculture personnel were pleased with the yield in light of stand establishment issues and harvest delays. The milling yield for the field was one of the program's best at 60/72.

The Desha County field was located between McGehee and Rohwer. The zero-grade field was 50 acres and the soil type was part Sharkey clay and part Desha clay. Precision-leveled 4 years ago, the only crop grown in this field has been rice. The field was planted with RiceTec CLXL745 seed, treated with CruiserMaxx Rice in addition to the company's standard seed treatment, on 28 April at a rate of 23 lb/acre. Glyphosate and Command herbicides were used for burndown and pre-emergence weed control, respectively. Rice emerged on 10 May with stand counts of 4 plants/ft^2. Ammonium sulfate was applied at a rate of 100 lb/acre on 17 May. The field was flushed twice in an unsuccessful attempt to improve plant stand. Clearpath herbicide followed by Newpath herbicide was applied for post-emergence weed control. The irrigation source was surface water. An adequate flood was maintained in the field throughout the year. Following N-ST*R recommendations, urea fertilizer was applied at 170 lb/acre preflood with 70 lb/acre applied at the late boot stage. The field was treated with Karate insecticide for control of above-threshold levels of rice stink bug. The field was harvested 18 September. The yield was 172 bu/acre and the milling was 45/70.

The 29-acre, precision-graded field in eastern Independence County was located near Oil Trough on an Egan silt loam soil. Rice was planted in the field the previous year. Prior to planting, a fertilizer blend of 10-28-54 lb/acre was applied based on soil-test analysis. Conventional tillage practices were used to prepare the field for planting. On 5 April, Jupiter rice seed, treated with CruiserMaxx Rice, was drill-seeded at a rate of 72 lb/acre. This planting date was considered early for the region. Two days after planting, Roundup PowerMax and Command were applied for pre-emergence control of annual grasses and post-emergence control of existing weedy vegetation. Ten days after planting, rice emerged to a uniform stand of 15 plants/ft^2. Prior to flooding, 220 lb/acre of urea and 30 lb/acre of ammonium sulfate were applied. Permanent flood was initiated on 10 May immediately following the preflood fertilizer application. The flood was well maintained throughout the year and surface irrigation water was provided from the White River. Barnyardgrass not controlled by early season herbicide applications were controlled with a post-flood mixture of Clincher and Facet on 18 May. The rice remained short in areas of the field during the season which was attributed to the field being leveled within the past few years. The rice responded well to a single mid-season urea application of 100 lb/acre and the uneven portions appeared to have leveled out across the field by the time rice reached the boot stage. Rice disease and insect pressure was low throughout the season, and no fungicide or insecticide applications were warranted. The field was drained 30 August, and a harvest application of sodium chlorate was applied 10 September. Harvest began 12 September with moisture levels at approximately 20%. The yield was the second highest in the RRVP this year at 221 bu/acre and one of the best milling yields at 60/70. This yield was considerably more than the producer had ever produced on this farm.

The precision-graded 36-acre Jackson county field was located west of Tuckerman on a Bosket fine sandy loam. The field has been in rice production since it was precision-leveled 2 years ago. To continue to restore the productivity of the leveled soil, 1.5 tons of chicken litter, as well as K, were applied mid-March according to soil-test recommendations. Conventional tillage practices were utilized in late winter and a pre-plant burndown herbicide application of Roundup PowerMax and 2,4-D was made in early March. Taggart, treated with CruiserMaxx Rice, was drill-seeded at a rate of 90 lb/acre on 31 March which was considered early for the area. Emergence was documented on 8 April with an average stand density of 21 plants/ft^2. An early post-emergence application of Facet and Riceshot was made for grass and broadleaf weed control a week following rice emergence. A subsequent herbicide application of SuperWham and Permit was applied preflood 32 days after rice emergence to control later emerging grass, broadleaves, and yellow nutsedge. No additional weed control measures were needed for the remainder of the season. Urea was applied preflood at 230 lb/acre and initiation of permanent flood began on 11 May. A single mid-season application of urea (100 lb/acre) was made on 13 June. Very low disease and insect pressure were observed throughout the year and treatment was not advised. The field was drained 15 August and harvest began 12 days later and extended into September due to Tropical Storm Isaac and mechanical failures. The field's yield of 171 bu/acre represented greater than a 25% yield improvement compared to the rice yield in this field the previous year. However, the milling yield of 41/71 was one of the lowest for the RRVP during 2012.

The Jefferson County field was located just off the Arkansas River between Pastoria and Altheimer. The field was 28 acres and the soil type was a Perry clay. The previous year the field was planted to soybean. RiceTec XL753 seed was planted on 9 April at 23 lb/acre and emergence was recorded on 30 April. A tank mix of Command and glyphosate herbicides was used for pre-emergence and burndown weed control, respectively. Propanil, Permit Plus, and Aim herbicides provided good weed control on the west side of the field, followed by an application of Facet and Permit Plus. Due to a miscommunication with the aerial applicator, the east side of the field was treated with both a ground and aerial application of herbicides equal to a 2x rate which caused severe rice stunting. As a result, only the west side of the field was used for verification. Ammonium sulfate was applied at 100 lb/acre on 23 April to help bring uniformity to the field. Urea was applied preflood at 270 lb/acre followed by 70 lb/acre at late boot. The irrigation source was from a diesel-powered well. An adequate flood was maintained throughout the summer. The west side of the field was harvested on 10 September yielding 198 bu/acre and the milling was 60/70.

The Lee County field was located just south of Moro. The field was 83 acres with soybean as the previous crop and the soil type was a Foley-Bonn complex. Roy J, treated with CruiserMaxx Rice seed treatment, was seeded at 65 lb/acre on 30 March.

The field emerged on 9 April with 15 plants/ft^2. Command was used as a pre-emergence herbicide. Crabgrass, morningglory, and broadleaf signalgrass were the main weed species. Facet and Aim herbicides were used post-emergence providing excellent weed control. Some pigweed escapes were prevalent but were controlled by the flood within a few weeks. Pre-plant fertilizer was applied at a rate of 0-60-90 lb/acre. Urea was applied according to N-ST*R recommendations at 270 lb/acre preflood and 100 lb/acre at mid-season. Multiple inlet irrigation was utilized to help maintain water levels in this large field and an adequate flood was maintained using an electric well. Quilt XL fungicide was applied for prevention of sheath blight, kernel smut, and false smut. No additional fungicide or insecticide treatments were warranted based on observations during regular fielding scouting. The field was harvested 16 September and the yield was an exceptional 196 bu/acre with a milling yield of 49/70.

The Lincoln County field was located between Star City and Gould. The 40-acre field was a Perry clay and the previous crop was soybean. RiceTec XL753 was seeded on 2 April at a rate of 24 lb/acre. Roundup PowerMax and Command herbicides were applied pre-emergence. A problem with the ground application equipment used for pre-emergence and burndown herbicides resulted in an area of barnyardgrass that was never fully controlled. Rice emerged on 16 April with stand counts averaging 7 plants/ft^2 overall, but some areas of the field had thin stands (4 to 5 plants/ft^2). Post-emergence herbicides were Facet, Permit Plus, and propanil. Herbicide efficiency overall was fair at best. Flood levels were maintained by well water throughout the year with 40 acre-inches recorded. Urea fertilizer was applied preflood at 270 lb/acre followed by 75 lb/acre at the late boot stage. Quilt Xcel fungicide was used for sheath blight control and as a kernel smut and false smut preventative. Rice stink bugs were present in the field but failed to reach threshold levels required to initiate an insecticide treatment. The field was harvested on 27 August. The grain yield was 176 bu/acre with a milling yield of 43/67.

The Phillips County field was located just south of Barton. The field was 40 acres of Foley silt loam with soybean as the previous crop. Roundup WeatherMax and 2,4-D were applied as early burndown herbicides. Glyphosate and Command herbicides were used for burndown and pre-emergence weed control, respectively. The cultivar was RiceTec CLXL745 treated with CruiserMaxx Rice in addition to the company's standard seed treatment. Rice was seeded on 6 April at a rate of 24 lb/acre and emerged on 24 April with a stand density of 7 plants/ft^2. Chinch bugs were a threat from neighboring wheat fields yet never reached threshold levels in the RRVP field. Clearpath and League herbicides followed by Newpath herbicide were used for post-emergence weed control providing excellent weed control. Preplant fertilizer was applied by ground at 0-60-60 lb/acre. Ammonium sulfate was applied at 100 lb/acre on 24 April. Following N-ST*R recommendations, 280 lb urea/acre was applied preflood followed by 75 lb/acre at late boot. Flood levels were adequate with an electric well as the water source. No fungicide or insecticide applications were required for treatment of disease or insects. The field was harvested 29 August and the grain yield was 178 bu/acre with a milling yield of 56/72. The grain yield in this field represented a 10 to 15 bu/acre improvement for hybrid performance on this farm.

The 107-acre Poinsett County field was located in the north central portion of the county on a Henry silt loam soil. Soybean was the previous crop that was grown on the field. A burndown herbicide mixture of Roundup PowerMax and 2,4-D amine was applied during the winter and conventional tillage practices were used for field preparation in early spring. Based on soil-test recommendations, a 0-28-58 lb/acre fertilizer blend was incorporated during the field tillage operation. Another burndown herbicide mixture of Roundup and Firstshot was used prior to planting for control of newly emerged weeds. Jupiter was drill-seeded on 10 April at a rate of 78 lb/acre. Command herbicide was applied pre-emergence two days after planting for grass control. Rice emerged to a uniform stand of 18 plants/ft^2 7 days after planting. To control emerging grasses and broadleaf weeds, a herbicide mixture of SuperWham, Prowl H2O, Permit, and Facet was applied 18 days after rice emergence. On 21 May, urea was applied preflood at 225 lb/acre and permanent flood was initiated. After flood establishment, Clincher herbicide was applied to approximately 15 acres, primarily on field edges, for control of barnyardgrass. Prior to mid-season N applications, reports in the surrounding area suggested that splitting the mid-season application was needed to offset suspected widespread N deficiency symptoms. To evaluate these reports, the RRVP field was divided in half to compare the contrasting methodologies. On 25 June, one half of the field received 100 lb/acre of urea, while the other half received 75 lb/acre followed by another 75 lb/acre one week later. Throughout the remainder of the season following the mid-season fertilizer applications, no differences were observed for plant appearance or yield. This supports past research statements on this topic which suggests that a single mid-season N fertilizer application is equal to two split mid-season applications. Disease and insect levels remained below threshold all season and no fungicide or insecticide applications were made. Water pumped from a local reservoir maintained the flood on the field for the duration of the season until pumping ceased on 22 August and the field drained 8 days later. Harvest began on 22 September and the field yielded 197 bu/acre with a milling yield of 59/69.

The Prairie County field was 82 acres located immediately west of Des Arc on a Callaway silt loam soil. The previous crop grown on the field was soybean. In March, a burndown application of Makazie (glyphosate) was used to control existing weedy vegetation. Conventional tillage practices were used on the field and a fertilizer blend of 0-60-90 lb/acre was applied to the field prior to planting according to soil-test recommendations. RiceTec CLXL745 with the company's standard seed treatment was drill-seeded at 20 lb/acre on 10 April. A uniform rice stand emergence was observed 10 days later and consisted of 5 plants/ft^2. Newpath herbicide was applied 6 days after rice emergence. Ammonium sulfate was applied at 150 lb/acre one day later to enhance growth of pre-tillering rice. A second application of Newpath herbicide was applied 11 May and included Aim herbicide for improved broadleaf weed control. Preflood urea treated with Agrotain was applied at 200 lb/acre on 13 May just prior to establishment of a permanent flood. Flood level on the field was maintained throughout the season utilizing the multiple inlet system. The recommended 65 lb/acre boot application of urea was applied 9 July. No fungicide or insecticide applications were made due to low pest pressure throughout the season. The field was drained 15 August and harvest began on 28 August. The grain yield was 193 bu/acre with a milling yield of 56/72.

The precision-graded, 68-acre field in Randolph County was located between Pocahontas and Delaplaine near the community of Sharum. The previous crop grown on the field was soybean and the soil type was a McCrory silt loam. Conventional tillage practices were utilized prior to planting. The field was planted on 30 April with 28 lb/acre of RiceTec XL723 seed treated with CruiserMaxx Rice in addition to the company's standard seed treatment. Two days following planting, a pre-emergence treatment of Command herbicide was applied for early grass control. Rice emergence was documented on 11 May with a uniform stand of 10 plants/ft^2. The rice grew actively during the warm temperatures experienced between emergence and flood establishment. The field received a preflood treatment of RiceBeaux and Facet herbicides to control grass and broadleaf weeds. Agrotain-coated urea at a rate of 250 lb/acre was applied preflood. Permanent flood establishment began on 1 June utilizing the multiple-inlet irrigation. Adequate flood levels on the field were achieved and successfully maintained using this system. On 5 July, urea was applied at 65 lb/acre to rice in the boot stage. Approximately one week later, portions of the field began to experience delayed growth and symptomology indicative of phenoxy herbicide injury. Upon further investigation, it was determined those areas were experiencing delayed phytotoxicity syndrome (DPS), which can occur from anaerobic conditions coupled with many of the herbicides used in rice. To correct this disorder, the field was drained until only a thin layer of water remained to speed oxygen movement back into the soil. The permanent flood was re-established after one week and plants began to improve and develop grain. No threshold levels of rice disease or insect incidence were noticed during weekly inspections. On 22 August, irrigation ceased and the field was drained a week later. Due to some minimal lodging from late summer storms, the grower wanted to harvest the field as soon as it reached 20% moisture; therefore, a gallon of Defol 5 (sodium chlorate) was applied as a desiccant on 6 September. Harvest began on 10 September and the field produced an average grain yield of 184 bu/acre and a milling yield of 54/70.

The 25-acre White County RRVP field was situated in the northern portion of the county near Russell. Soybean was planted previously on the field and the soil was a Calhoun-Callaway silt loam. The field had not been precision graded. This past spring a burndown application of Roundup PowerMax herbicide was applied to minimize existing weedy vegetation and the field was tilled using conventional practices. A fertilizer blend of 0-30-90 lb/acre was applied preplant in accordance with soil-test analysis recommendations. Taggart seed, treated with Release and Apron XL, was drill-seeded on 1 May directly followed by an application of Command herbicide for pre-emergence annual grass control. Rice emerged uniformly to a stand averaging 28 plants/ft^2 on 5 May. On 30 May, at the preflood timing or tillering rice stage, the field was treated with Ricestar HT for annual grasses and urea at 230 lb/acre was applied. A permanent flood was initiated the following day. Once the rice reached panicle initiation on 22 June, the field was treated with 2,4-D herbicide for broadleaf weed control and was followed 3 days later with a 100 lb/acre mid-season urea application. While sheath blight was observed at moderate levels prior to mid-season, it was not until after the mid-season urea application that the disease reached treatment threshold and began to approach the upper rice foliage. Subsequently, Quadris and Tide Propiconazole fungicides were applied in a tank mixture for suppression of the sheath blight fungus and as a preventative measure for a field history of kernel smut, respectively. Following field draining on 30 August, rainy and windy weather conditions caused lodging throughout the field.

Complications caused by lodging resulted in a prolonged harvest extending from early October into December. This field's yield potential was promising before the storms, but likely due to lodged and sprouted rice, the average of the field was 146 bu/acre. The milling yield was 50/72.

SIGNIFICANCE OF FINDINGS

Data collected from the 2012 RRVP reflect the general trend of increasing rice yields and above average returns in the 2012 growing season. Analysis of this data showed that the average yield was higher in the RRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

ACKNOWLEDGMENTS

We appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the rice check-off funds administered by the Arkansas Rice Research and Promotion Board. We appreciate the cooperation of all participating County Extension Agents. We also thank the professors, specialists, and program associates of the University of Arkansas System Division of Agriculture Agriculture Experiment Station and Cooperative Extension Service and the district administration for their support.

Table 1. Agronomic information for fields enrolled in the 2012 Rice Research Verification Program.

Field location by county	Cultivar	Field size	Previous crop	Seeding rate[a]	Stand density[b]	Planting date	Emergence date	Harvest date	Yield	Milling yield[c]	Harvest moisture
		(acres)		(lb/acre)	(plants/ft^2)			(bu/acre)		(%)	
Arkansas 1	RTCLXL 745	51	Soybean	22	8	30 Mar	10 Apr	10 Aug	199	51/70	19
Arkansas 2	Roy J	96	Soybean	67	14	29 Mar	7 Apr	29 Aug	197	55/72	17
Arkansas 3	CL151	120	Corn	56	14	10 Apr	23 Apr	28 Aug	180	51/72	19
Chicot 1	CL151	50	Fallow	55	16	28 Mar	12 Apr	21 Aug	242	51/70	17
Chicot 2	CL111	47	Soybean	50	12	1 Apr	12 Apr	21 Aug	182	53/71	18
Clark	Francis	73	Corn	70	9	12 Apr	27 Apr	6 Oct	146	24/61	15
Clay	RTXL753	79	Soybean	24	8	10 Apr	22 Apr	20 Sept	196	49/70	16
Conway	RTXL753	53	Rice	20	8	23 Apr	5 May	4 Sept	211	51/69	15
Craighead	Roy J	58	Soybean	100	21	28 Mar	2 Apr	23 Aug	196	52/69	15
Cross	CL151	127	Rice	50	11	20 Apr	4 May	19 Sept	162	60/72	16
Desha	RTCLXL745	50	Rice	23	4	28 Apr	10 May	18 Sept	172	45/70	19
Independence	Jupiter	29	Rice	72	15	5 Apr	15 Apr	12 Sept	221	60/70	20
Jackson	Taggart	36	Rice	90	21	31 Mar	8 Apr	27 Aug	171	41/71	16
Jefferson	RTXL753	28	Soybean	23	8	9 Apr	30 Apr	10 Sept	198	60/70	16
Lee	Roy J	83	Soybean	65	15	30 Mar	9 Apr	16 Sept	196	49/70	15
Lincoln	RTXP753	40	Soybean	23	6	2 Apr	16 Apr	27 Aug	176	43/67	17
Phillips	RTCLXL745	40	Soybean	24	7	6 Apr	24 Apr	29 Aug	178	51/72	18
Poinsett	Jupiter	107	Soybean	78	28	10 Apr	17 Apr	22 Sept	197	59/69	18
Prairie	RTCLXL745	82	Soybean	20	5	10 Apr	20 Apr	28 Aug	193	56/72	17
Randolph	RTXL723	68	Soybean	28	10	30 Apr	11 May	10 Sept	184	54/70	17
White	Taggart	25	Soybean	84	28	1 May	5 May	1 Dec	146	50/72	17
Average	-----	64	-----	50[b]	13[c]	9 Apr	20 Apr	7 Sept	188	51/70	17

[a] Seeding rates averaged 70 lb/acre for conventional cultivars and 23 lb/acre for hybrid cultivars.

[b] Stand density averaged 17 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

[c] Head rice milling yield/total rice milling yield.

Table 2. Soil test results, fertilization program, and soil classification for fields enrolled in the 2012 Rice Research Verification Program.

Field location	Soil test				Applied fertilizer			
by county	pH	P[a]	K[a]	N[a]	Preplant[b] N-P-K-Zn-S[a]	Urea (45%N) rates applied by timing[c]	Total N rate[d]	Soil classification
		-----	-----	-----	(lb/acre)	-----	-----	
Arkansas 1	6.1	40	246	6.8	21-30-60-10-24	270-0-70	153	Dewitt Silt Loam
Arkansas 2	6.2	15	115	7.0	0-50-120-10-0	200-100-0	135*	Dewitt Silt Loam
Arkansas 3	7.6	89	116	3.4	36-46-90-10-24	200-100-0	135*	Dewitt Silt Loam
Chicot 1	5.8	30	834	6.2	21-18-46-0-24	130-100-0	103*	Sharkey Clay
Chicot 2	6.4	30	558	3.6	21-18-46-0-24	300-100-0	180	Perry Clay
Clark	5.2	21	98	3.2	60-60-70-0-0[e]	240-100-100	198	Gurdon Silt Loam
Clay	6.2	45	149	3.7	21-30-60-0-24	200-0-67	141	Knobel Silty Clay
Conway	6.1	70	368	3.6	21-0-0-0-24	150-100-0	134	Dardanelle Silt Loam
Craighead	6.4	94	298	6.0	10-60-120-0-0	200-100-0	145	Sharkey Clay
Cross	6.9	54	642	7.6	0-0-0-0-0	300-100-0	180	Alligator Clay
Desha	7.2	48	653	7.7	21-0-0-0-24	170-0-70	108*	Sharkey/Desha Clay
Independence	6.7	48	318	15.2	16-28-54-0-7	220-100-0	160	Egam Silt Loam
Jackson	5.9	86	133	3.2	40-50-120-0-0[f]	230-100-0	189	Bosket Fine Sandy Loam
Jefferson	7.0	54	740	8.0	21-0-0-0-24	270-0-70	153	Perry Clay
Lee	6.9	93	197	7.6	0-60-90-0-0	270-100-0	166*	Foley- Bonn Complex
Lincoln	7.1	44	342	2.1	18-46-0-10-0	270-0-75	173	Perry Clay
Phillips	8.2	92	252	9.2	0-60-60-0-0	280-0-75	160*	Foley Silt Loam
Poinsett	7.6	62	220	14.5	0-28-58-0-0	225-100-0	146	Henry Silt Loam
Prairie	7.1	34	108	6.6	32-60-90-0-36	200-0-67	152	Callaway Silt Loam
Randolph	6.8	54	456	8.7	0-0-0-0-0	250-0-67	143	McCrory Fine Sandy Loam
White	5.6	44	150	13.8	0-30-60-0-0	230-100-0	149	Callaway Silt Loam

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

[b] N-P_2O_5-K_2O-Zn-S (includes seed treatments and preplant applications).

[c] Timing: preflood - midseason - boot.

[d] Column values with an (*) beside them were fertilized according to N-ST*R recommendations.

[e] Analysis established from 1 ton/acre chicken litter.

[f] Analysis established from 1.5 tons/acre chicken litter and 100 lb/acre of potash fertilizer.

Table 3. Herbicide rates and timings for fields enrolled in the 2012 Rice Research Verification Program.

Field location by county	Pre-emergence herbicide applications	Post-emergence herbicide applications
	---------- (trade name & product rate/acre)[a] ----------	
Arkansas 1	Newpath (6 oz)	Clearpath (0.5 lb) + Permit (1 oz)
Arkansas 2	Command (12.8 oz) + League (4 oz)	Superwham (4 qt) + Facet (0.5 lb) + Aim (1 oz)
Arkansas 3	Command (16 oz) + Glyphosate (32 oz)	Clearpath (0.5 lb) + Permit Plus (0.75 oz) fb Beyond (5 oz)
Chicot 1	Touchdown (32 oz) fb Touchdown (32 oz)	Clearpath (0.5 lb) + League (3.2 oz) fb Facet (0.25 lb) + Newpath (6 oz)
Chicot 2	Glyphosate (32 oz) + Newpath (4 oz)	Newpath (4 oz) fb Facet (0.5 lb) + Permit (1 oz)
Clark	Command (18 oz) + Glyphosate (32 oz)	Facet (0.5 lb) + Permit Plus (0.75 oz)
Clay[b]	Command (10 oz)	Facet (0.33 lb) + Riceshot (3 qt)
Conway	------[c]	Facet (0.5 lb) + Permit (0.67 oz) + Command (16 oz) fb Clincher (15 oz)
Craighead	League (3.2 oz) + Roundup PowerMax (32 oz)	Prowl (2 pt) + RiceBeaux (4 qt)
Cross[b]	------[c]	Clearpath (0.5 lb) fb Newpath (5 oz) + Command (8 oz) fb Ultra Blazer (16 oz)
Desha[b]	Glyphosate (32 oz) + Command (8 oz)	Clearpath (0.5 lb) fb Newpath (4 oz)
Independence	Roundup PowerMax (32 oz) + Command (16 oz)	Clincher (15 oz) + Facet (0.33 lb)
Jackson	Roundup PowerMax (32 oz) + 2,4-D (1 pt))	Facet (0.33 lb) + Riceshot (4 qt) fb Superwham (4 qt) + Permit (0.75 oz)
Jefferson	Glyphosate (32 oz) + Command (18 oz)	Propanil (4 qt) + Permit Plus (0.75 oz) + Aim (1 oz) fb Facet (0.33 lb) + Permit Plus (0.75 lb)
Lee	Command (12.8 oz)	Facet (0.67 lb) + Aim (1 oz)
Lincoln	Roundup PowerMax (32 oz) + Command (21 oz)	Facet (0.5 lb) + Permit Plus (0.75 oz) + Propanil (4 qt)
Phillips	Glyphosate (32 oz) + 2,4,D (16 oz) fb Gramoxone (32 oz)	Clearpath (0.5 lb) + League (3.2 oz) fb Newpath (6 oz)
Poinsett[b]	Roundup PowerMax (22 oz) + 2,4-D amine (16 oz) fb Roundup PowerMax (32 oz) + Firstshot (0.5 oz) fb Command (10 oz)	SuperWham (4qt) + Prowl (2 pt) + Permit (0.67 oz) + Facet (0.33 lb) fb Clincher (15 oz)
Prairie	Glyphosate (32 oz)	Newpath (4 oz) fb Newpath (4 oz) + Aim (1 oz)
Randolph	Command (12.8 oz)	RiceBeaux (3 qt) + Facet (0.33 lb)
White[b]	Roundup PowerMax (32 oz) fb Command (10 oz)	Ricestar HT (24 oz) fb 2,4-D (16 oz)

[a] The abbreviation fb stands for ‘followed by’ and is used to separate herbicide application events.

[b] Field received applications of Command herbicide at rates which provided effective weed control, but were below the current manufacturer’s labeled rate. Due to the more frequent occurrence of herbicide-resistant weeds, the University of Arkansas System Division of Agriculture Cooperative Extension Service does not recommend the use of any herbicides at reduced rates.

[c] Field did not receive pre-emergence herbicide applications due to historical field issues with these applications.

Table 4. Seed treatments used and foliar fungicide and insecticide applications made on fields enrolled in the 2012 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 attacking seedling rice	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 1	RTST[a] + Nipsit Inside (1.92 fl oz)	Stratego (19 oz)	------	------	Karate (2.1 oz)
Arkansas 2	------	Tilt (6 oz)	------	------	------
Arkansas 3	------	Quilt Xcel (14 oz) + Tilt (6 oz)	------	------	------
Chicot 1	CruiserMaxx Rice (7 fl oz)	Quilt Xcel (17.5 (oz) + Bumper (1.5 oz)	------	------	------
Chicot 2	------	Quilt Xcel (21 oz)	------	------	------
Clark	------	------	------	------	Mustang Max (3.2 oz)
Clay	CruiserMaxx Rice (7 fl oz)	------	------	------	-----
Conway	CruiserMaxx Rice (7 fl oz)	------	------	------	Kendo (5 oz)
Craighead	CruiserMaxx Rice (7 fl oz) + Release LC (2 fl oz)	------	------	------	------
Cross	Apron XL (0.64 fl oz) + Maxim 4FS (0.12 fl oz) + Release LC (2 fl oz)	Stratego (19 oz)	------	------	Mustang Max (3.6 oz)
Desha	RTST + CruiserMaxx Rice (7 fl oz)	------	------	------	Karate (2.1 oz)
Independence	CruiserMaxx Rice (7 fl oz)	------	------	------	------
Jackson	CruiserMaxx Rice (7 fl oz/)	------	------	------	------
Jefferson	RTST	------	------	------	------
Lee	CruiserMaxx Rice (7 fl oz)	Quilt Xcel (21 oz)	------	------	------
Lincoln	RTST	Quilt Xcel (14 oz)	------	------	------
Phillips	RTST + CruiserMaxx Rice (7 fl oz)	------	------	------	------

continued

Table 4. Continued.

	Seed treatments	Foliar fungicide and insecticide applications			
Field location by county	Fungicide and/or insecticide seed treatment for control of diseases and insects attacking seedling rice	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)--			
Poinsett	------	------	------	------	-------
Prairie	RTST	------	------	------	-------
Randolph	CruiserMaxx Rice (7 fl oz)	------	------	------	-------
White	Apron XL (0.64 fl oz/cwt seed) + Release LC (2 fl oz/cwt seed)	Tide Propiconazole (6 oz) + Quadris (10 oz)	------	------	-------

[a] RTST refers to RiceTec Seed Treatment and is used to define those fields whose seed was treated by RiceTec, Inc. prior to seed purchase. Seed was treated with compounds intended to enhance germination and early-season plant growth.

Table 5. Rainfall and irrigation information for fields enrolled in the 2012 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + irrigation
	(inches)	(acre-inches)	(inches)
Arkansas 1	6.60	20.00	26.60
Arkansas 2	10.00	30.00*	40.00
Arkansas 3	5.45	30.00*	35.45
Chicot 1	14.70	43.50	58.20
Chicot 2	15.30	18.00	33.30
Clark	5.25	30.00*	35.25
Clay	8.35	30.00*	38.35
Conway	3.88	30.00*	33.88
Craighead	5.74	30.00*	35.74
Cross	7.29	24.26	31.55
Desha	13.40	30.00*	43.40
Independence	7.95	30.00*	37.95
Jackson	9.07	30.00*	39.07
Jefferson	18.30	17.50	35.80
Lee	10.40	32.00	42.40
Lincoln	7.85	40.00	47.85
Phillips	3.00	30.00*	33.00
Poinsett	7.77	30.00*	37.77
Prairie	9.48	30.00*	39.48
Randolph	8.19	30.00*	38.19
White	10.65	45.32	55.97
Average	8.98	30.02	39.00

[a] Not all fields were equipped with flow meters to monitor water use for irrigation. Therefore, the average irrigation amount used in fields with flow meters was calculated and this average was used for fields with no irrigation data. Irrigation amounts using this calculated average are followed by an asterisk (*).

Table 6. Summary of revenue and expenses per acre, Rice Research Verification Program, 2012.

Receipts	Arkansas 1	Arkansas 2	Arkansas 3	Chicot 1	Chicot 2	Clark	Clay
	(bu/acre)						
Yield	199	197	180	242	182	146	196
	($)						
Price received	6.75	6.40	6.28	6.15	6.27	4.77	6.09
Total crop revenue	**1,343.72**	**1,260.51**	**1,131.07**	**1,488.26**	**1,141.90**	**696.80**	**1,194.12**
Operating expenses							
Seed	145.98	37.72	49.84	63.97	47.70	20.30	121.75
Fertilizers and nutrients	185.71	203.24	211.02	131.12	191.50	191.39	150.27
Chemicals	93.90	113.98	102.42	102.79	98.83	70.43	43.90
Custom applications	57.80	42.00	63.00	23.10	63.00	51.80	47.00
Fuel and lube	28.62	29.86	34.53	28.35	28.99	24.75	28.14
Repairs and maintenance	23.63	27.11	28.92	29.92	26.95	25.67	27.49
Irrigation energy costs	16.15	9.37	122.60	177.77	14.53	24.22	120.48
Labor, field activities	7.91	8.81	10.06	8.41	8.16	7.50	9.61
Other inputs and fees, pre-harvest	13.71	19.69	22.88	19.98	12.03	17.83	26.07
Post-harvest expenses	116.12	114.95	105.03	141.21	106.20	85.19	114.37
Total operating expenses	**689.53**	**606.73**	**750.31**	**726.63**	**597.88**	**519.09**	**689.09**
Returns to operating expenses	**654.19**	**653.77**	**380.77**	**761.63**	**544.02**	**177.71**	**505.03**
Capital recovery and fixed costs	81.41	89.06	103.67	113.80	84.79	93.46	100.47
Total specified expenses[a]	**770.94**	**695.80**	**853.97**	**840.43**	**682.68**	**612.54**	**789.56**
Returns to specified expenses	**572.79**	**564.71**	**277.10**	**647.83**	**459.22**	**84.25**	**404.56**
Operating expenses/yield unit	3.46	3.08	4.17	3.00	3.29	3.56	3.52
Total expenses/yield unit	3.87	3.53	4.74	3.47	3.75	4.20	4.03

continued

Table 6. Continued.

Receipts	Conway	Craighead	Cross	Desha	Independence	Jackson	Jefferson
	(bu/acre)						
Yield	211	196	162	172	221	171	198
	($)						
Price received	6.08	6.11	6.54	5.43	8.12	5.93	6.94
Total crop revenue	**1,283.49**	**1,197.87**	**1,059.80**	**933.96**	**1,794.03**	**1,014.01**	**1,374.85**
Operating expenses							
Seed	98.92	60.20	52.85	149.04	40.54	50.67	110.40
Fertilizers and nutrients	92.48	214.33	93.84	89.35	159.68	214.06	127.11
Chemicals	65.86	48.54	89.54	81.56	72.85	91.82	100.27
Custom applications	33.00	35.00	56.00	64.80	50.50	63.10	50.90
Fuel and lube	28.09	33.85	24.60	22.07	25.75	32.81	31.26
Repairs and maintenance	28.37	29.93	22.25	24.88	27.82	25.96	27.12
Irrigation energy costs	24.22	122.60	38.35	24.22	24.22	51.94	71.52
Labor, field activities	8.29	10.58	7.77	6.21	7.69	10.67	10.74
Other inputs and fees, pre-harvest	9.29	31.87	15.56	11.32	16.83	19.38	20.60
Post-harvest expenses	123.12	114.37	94.53	100.36	128.95	99.78	115.53
Total operating expenses	**511.65**	**701.27**	**495.29**	**573.82**	**554.82**	**660.19**	**665.45**
Returns to operating expenses	**771.84**	**496.60**	**564.51**	**360.14**	**1,239.21**	**353.82**	**709.40**
Capital recovery and fixed costs	104.29	105.75	70.12	90.12	97.57	86.30	88.21
Total specified expenses[a]	**615.93**	**807.03**	**565.42**	**663.94**	**652.39**	**746.49**	**753.66**
Returns to specified expenses	**667.55**	**390.84**	**494.38**	**270.02**	**1,141.64**	**267.51**	**621.18**
Operating expenses/yield unit	2.42	3.58	3.06	3.34	2.51	3.86	3.36
Total expenses/yield unit	2.92	4.12	3.49	3.86	2.95	4.37	3.81

continued

Table 6. Continued.

Receipts	Lee	Lincoln	Philips	Poinsett	Prairie	Randolph	White	Average
	(bu/acre)							
Yield	196	176	178	197	193	184	146	188
	($)							
Price received	6.09	5.72	6.28	7.83	6.43	6.24	6.26	6.32
Total crop revenue	**1,194.12**	**1,006.62**	**1,118.50**	**1,543.09**	**1,240.45**	**1,147.41**	**913.24**	**1,194.00**
Operating expenses								
Seed	12.95	111.87	162.55	22.62	135.34	108.44	33.01	77.94
Fertilizers and nutrients	212.52	175.80	244.62	160.03	199.41	104.53	172.22	167.82
Chemicals	84.42	106.81	71.83	98.12	59.07	39.59	87.61	82.10
Custom applications	52.90	52.90	53.60	60.00	54.00	44.50	56.10	51.19
Fuel and lube	24.31	28.02	24.53	28.85	22.18	29.30	35.94	28.32
Repairs and maintenance	23.23	28.05	21.77	27.97	21.39	27.56	28.79	26.42
Irrigation energy costs	50.58	163.47	47.42	24.22	47.42	122.60	78.46	65.54
Labor, field activities	7.82	8.18	7.22	7.79	7.53	9.77	11.38	8.67
Other inputs and fees, pre-harvest	24.75	24.17	21.96	18.90	28.60	23.68	21.95	20.05
Post-harvest expenses	114.37	102.70	103.86	114.95	112.62	107.36	85.19	109.56
Total operating expenses	**607.84**	**801.97**	**759.36**	**563.45**	**687.56**	**617.33**	**610.65**	**637.61**
Returns to operating expenses	**586.28**	**204.65**	**359.14**	**979.64**	**552.89**	**530.08**	**302.58**	**556.57**
Capital recovery and fixed costs	76.63	106.81	72.07	99.55	70.84	98.50	105.87	92.35
Total specified expenses[a]	**684.47**	**908.77**	**831.43**	**663.00**	**758.40**	**715.83**	**716.52**	**729.96**
Returns to specified expenses	**509.65**	**97.85**	**287.08**	**880.09**	**482.05**	**431.57**	**196.72**	**464.22**
Operating expenses/yield unit	3.10	4.56	4.27	2.86	3.56	3.36	4.18	3.43
Total expenses/yield unit	3.49	5.16	4.67	3.37	3.93	3.89	4.91	3.93

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

Table 7. Operating costs, total costs, and returns for the 2012 Rice Research Verification Program.

County	Operating costs	Operating costs	Returns to operating costs	Fixed costs	Total costs	Returns to total costs	Total costs
	($/acre)	($/bu)	($/acre)		($/acre)		($/bu)
Arkansas 1	689.53	3.46	654.19	81.41	770.94	572.79	3.87
Arkansas 2	606.73	3.08	653.77	89.06	695.80	564.71	3.53
Arkansas 3	750.31	4.17	380.77	103.67	853.97	277.10	4.74
Chicot 1	726.63	3.00	761.63	113.80	840.43	647.83	3.47
Chicot 2	597.88	3.29	544.02	84.79	682.68	459.22	3.75
Clark	519.09	3.56	177.71	93.46	612.54	84.25	4.20
Clay	689.09	3.52	505.03	100.47	789.56	404.56	4.03
Conway	511.65	2.42	771.84	104.29	615.93	667.55	2.92
Craighead	701.27	3.58	496.51	105.75	807.11	390.76	4.12
Cross	495.29	3.06	564.51	70.12	565.42	494.38	3.49
Desha	573.82	3.34	360.14	90.12	663.94	270.02	3.86
Independence	554.82	2.51	1,239.21	97.57	652.39	1,141.64	2.95
Jackson	660.19	3.86	353.82	86.30	746.49	267.51	4.37
Jefferson	665.45	3.36	709.40	88.21	753.66	621.18	3.81
Lee	607.84	3.10	586.28	76.63	684.47	509.65	3.49
Lincoln	801.97	4.56	204.65	106.81	908.77	97.85	5.16
Phillips	759.36	4.27	359.14	72.07	831.43	287.08	4.67
Poinsett	563.45	2.86	979.64	99.55	663.00	880.09	3.37
Prairie	687.56	3.56	552.89	70.84	758.40	482.05	3.93
Randolph	617.33	3.36	530.08	98.50	715.83	431.57	3.89
White	610.65	4.18	302.58	105.87	716.52	196.72	4.91
Average	637.61	3.43	556.56	92.35	729.97	464.22	3.93

Table 8. Selected variable input costs per acre from fields in the 2012 Rice Research Verification Program.

County	Rice variety	Seed	Fertilizers	Herbicides	Insecticides	Fungicides and other	Machinery fuel and lube	Irrigation energy costs
Arkansas 1	CLXL745	145.98	185.71	65.24	5.73	22.93	28.62	16.15
Arkansas 2	Roy J	37.72	203.24	106.48		7.50	29.86	9.37
Arkansas 3	CL151	49.84	211.02	80.15		22.27	34.53	122.60
Chicot 1	CL151	63.97	131.12	82.46		20.34	28.35	177.77
Chicot 2	CL111	47.70	191.50	76.67		22.16	28.99	14.53
Clark	Francis	20.30	191.39	62.86	4.58	3.00	24.75	24.22
Clay	RTXL753	121.75	150.27	43.90			28.14	120.48
Conway	RTXL753	98.92	92.48	62.93	2.93		28.09	24.22
Craighead	Roy J	60.20	214.42	45.54		3.00	33.85	122.60
Cross	CL151	52.85	93.84	61.46	5.15	22.93	24.60	38.35
Desha	CLXL745	150.00	93.43	75.83	5.73		22.07	24.22
Independence	Jupiter	40.54	159.68	66.90		5.95	25.75	24.22
Jackson	Taggart	50.67	214.06	91.82			32.81	51.94
Jefferson	RT XL753	110.40	127.11	100.27			31.26	71.52
Lee	Roy J	12.95	212.52	55.47		28.95	24.31	50.58
Lincoln	RTXL753	111.87	175.80	87.51		19.30	28.02	163.47
Phillips	CLXL745	162.55	244.62	71.83			24.53	47.42
Poinsett	Jupiter	22.62	160.03	98.12			28.85	24.22
Prairie	CLXL745	135.34	199.41	59.07			22.18	47.42
Randolph	RTXL723	108.44	104.53	33.64		5.95	29.30	122.60
White	Taggart	33.01	172.22	48.71		38.90	35.94	78.46
Average		**77.98**	**168.02**	**70.33**	**4.82**	**17.17**	**28.32**	**65.54**

OVERVIEW AND VERIFICATION

Trends in Arkansas Rice Production

J.T. Hardke and C.E. Wilson Jr.

ABSTRACT

Arkansas is the leading rice-producing state in the United States. The state represents 48.1% of total U.S. rice production and 47.8% of the total acres planted to rice in 2012. 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.

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 was obtained from the USDA National Agricultural Statistics Service (http://www.nass.usda.gov). Rice variety distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture Rice DD50 program enrollment.

RESULTS AND DISCUSSION

Rice acreage by county is presented in Table 1 with distribution of the most widely produced cultivars. RiceTec CL XL745 was the most widely planted cultivar in 2012 at 27.5% of the acreage, followed by CL151 (12.7%), RiceTec CL XL729 (11.1%), RiceTec XL723 (9.5%), Jupiter (7.3%), Roy J (6.2%), and Wells (5.9%). Additional cultivars of importance in 2012, though not shown in the table, were CL111, CL152, Francis, and RiceTec XL753.

There were 1,291,000 acres of rice planted in Arkansas in 2012 which accounted for 47.8% of the total U.S. rice crop in 2012 (Table 2). The state-average yield of 7,470 lb/acre (166 bu/acre) was a new state record yield and bested the previous record set in 2007 of 7,230 lb/acre (161 bu/acre). In addition, the 2012 average yield was a 10% increase in average yield from the 2011 crop. The average yields in Arkansas represented the third highest average in the U.S. behind California and Texas. Lower yields observed in 2010 can be attributed to early-season flooding, excessively hot and dry conditions during July and August, and an unusually large acreage causing some rice to be grown on marginal land and/or with marginal irrigation capacity. The total rice produced in Arkansas during 2012 was 95.9 million hundredweight (cwt). This represents 48.1% of the 199.4 million cwt produced in the U.S. during 2012. Arkansas was the only state to drastically increase overall production compared to 2011 (19.0% increase). Over the past 3 years, Arkansas has produced 46.2% of all rice produced in the U.S. The five largest rice-producing counties in Arkansas during 2012 included Poinsett, Lawrence, Arkansas, Greene, and Lonoke, representing 35.0% of the state's total rice acreage (Table 1).

Planting in 2012 was well ahead of the 5-year state average due to warm, dry conditions during the end of March and early April (Fig. 1). Planting progress reached 92% by 29 April in 2012 compared to an average of 50% planting progress by this date in previous years. Planting was almost fully complete by 13 May. The early planting, combined with hot, dry conditions throughout the summer also resulted in an early harvest (Fig. 2). About 84% of the crop was harvested by 23 Sept compared with 50%

harvest progress on the same date in previous years. Harvest progress was nearly complete (98%) by 14 Oct while harvest usually extends to 11 Nov.

Approximately 55% of the rice produced in Arkansas was planted using conventional tillage methods in 2012 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. This is a slight increase compared to previous years. True no-till rice production is not common but is done in a few select regions of the state. According to the survey, no-till rice production has remained relatively static at ~10%.

The majority (52.8%) of rice is still produced on silt loam soils (Table 3). Rice production on clay or clay loam soils (20.8% and 22.0%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil texture present unique challenges in rice production such as tillage, seeding rates, fertilizer management, and irrigation.

Rice most commonly follows soybean in rotation and accounts for about 71% of the rice acreage in 2012 (Table 3). Approximately 24% of the acreage was planted following rice, with the remaining 4% 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 approximately 5% using a water-seeded system. In 2012, approximately 80% of all the Arkansas rice acreage was drill-seeded with the remaining 20% 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 76.8% of the rice acreage in Arkansas in 2012 with the remaining 23.2% irrigated with surface water obtained from reservoirs, streams, and/or bayous (Table 3).

During the mid-1990s, 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 2012, rice farmers utilize this practice on 38.5% of the rice acreage. About 62% of rice is still irrigated with conventional levee and gate systems. A small percentage of rice acreage is produced in more upland conditions utilizing furrow or overhead irrigation systems.

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 2012, approximately 25.5% of the acreage was burned, 38.5% was tilled, 22.5% was rolled, and 18.0% 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.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 46.2% of rice acres in 2012. This number would have likely been higher were it not for a lack of rainfall and sustained high temperatures throughout the season which kept disease pressure relatively low. Only 29.0% of rice acres received a foliar insecticide application due to rice stink bug infestation levels which were notably lower in 2012 than in previous years. Insecticide seed treatments were used on 58.1% of rice acreage as producers continue to adopt this technology more widely 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 59% of the total rice acreage in 2012 (Fig. 3). This represents a 10% decrease in Clearfield rice acreage compared to 2011 and is only the second year since 2001 that plantings of Clearfield cultivars have decreased from the previous year. 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.

SIGNIFICANCE OF FINDINGS

During the past 20 years, the state average yields in Arkansas have increased approximately 1,970 lb/acre (about 44 bu/acre) or 2.2 bu/acre/year. 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, 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

The authors would like to extend thanks to all of the county agents who participated in this study and the rice farmers of Arkansas who provide support through the rice check-off program.

LITERATURE CITED

USDA-FSA. 2013. United States Department of Agriculture Farm Service Agency. Accessed: Feb. 1, 2013. http://www.fsa.usda.gov/FSA/webapp?area=newsroom&subject=landing&topic=foi-er-fri-cad

USDA-NASS. 2013. United States Department of Agriculture National Agricultural Statistics Service. Accessed: 1 Feb. 2013. http://quickstats.nass.usda.gov/

Table 1. 2012 Arkansas harvested rice acreage summary by county and cultivar.

	Harvested acreage[a]		Medium-grain		
County	2011	2012	CL261	Jupiter	Others[b]
Arkansas	90,106	88,891	1,113	6,154	527
Ashley	9,476	7,432	0	0	0
Chicot	26,981	26,443	0	0	0
Clay	59,946	77,474	599	6,243	0
Conway	1,237	1,715	0	0	0
Craighead	65,831	67,871	0	5,770	0
Crittenden	22,215	31,673	1,380	2,534	0
Cross	73,681	71,825	0	2,540	0
Desha	16,970	14,358	0	313	0
Drew	7,921	8,529	0	0	0
Faulkner	2,412	2,685	0	0	0
Greene	57,797	79,625	1,000	1,356	0
Independence	6,382	11,632	0	264	0
Jackson	68,905	76,208	1,606	12,282	0
Jefferson	57,199	59,832	0	647	0
Lafayette	2,011	2,676	0	0	0
Lawrence	91,045	96,131	5,371	9,166	0
Lee	11,570	18,372	0	90	0
Lincoln	19,372	18,441	0	0	0
Lonoke	77,783	77,697	624	2,933	0
Mississippi	24,888	34,093	91	400	0
Monroe	42,512	50,141	301	3,413	0
Phillips	18,345	16,140	0	47	0
Poinsett	98,692	106,696	1,076	21,165	0
Prairie	53,244	54,432	221	7,035	0
Pulaski	4,375	3,333	0	0	0
Randolph	30,608	34,028	0	6,710	0
St. Francis	32,413	30,283	0	2,979	0
White	9,142	12,348	0	405	0
Woodruff	44,196	53,219	637	1,274	0
Others[c]	5,929	6,370	0	0	0
Unaccounted[d]	21,818	39,407			
2012 Total		1,280,000	14,019	93,719	527
2012 Percent		100	1.10	7.32	0.04
2011 Total	1,155,000		65,359	151,551	15,644
2011 Percent	100		5.66	13.12	1.35

continued

Table 1. Continued.

	Long-grain							
County	CL111	CL151	CLXL729	CLXL745	XL723	Roy J	Wells	Others[b]
Arkansas	1,420	4,969	6,566	30,522	14,995	7,010	2,307	13,309
Ashley	0	0	2,532	958	0	0	0	3,943
Chicot	2,138	1,425	5,806	10,239	158	2,481	0	4,196
Clay	2,042	17,356	5,290	25,803	10,488	0	6,404	3,249
Conway	0	893	0	0	0	0	415	406
Craighead	7,846	18,443	0	16,028	402	14,016	3,957	1,408
Crittenden	0	2,481	436	11,633	5,699	2,883	1,039	3,587
Cross	9,294	13,589	2,394	24,855	3,873	3,661	4,718	6,900
Desha	2,247	492	1,348	3,483	1,124	0	0	5,351
Drew	0	0	4,916	3,556	28	0	0	28
Faulkner	0	0	332	403	106	855	868	121
Greene	1,159	12,054	27,817	15,686	6,954	695	8,345	4,559
Independence	0	1,076	2,603	946	0	0	0	6,743
Jackson	219	10,136	9,553	19,543	5,250	11,959	1,386	4,230
Jefferson	0	0	3,018	23,852	25,627	0	0	6,688
Lafayette	107	642	268	803	0	187	0	482
Lawrence	9,009	11,569	6,757	30,611	2,150	3,890	5,119	12,490
Lee	0	1,409	0	8,546	0	2,086	0	6,240
Lincoln	0	0	2,748	9,202	2,508	2,950	1,033	0
Lonoke	393	2,984	12,330	35,970	6,047	3,848	550	12,016
Mississippi	0	7,071	0	1,818	9,528	0	14,040	1,145
Monroe	2,298	1,253	1,932	11,489	8,356	1,515	5,484	14,101
Phillips	0	0	5,681	8,144	0	0	0	2,269
Poinsett	1,462	25,078	10,346	14,057	3,261	9,784	10,233	10,233
Prairie	2,701	3,758	8,514	19,611	1,820	2,525	470	7,750
Pulaski	167	767	400	1,333	0	333	333	0
Randolph	1,310	10,875	4,291	2,719	7,370	753	0	0
St. Francis	2,513	6,155	0	169	791	4,179	2,993	10,503
White	251	549	3,305	5,727	1,122	0	0	990
Woodruff	3,396	6,367	12,044	12,999	3,449	2,653	5,677	4,722
Others[c]	338	571	633	1,485	458	400	312	2,172
Unaccounted[d]			39,407					
2012 Total	50,309	161,963	141,861	352,192	121,566	78,665	75,682	189,240
2012 Percent	3.93	12.65	11.08	27.52	9.50	6.15	5.91	14.78
2011 Total	34,394	140,049	79,137	332,955	35,601	23,724	73,809	202,777
2011 Percent	2.98	12.13	6.85	28.83	3.08	2.09	6.39	17.52

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

[b] Other varieties: Arize QM1003, CL111, CL131, CL142-AR, CL152, CL161, CL261, Catahoula, Cheniere, Cocodrie, Cypress, Dellrose, Francis, Jasmine, Jazzman, Neptune, Presidio, RiceTec CLXL746, RiceTec XL753, RiceTec CLXP4534, RiceTec XP4523, Spring, Taggart, and Templeton.

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

[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and preliminary estimates obtained from each county FSA (USDA-FSA, 2013).

Table 2. Acreage, grain yield, and production of rice in the United States from 2010 to 2012.[a]

	Area planted			Area harvested			Yield			Production		
State	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
	(1,000 acres)						(lb/acre)			(1,000 cwt[b])		
Arkansas	1,791	1,196	1,291	1,785	1,154	1,285	6,480	6,770	7,470	115,675	78,100	95,922
California	558	585	561	553	580	556	8,020	8,350	8,110	44,326	48,402	45,070
Louisiana	540	423	402	535	418	397	6,100	6,320	6,430	32,625	26,430	25,540
Mississippi	305	160	130	303	157	129	6,850	6,850	7,200	20,756	10,755	9,288
Missouri	253	143	180	251	128	177	6,480	6,490	6,990	16,254	8,308	12,372
Texas	189	182	135	188	180	134	7,160	7,190	8,370	13,468	12,946	11,217
U.S.	3,636	2,689	2,699	3,615	2,617	2,678	6,725	6,995	7,428	243,104	184,941	199,409

[a] Source: USDA-NASS, 2013.

[b] cwt = hundredweight.

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

	2010		2011[b]		2012	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Arkansas rice acreage	1,785,000	100.00	----	----	1,235,510	0.00
Soil texture						
Clay	421,048	23.6	----	----	237,243	20.8
Clay loam	368,753	20.7			271,847	22.0
Silt loam	947,311	53.1			651,841	52.8
Sandy loam	43,478	2.4			45,978	3.7
Sand	3,530	0.2			8,601	0.7
Tillage practices						
Conventional	1,253,005	70.2	----	----	687,176	55.8
Stale seedbed	388,184	21.			428,326	34.7
No-till	139,403	7.8			118,007	9.6
Crop rotations						
Soybean	1,267,226	71.0	----	----	881,007	71.3
Rice	373,008	20.9			299,374	24.2
Cotton	15,192	0.9			3,076	0.2
Corn	41,277	2.3			33,686	2.7
Grain sorghum	7,803	0.4			6,268	0.5
Wheat	3,439	0.2			1,729	0.1
Fallow	12,478	0.7			10,369	0.8
Other	0	0.0			0	0.0
Seeding methods						
Drill seeded	1,244,919	69.7	----	----	985,525	79.8
Broadcast seeded	487,386	27.3			249.975	20.2
Water seeded	92,064	5.2			63,442	5.1
Irrigation water sources						
Groundwater	1,395,155	78.2	----	----	949,141	76.8
Stream, rivers, etc.	181,883	10.2			159,240	12.9
Reservoirs	182,082	10.2			127,127	10.3
Irrigation methods						
Flood, levees	953,821	53.4	----	----	754,867	61.1
Flood, multiple inlet	804,524	45.1			476,279	38.5
Furrow	9,810	0.5			4,156	0.3
Sprinkler	1,340	0.1			206	0.0
Stubble management						
Burned	782,838	43.9	----	----	315,077	25.5
Tilled	898,870	50.4			475,526	38.5
Rolled	790,564	44.3			278,064	22.5
Winter flooded	265,562	14.9			222,703	18.0
Land management						
Contour levees	838,815	47.0	----	----	416,053	33.7
Precision-level	822,441	50.4			691,653	56.0
Zero-grade	123,743	6.9			127,799	10.3
Precision agriculture						
Yield monitors	498,711	27.9	----	----	719,870	58.3
Grid sampling	189,995	10.6			299,701	24.3
Variable-rate fertilizer	161,817	9.1			276,191	22.4

continued

Table 3. Continued.

	2010		2011[b]		2012	
Cultural practice	Acreage	% of total	Acreage	% of total	Acreage	% of total
Pest management						
Fungicide (foliar application)	949,735	53.2	----	----	570,857	46.2
Insecticide (foliar application)	798,647	44.7			358,876	29.0
Insecticide seed treatment	----	----			717,708	58.1

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

[b] Survey used to generate data contained in this table was not conducted in 2011.

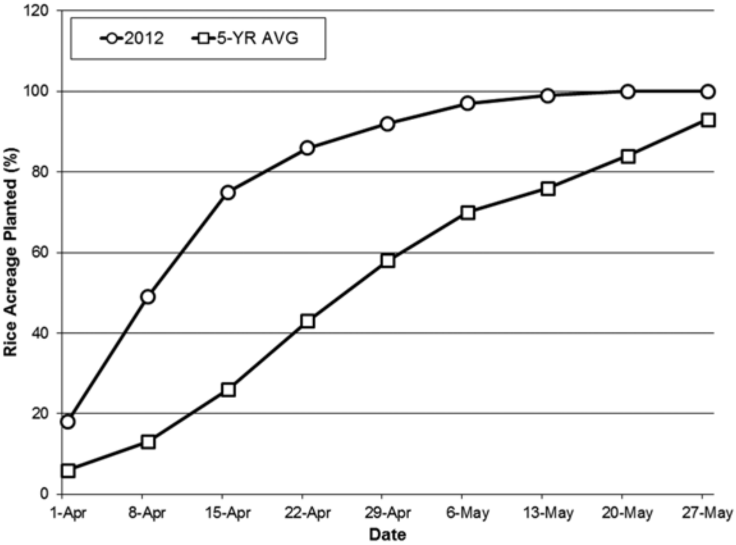


Fig. 1. Arkansas rice planting progress during 2012 compared to the five-year state average (NASS, 2013).

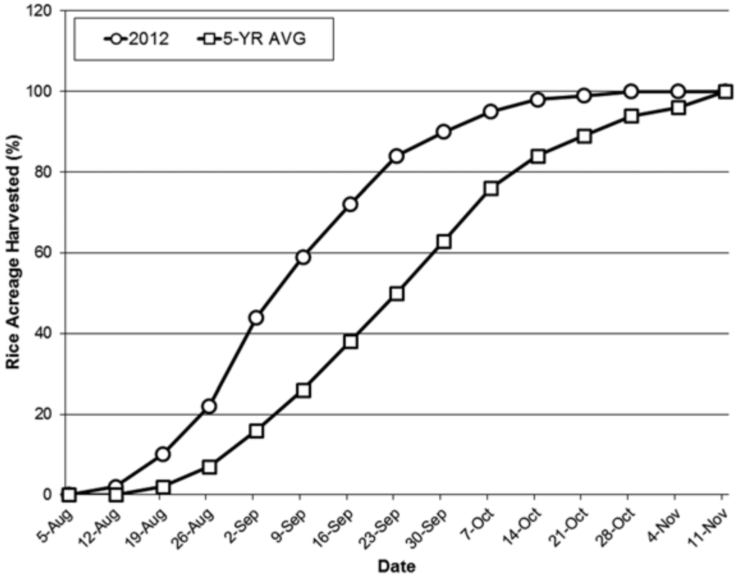


Fig. 2. Arkansas rice harvest progress during 2012 compared to the five-year state average (NASS, 2013).

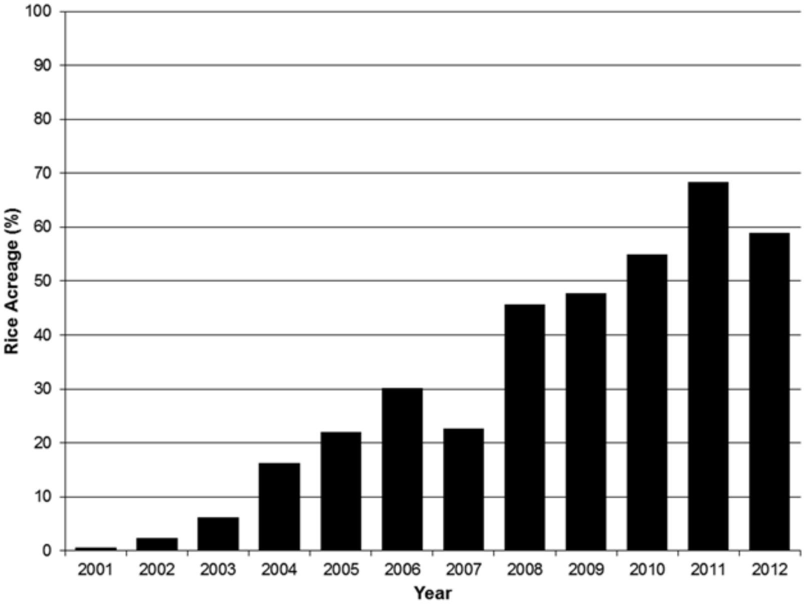


Fig. 3. Percentage of rice planted in Arkansas to Clearfield rice cultivars between 2001 and 2012.

Development of Aromatic Rice Varieties

D.K. Ahrent, K.A.K. Moldenhauer, C.W. Wilson Jr., and C. Grimm

ABSTRACT

The University of Arkansas System Division of Agriculture Aromatic Rice Breeding Program at the Rice Research and Extension Center (RREC), Stuttgart, Ark., was implemented to develop aromatic rice varieties for the southern rice-producing regions. Evaluating cultural practices is essential for the selection of the best lines in the breeding program as well as for developing grower recommendations. Information regarding successful cultural practices of aromatic rice varieties is very limited for the southern United States growing regions, and especially for Arkansas. Beginning in 2010, an experiment was established at the RREC to determine the effect of different nitrogen (N) fertilizer rates on the aroma and yield of aromatic rice varieties. In this test, six N rates were applied to seven aromatic rice varieties and one non-aromatic rice variety. Agronomic and yield data were collected. Hulled and milled seed were tested for the analysis of 2-acetyl-1-pyrroline (2a-p) concentration conducted at USDA-ARS Southern Regional Research Center, New Orleans, La. Results of the yield trials showed mixed varietal response to increased N fertilizer. Some varieties increased in yield while others remained unchanged or decreased with increased N fertilization. Total rice percentages from the first two years of the study varied significantly across varieties.

INTRODUCTION

Approximately 12.9 million cwt of milled rice were imported to the United States in the fiscal year 2010/2011 (USA Rice Federation, 2011). The top exporting countries are Thailand, which produces high quality Jasmine rice, and India, which produces highly desired Basmati rice (USA Rice Federation, 2011). United States consumers are purchasing more aromatic or specialty rices and the overseas markets cannot meet the demand. It has been difficult for U.S. producers to grow the true Jasmine and Basmati varieties due to environmental differences, photoperiod sensitivity, fertilizer sensitivity, and low yields, thus making aromatic rice a valuable commodity. Adapted aromatic rice varieties need to be developed for Arkansas producers which meet the taste requirements for either Jasmine-type or Basmati-type rice. International research on aromatic rice and N fertilizer indicate that genotype differences in N-use efficiency exists. Two international studies found excess N fertilizer had no effect on grain yield in native aromatic rice cultivars. Research needs to be directed to determine what type of Arkansas soils will produce the best aromatic rice and what is the optimum fertility to produce the best milling quality which will meet the consumers' demands.

PROCEDURES

The aromatic rice breeding program collected parental material from the U.S. breeding programs and the USDA World Collection. Crosses were made to incorporate traits for aroma, yield, improved plant type, superior quality, and broad-based disease resistance. The winter nursery in Puerto Rico is being employed to accelerate generation advance of potential varieties for testing in Arkansas during the summer of 2013. In 2012, 151 heterozygous lines from nine F_4 populations were screened through marker-assisted selection for aroma and amylose content.

A three-year Aromatic Rice by Nitrogen Rate study began in 2010 to help determine the fertility requirements of the various aromatic rice varieties for optimum aroma quality and yield. Eight rice lines: Dellrose, Jasmine 85, Jazzman, Jazzman II, JES, Sierra, Wells, and two University of Arkansas experimental lines were treated with six different N rates: 0, 30, 60, 90, 120, and 150 lb/acre. In 2011, one experimental line was removed from the experiment because it was determined by genetic marker analysis to be non-aromatic. The non-aromatic experimental line was replaced with Jazzman II. Typical plant characteristic data was collected including heading date, plant height, and lodging. The weight and moisture content of each plot was recorded. Hulled and milled seed samples from each plot were tested for the analysis of the aroma compound 2-acetyl-1-pyrroline (2a-p) concentration, which was conducted at the USDA-ARS Southern Regional Research Center, New Orleans, La.

RESULTS AND DISCUSSION

In 2012, seven cross-pollinations were made to produce aromatic lines for screening. The F_1 plants from these crosses will be grown in the greenhouse during the winter to produce F_2 seed. The F_2 populations will be planted in 2013 at RREC for observation and selection.

Panicles were selected from 43 F_2 populations in 2012. The parents in these crosses were selected for their aromatic or high seed quality or high yield potential. Approximately 1,650 F_3 lines from 41 populations were shipped to the winter nursery in Puerto Rico to advance. The harvested seed from Puerto Rico will be planted at RREC for further observation and selection in 2013. Marker analysis will be conducted to detect or determine the characteristics of aroma, cooking quality, and blast resistance.

Results of the marker-assisted selections of 151 lines from nine F_4 populations screened in 2012 for aroma and amylose content helped to eliminate lines which did not meet the breeding program requirements. Approximately 33% of the entries were homozygous aromatic and had desirable cooking quality (Boyett et al., 2013). Ten percent of the lines were discarded due to non-parental alleles.

Results of the 2010 Aromatic Rice by Nitrogen Rate study showed grain yield responses to increased N fertilizer differed among varieties. Dellrose, Jazzman, and Sierra appeared to be the least affected by the additional fertilizer with Sierra having the lowest overall yield. STG03-085 had the highest yield with 90 lb N/acre and had the highest overall yield across the varieties. The yields of JES, Jasmine 85, STG06-126, and Wells increased with increasing levels of applied N.

Total rice percentages for 2010 resulted in significant differences across varieties and across nitrogen fertilizer treatments. JES had the lowest and Jazzman had the highest overall percentage of total rice. The lowest percentage of total rice was found in all varieties receiving 0 lb N/acre and the highest percentage was at the 150 lb N/acre rate.

Results of the 2011 Aromatic Rice by Nitrogen Rate study showed grain yield response to N rates varied among the varieties. Dellrose, Jasmine 85, and STG03-085 grain yields decreased with increased N. STG03-085 had the lowest yields across all varieties. Jazzman and Wells responded with increasing yields to the additional N. Jazzman II, JES, and Sierra had no significant yield changes across the N rates. The non-aromatic control, Wells, had the highest yield in the 2011 test, followed by JES.

Total rice percentages for 2011 were significantly different across varieties but not across N fertilizer treatments. STG03-085 had the lowest and Sierra had the highest overall percentage of total rice.

Results of the 2012 Aromatic Rice by Nitrogen Rate study showed grain yield responses of all varieties increased beginning at 60 lb N/acre. There was no significant difference in the yields of plots receiving 0 and 30 lb N/acre. There was no significant difference in the yields of plots receiving 60, 90, 120, and 150 lb N/acre. Sierra and Dellrose appeared to be the least affected by increased N fertilizer applications, with Sierra having the lowest yield. STG-085 had the highest yield with 90 lb N/acre and had the highest yield in this year's experiment although there was no significant difference in the yield of STG-085 and Jasmine 85. Jazzman yields ranked third in this year's experiment. There was no significant difference in the yields of Wells, Jazzman II, and JES. Milling results were not available at publication deadline.

ACKNOWLEDGMENTS

The authors appreciate the financial support of the rice producers of Arkansas through monies administered by the Arkansas Rice Research and Promotion Board. We thank Virginia Boyett, Veronica Booth, and Vetress Thompson for conducting marker analysis. We thank Donna Frizzell for planting experiment, Chuck Pipkins for planting and fertilizing experiment. We thank Merle Anders for statistical assistance.

LITERATURE CITED

Boyett, V.A., V. Booth, V. Thompson, K.A.K. Moldenhauer, D. Ahrent, J. Bulloch, H. Sater, and S.Pinson. 2013. Molecular genetics at the University of Arkansas Rice Research and Extension Center. *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 609:60-63. Fayetteville.

USA Rice Federation. 2011. “U. S. Rice Domestic Usage Report For the Milling Year August 1, 2010 - July 31, 2011.”

BREEDING, GENETICS, AND PHYSIOLOGY

Development of Hybrid Rice Cultivars

G.L. Berger, Z.B. Yan, W.-G. Yan, and C.W. Deren

ABSTRACT

In 2012, hybrid rice was produced on more than 50% of the rice production acreage in Arkansas. Development of high-yielding hybrid rice cultivars is currently ongoing at the Rice Research and Extension Center (RREC). During 2012, 24 experimental hybrids were tested in a replicated yield trial at the RREC. Additionally, eight experimental hybrids were tested in the Arkansas Rice Performance Trial (ARPT) and the Cooperative Uniform Regional Rice Nursery (URRN). Grain yields of 14 of the 24 experimental hybrids tested were 15% to 55% greater than the check cultivar Francis. In the URRN, three promising hybrids were identified and will be advanced for further testing in regional nurseries in 2013. Breeding efforts will continue to focus on the identification of male-steriles and restorers that produce superior hybrids.

INTRODUCTION

The hybrid rice program began in 2010 at the RREC, utilizing over two hundred accessions of diverse germplasm found in the United States Department of Agriculture (USDA) rice core collection (Yan et al., 2011). Germplasm obtained from this collection is very diverse and is representative of rice grown in 30 countries on five continents. Along with diverse germplasm from the world collection, material adapted to Arkansas was used in the development of breeding populations. Male-sterile lines, restorers, and maintainers were developed from this initial germplasm with the overall goal of developing hybrid rice cultivars adapted to Arkansas (Yan et al., 2007 and 2011). Over the past two years selections have been made for agronomic desirability, disease resistance, and grain quality. Ongoing efforts will focus on continued improvement of breeding populations in the program, development of new breeding populations, identification of 2- and 3-line male sterile systems, restorers, maintainers, and superior hybrid combinations.

PROCEDURES

During the 2012 growing season the hybrid rice breeding program tested 24 new hybrid combinations in a replicated study at the RREC in Stuttgart, Ark. Standard agronomic practices were followed based on recommendations for Arkansas. Additionally, eight new hybrid combinations were tested in the ARPT and the URRN. During 2012, the ARPT was grown at the RREC, Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), Newport Research Station (NRS), and a Clay county producer field. The URRN was grown at the RREC; Malden, Missouri; Crowley, Louisiana; Stoneville, Mississippi; and Beaumont, Texas.

Crosses were made utilizing different sterile, maintainer and restorer lines identified in the breeding program. Breeding objectives focused on improved agronomic traits, quality characteristics, disease resistance, and traits important to hybrid seed production. Agronomic traits included decreased plant height, earlier maturation, and improved lodging resistance. Quality characteristics including increased amylose content, decreased chalkiness, and improved gelatinization temperature. Traits important to the production of hybrid seed including large, exerted stigmas for effective cross pollination, restorer genes from unadapted sources, and improved combining ability. Segregating populations were also grown and selections were made.

Isolated hybrid seed production tests were located at two locations at the RREC in 2012. The goal was production of new hybrid combinations from 12 new restorers, five 2-line and, two 3-line male-sterile lines. A total of 108 hybrid combinations were possible from the seed production test, with 87 successful combinations being made. New 2-line and 3-line male steriles were increased and will be used for seed production in 2013.

RESULTS AND DISCUSSION

Experimental hybrids were developed using both 2- and 3-line male sterile systems unique to the University of Arkansas program. Heading dates (days from emergence to heading) for experimental hybrids ranged from 79 days to 95 days (Table 1). For several hybrid combinations, heading dates were similar to those of the check cultivars Francis (79 days) and Wells (84 days). Plant heights ranged from 44 inches to 48 inches, exceeding those of Francis (39 inches) and Wells (37 inches). Commonly, a 15% to 20% grain yield advantage for hybrid rice over traditional inbred cultivars is reported. Grain yields of 14 experimental hybrids tested were 15% to 55% greater than the check cultivar Francis.

In the ARPT test, heading dates for experimental hybrids ranged from 81 days to 93 days which compared favorably with those of Wells (85 days), Roy J (89 days), and Taggart (88 days) (Table 2). Plant heights of experimental hybrids ranged from 45 inches to 49 inches which were comparable with Wells (40 inches), Roy J (41 inches), and Taggart (45 inches). Average grain yields of experimental hybrids ranged from 166 bu/acre to 183 bu/acre which were less than Taggart (199 bu/acre), Wells (205 bu/acre), and Roy J (234 bu/acre). A similar trend was observed for the hybrids when planted in the URRN at the RREC and Beaumont, Texas, station (Table 3). When planted in Mississippi and Louisiana, experimental hybrids produced yields greater than the experimental checks.

Crosses focusing of the development of sterile, maintainer and restorer lines resulted in 763 new combinations, which will be further evaluated in 2013. A total of 7,492 segregating lines were evaluated in six breeding bays at the RREC during 2012, with 5,640 panicles being selected for advancement in 2013. Grain yield of harvested hybrid combinations from seed production ranged from 108.9 lb/acre to 2,254 lb/acre.

SIGNIFICANCE OF FINDINGS

The research presented shows the significant advances made by the hybrid rice breeding program over the past three years. Continued research promises to identify high yielding hybrids adapted to Arkansas.

ACKNOWLEDGMENTS

Funding for this project was supported by the Arkansas Rice Research and Promotion Board. Additional thanks goes to the cooperators of the URRN.

LITERATURE CITED

Yan, W.G., J.N. Rutger, R.J. Bryant, H.E. Bockelman, R.G. Fjellstrom, M.H. Chen, T.H. Tai, and A.M. McClung. 2007. Development and evaluation of a core subset of the USDA rice (*Oryza sativa* L.) germplasm collection. Crop Sci. 47:869-878.

Yan, Z.B., W.G. Yan, C.W. Deren, and A. McClung. 2011. Hybrid rice breeding. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:61-63. Fayetteville.

Table 1. Agronomic data for 24 experimental hybrids and check cultivars grown at the Rice Research and Extension Center in 2012.

Entry	Type	50% heading	Plant height	Grain yield	Grain yield increase[a]
		(days)	(inches)	(lb/acre)	(%)
810S/378	Hybrid	79	46	12183.0	55.7
873A/385	Hybrid	95	48	11871.8	51.7
873A/190	Hybrid	94	48	11467.2	46.5
811S/378	Hybrid	82	45	11249.4	43.7
811S/376	Hybrid	83	47	10736.0	37.2
873A/378	Hybrid	90	46	10424.8	33.2
811S/190	Hybrid	85	47	10160.3	29.8
810S/190	Hybrid	80	47	9958.0	27.2
810S/376	Hybrid	78	47	9911.3	26.6
799S/378	Hybrid	88	45	9600.1	22.7
810S/385	Hybrid	82	44	9393.2	20.0
Arkflor	Check	92	42	9335.6	19.3
799S/190	Hybrid	87	46	9226.7	17.9
873A/376	Hybrid	94	46	9226.7	17.9
811S/385	Hybrid	84	46	8962.2	15.5
805S/378	Hybrid	84	46	8977.8	14.7
805S/376	Hybrid	84	48	8822.2	12.7
799S/385	Hybrid	85	47	8355.4	6.8
805S/190	Hybrid	83	47	8355.4	6.8
800S/376	Hybrid	83	46	8044.2	2.8
800S/378	Hybrid	82	44	7935.3	1.4
805S/385	Hybrid	86	45	7935.3	1.4
800S/190	Hybrid	84	45	7888.6	0.8
Francis	Check	79	39	7826.4	0.0
Wells	Check	84	37	7421.8	-5.2
800S/385	Hybrid	85	44	7312.9	-6.6
799S/376	Hybrid	90	45	6846.1	-12.5

[a] Percent (%) yield increase or decrease relative to the check Francis.

Table 2. Average agronomic performance data from the Arkansas Rice Performance Trials for 8 experimental hybrids and check cultivars in 2012.

Entry	Type	Grain yield[a]	50% heading	Height	Lodging
		(bu/acre)	(days)	(inches)	(%)
RoyJ	Check	234	89	41	3
Wells	Check	205	85	40	36
Taggart	Check	199	88	45	21
873A/190	Hybrid	183	91	49	23
811S/378	Hybrid	179	82	45	45
805S/376	Hybrid	177	82	47	25
811S/376	Hybrid	175	82	46	31
811S/190	Hybrid	173	84	45	38
805S/190	Hybrid	171	81	47	33
873A/378	Hybrid	166	83	46	27
873A/376	Hybrid	157	93	49	26

[a] Data collected from five environments including the Rice Research and Extensions Center (RREC), Stuttgart, Ark.; Northeast Research and Extension Center (NEREC), Keiser, Ark.; Pine Tree Research Station (PTRS); Newport Research Station (NRS); and a Clay county producer field.

Table 3. Grain yield data from the Uniform Rice Regional Nursery for 8 experimental hybrids and check cultivars in 2012.

		Grain yield[a]			
Entry	Type	AR[b]	MS	TX	LA
		------------------------- (lb/acre)			---------------------------
Francis	Check	11989	10195	7894	3917
RoyJ	Check	11325	9853	8165	4811
Taggart	Check	10585	10096	8531	7179
Wells	Check	10428	9986	6998	5237
811S/376	Hybrid	10003	10842	7772	9164
811S/378	Hybrid	9929	11815	7668	11390
873A/190	Hybrid	9775	10722	6575	7280
811S/190	Hybrid	9702	11197	7118	9008
873A/376	Hybrid	9497	11226	5499	8162
805S/376	Hybrid	9104	9009	7428	8191
805S/190	Hybrid	8923	9358	6223	8518
873A/378	Hybrid	8428	9679	4860	8154

[a] Grain yield (lb/acre) from Uniform Rice Regional Nursery (URRN) at multiple environments.

[b] AR = RREC, Stuttgart, Ark.; MS = Stoneville, Miss.; TX = Beaumont, Texas; and LA = Crowley, La.

BREEDING, GENETICS, AND PHYSIOLOGY

Molecular Genetics at the University of Arkansas Rice Research and Extension Center

V.A. Boyett, V. Booth, V. Thompson,
K.A.K. Moldenhauer, D. Ahrent, J. Bulloch, H. Sater, and S. Pinson

ABSTRACT

For more than 12 years the University of Arkansas System Division of Agriculture Rice Research and Extension Center has had a molecular genetics lab to perform DNA marker analysis to assist with the breeding efforts of the center. The molecular genetics lab analyzes several thousand genomic DNA samples each year using markers linked to specific traits for parental screens and DNA marker-assisted selection. Molecular markers spanning the genome and not linked to specific traits are also used for genotyping or fingerprinting rice populations. In 2012, the molecular genetics laboratory analyzed materials from six major projects and some smaller side investigations. These projects included the yearly molecular characterization of new entries of the Working Germplasm Collection (Seed Bank), screening of parental lines for several new backcross populations, marker-assisted selection of F_4 populations for the Aromatic Breeding Program, genotyping of some materials produced in a hybrid breeding effort, genotyping to ensure seed purity in advanced material, and a molecular mapping project to help determine the loci associated with fissure resistance. In all, over 18,600 data points were generated in the analysis of these populations in 2012.

INTRODUCTION

DNA marker analysis can be a useful tool for rice breeders to enhance the germplasm development process. Using DNA markers enables characterization of breeding materials on a level not affected by time or environmental influences. The technology can benefit breeding programs by allowing identification of new genetic resources to increase yields and disease resistance and genotyping of parental materials for these resources prior to use in crossing. Molecular markers can be used to confirm hybridity, track alleles through generations of progeny, select those progeny containing desirable traits, confirm genotype-phenotype correlations, and determine seed purity.

Each year the working germplasm collection receives about 40 new entries. These are screened with molecular markers linked to the rice blast resistance genes *Pi-b, Pi-i, Pi-k*^{h}*, Pi-k*^{s}*, Pi-ta*, and *Pi-z* (Conaway-Bormans et al., 2003; Fjellstrom et al., 2004, 2006; Jia et al., 2004) and the cooking quality traits of amylose content, amylopectin content, starch pasting properties, gelatinization temperature, aroma, and elongation (Bao et al., 2002; Bergman et al., 2001; McClung et al., 2004). This genotype information is made available to the breeders to aid in selecting parents for crosses and predicting the phenotypes of the progeny.

Marker-assisted selection is conducted each year on segregating populations from the Breeding Program. The populations are screened with the molecular markers which were determined to be informative from the parental genotyping data. The information obtained allows the breeder to select material with the desired traits and conserve field resources.

Molecular mapping allows the identification of genomic regions associated with a particular trait of interest. After pinpointing a location in the genome that correlates with a desired phenotype, molecular markers linked to the trait of interest can be developed for future use in the breeding program, increasing the potential of developing germplasm with the trait.

The objective of this ongoing study is to apply DNA marker technology to assist with the projects of the rice breeding program. The goals include (i) identification of novel genetic sources of increased yield potential and disease resistance, (ii) characterizing parental materials on a molecular level for important agronomic traits, (iii) performing DNA marker-assisted selection of progeny to increase efficiency and reduce production time, and (iv) confirming hybridity and eliminating off types.

PROCEDURES

For most DNA marker-assisted selection projects or short-term genotyping projects in which only one generation is being assessed and a short turnaround time for the final data is required, sampling is performed by extracting the DNA from seed embryos. De-hulled seed is placed into 2-ml ScrewCap Mictrotubes or a 96-well block with about twenty 1-mm glass beads per sample. The seed samples are processed in a BeadBeater-96 (BioSpec Products, Bartlesville, Okla.). The endosperm is removed and the embryo is extracted using a Sodium hydroxide/Tween 20 buffer and neutralized with 100mM Tris-HCl, 2 mM EDTA (Xin et al., 2003).

If seed is not available or if the plants need to grow to maturity, then leaf tissue is sampled. Leaf tissue from individually tagged field plants or greenhouse-grown seedlings is collected in manila coin envelopes which are kept in plastic bags on ice until arrival at the molecular genetics lab. The leaf tissue is then stored at -80 °C until sampled.

Quick projects are sampled using a single hole-punch, and total genomic DNA is extracted using the above mentioned alkaline extraction method (Xin et al., 2003). Projects requiring long-term storage of DNA samples or analysis of multiple generations are sampled by freeze drying the tissue in a VirTis Freezemobile 25XL (VirTis Company, Gardiner, N.Y.) prior to extracting the DNA using a modified PEX/CTAB/chloroform extraction method (Williams and Ronald, 1994) which produces a cleaner and more stable DNA sample. Each DNA sample is arrayed in a 96-well format and 2 µl of template is used for each 25 µl polymerase chain reaction (PCR) analysis.

To save on processing and analysis costs, samples are grouped according to the markers that will be run on them minimizing the number of PCR plates required. Polymerase chain reaction is performed with either HEX-, FAM-, or NED-labeled primers by adding template and enough bovine serum albumin and polyvinylpyrrolidone 40 to have final concentrations of 0.1% and 1%, respectively (Xin et al., 2003) and cycling the reactions in a Mastercycler Gradient S thermal cycler (Eppendorf North America, Inc., Westbury, N.Y.). Resulting PCR products are grouped according to allele sizes and dye colors and diluted together with an epMotion 5070 liquid handling robot (Eppendorf North America, Inc., Westbury, N.Y.), separated on an Applied Biosystems 3730 DNA Analyzer, and analyzed using GeneMapper Software (Applied Biosystems, Foster City, Calif.).

RESULTS AND DISCUSSION

In 2012 the working germplasm collection received 44 new entries which were screened with nine markers linked to disease resistance, cooking quality, and plant height. Currently the collection has 375 entries that have been genotyped with at least eight trait-linked markers. The first 178 entries have been genotyped with 27 markers linked to disease resistance and cooking quality.

DNA was extracted from duplicate samples of five bulked seeds of nine aromatic F_4 populations. The samples were analyzed using markers linked to aroma and amylose content, generating data successfully on 151 lines. The breeder was able to select those lines that were homozygous aromatic and had the desired cooking quality allele for continued development of aromatic varieties.

Approximately 850 samples of 10 populations of F_1 hybrids were genotyped with 14 markers to determine seed purity and uniformity. The information enabled the breeder to eliminate off types from further production.

Over 600 samples of three F_2 populations were screened with five markers to assess population structure prior to use in molecular mapping. Only one of the three populations was selected for mapping with an additional 22 markers. The analysis on 13 of the markers was completed by the end of 2012. The goal is to correlate a region of the genome with fissure resistance.

Some small projects to identify off types in growers' fields were performed at the request of University of Arkansas Cooperative Extension Service agronomists or agents. In each case, the data confirmed the grower's suspicion that the plants in question were not the cultivar being grown in that field.

SIGNIFICANCE OF FINDINGS

Applying molecular marker technology to these projects enabled the breeders to eliminate materials that would otherwise waste valuable resources and also helped establish a foundation for future breeding efforts. Employing advanced tools enables the breeders to conquer challenges to germplasm improvement and make all stages of the breeding process more successful.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board and the USDA-ARS for their financial support of this research. We thank A. McClung, R. Fjellstrom, A. Jackson, and M. Jia for promoting the Rice Genomics Program and allowing the use of equipment, facilities and supplies at the Dale Bumpers National Rice Research Center. We thank S. Belmar, M. Blocker, D. Curtis, H. Ellenburg, J. Griffith, and C. Kelsey for their excellent technical assistance.

LITERATURE CITED

Bao, J.S., H. Corke, and M. Sun. 2002. Microsatellites in starch-synthesizing genes in relation to starch physicochemical properties in waxy rice (*Oryza sativa* L.) Theor. Appl. Genet. 105:898-905.

Bergman, C.J., J.T. Delgado, A.M. McClung, and R.J. Fjellstrom. 2001. An improved method for using a microsatellite in the rice *Waxy* gene to determine amylose class. Cer. Chem. 78:257-260.

Conaway-Bormans, C.A., M.A. Marchetti, C.W. Johnson, A.M. McClung, and W.D. Park. 2003. Molecular markers linked to the blast resistance gene *Pi-z* in rice for use in marker -assisted selection. Theor. Appl. Genet. 107:1014-1020.

Fjellstrom, R.G., C.A. Conaway-Bormans, A.M. McClung, M.A. Marchetti, A.R. Shank, and W.D. Park. 2004. Development of DNA markers suitable for marker assisted selection of three Pi genes conferring resistance to multiple *Pyricularia grisea* pathotypes. Crop Sci. 44:1790-1798.

Fjellstrom, R.G., A.M. McClung, and A.R. Shank. 2006. SSR markers closely linked to the *Pi-z* locus are useful for selection of blast resistance in a broad array of rice germplasm. Mol. Breed. 17:149-157.

Jia, Y., M.A. Redus, Z. Wang, and J.N. Rutger. 2004. Development of a SNLP marker from the *Pi-ta* blast resistance gene by tri-primer PCR. Euphytica 138:97-105.

McClung, A.M., M. Chen, H. Bockelman, R. Bryant, W. Yan, and R.G. Fjellstrom. 2004. Characterization of a core collection of rice germplasm and elite breeding lines in the US with genetic markers associated with cooking quality. PAG XII; 2004 10-14 Jan.; San Diego, Calif.

Williams, C.E. and P.C. Ronald. 1994. PCR template-DNA isolated quickly from monocot and dicot leaves without tissue homogenization. Nuc. Acids Res. 22:1917-1918.

Xin, Z., J.P. Velten, M.J. Oliver, and J.J. Burke. 2003. High-throughput DNA extraction method suitable for PCR. BioTech. 34:820-825.

Rice Breeding and Pathology Technology Support Program

C.D. Kelsey, S. Belmar, K.A.K. Moldenhauer, Y. Wamishe, and D.L. McCarty

ABSTRACT

Development of disease resistant rice is one of the most important achievements rice breeders attempt to accomplish. The plant pathology group assists with this goal by providing screening tests in the greenhouse and the field. Blast [*Magnaportha grisea* (T.T.Hebert) M.E. Barr], sheath blight (*Rhizoctonia solani* Kuhn), and bacterial panicle blight [*Burkholderia glumae* (Kurita and Tabei)] are the diseases currently being screened at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC). Artificial inoculation of these pathogens on rice is key to collecting disease severity data for rice breeders. The pathology group screens lines for rice blast, sheath blight, and bacterial panicle blight. Inocula are prepared in the lab and applied to the appropriate test. Blast and bacterial panicle blight screening is conducted in the greenhouse and the field. Sheath blight is screened only in the field. Data from these tests are used to determine which lines in the breeding program will be advanced to the next stage of testing.

INTRODUCTION

Plant breeders working in cooperation with the plant pathologists develop disease resistant and high yielding cultivars. Early and advanced breeding lines need to be evaluated and screened at the seedling stage in the greenhouse. Rice blast screening is more successful in the greenhouse than in the field. The inocula preparation for blast usually suffers contamination unless it is done carefully by trained technicians. Field sheath blight inoculation also requires massive inocula preparation that takes months of careful handling. To decrease expenses, a person trained for greenhouse blast screening would also be trained for bacterial panicle blight screening. Bacterial inocula preparation and the inoculation require careful handling of inocula preservation, media preparation, and keeping the laboratory utensils and equipment clean.

Breeding for disease resistance is the major area of emphasis in any breeding program. Rice breeders at the Rice Research and Extension Center, near Stuttgart, Ark., work together with rice pathologists to develop varieties having good agronomic qualities and resistance to major diseases. Cultivars are evaluated and selected for desirable characteristics, disease resistance being one of the important traits. Screening early generation material for the most problematic diseases is important for a successful breeding program. Lines which have good yield, quality, or disease resistance, but require further improvement for one or more traits can be utilized as parents in future crosses. Rice blast and sheath blight still remain as major diseases of rice and can result in a significant yield loss under favorable environments unless they are managed properly. Bacterial panicle blight, once considered minor and sporadic, is emerging as the top priority disease particularly in the growing seasons with hot temperatures. This disease requires answers for several unknowns about the bacterial complexity, host pathogen interactions, and disease spreading mechanisms. Tackling the problems in laboratory, greenhouse, and field tests and deriving sound management strategies for this disease requires several coworkers.

PROCEDURES

Greenhouse testing is conducted for blast and bacteria panicle blight. Greenhouse blast testing is uses a spore suspension sprayed directly on the rice plants grown to a 4-lf stage (approximately 21 d). The suspension consists of six different blast races either applied in a bulk or individually. The blast cultures are grown on a specific agar medium for seven days, after which the petri dishes are rinsed with a xanthan gum suspension to provide the inoculum needed to spray the plants. Artificially inoculated plants are placed in a dew chamber for approximately 14 h. Disease data is then collected 7-10 days after the plants are removed from the dew chamber. One cycle of seedling greenhouse testing for blast takes approximately 28 d. Over 300 entries of the Uniform Regional Rice Nursery (URRN) and Arkansas Rice Performance Trial (ARPT) were tested and evaluated using individual races in 2012. Testing bacterial panicle blight in the greenhouse is used to develop various methods to artificially inoculate plants at both the seedling and adult developmental stages. Methods include treating seed with a bacterial suspension before planting, spray inoculation, stem "pricking" with a syringe containing a bacterial suspension, and cutting leaves with scissor tips dipped in inoculum.

Field testing is done for blast, sheath blight, and bacterial panicle blight. Inoculum for blast and sheath blight consists of sterilizing several hundred gallons of cracked corn (corn chops) and rye grass seed. The sterilization process takes three days to accomplish for approximately 16 gallons of sheath blight and approximately 12 gallons of blast. The cultures are grown on a specific medium for 7 days and are mixed in the sterile chops/rye grass. Sterility must be maintained throughout the entire process to ensure contaminate-free inocula. Field tests are inoculated with dried inoculum at the tillering stage for blast and before boot split for sheath blight. Artificial inoculation for bacterial panicle blight is currently made by two separate methods. One is inoculation using pressure to force the bacteria into seeds and the other is spraying plants between the boot-split to flowering stage with the bacteria suspension. Seeds were inoculated with the bacterial suspension for 256 plots in 2012. Foliar inoculation was used for the ARPT and URRN. Both methods were found effective after review of the collected data from the 300 combined test entries in 2012.

Disease data are collected from ongoing inoculated disease plots, including inoculated sheath blight and blast. General observation tests planted in problem disease fields along with general observations made during the agronomic testing of entries provide additional disease assessments.

RESULTS AND DISCUSSION

A total of nearly 2,100 entries were replicated four times and tested for each pathogen group in 2012. The data were provided to the rice breeders for use in selecting material to advance or utilize (those having good level of disease resistance) as parents in their crossing programs.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum yielding cultivars with good levels of disease resistance for release to Arkansas rice producers. Plant pathology will continue to provide support to the breeding group and the extension program for the above listed diseases, as well as any other pathogens that become problematic. Assisting the breeders to select resistant rice varieties and helping commercial/private growers will be a continuous effort by the plant pathology group.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Arkansas rice producers, and the support of the Arkansas Rice Research and Promotion Board through their continued interest and funding. Thanks also go to the USDA-ARS for their cooperation, interest, and evaluation of materials, and to the other University of Arkansas System Division of Agriculture Research Stations located throughout Arkansas for their continued support.

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

K.A.K. Moldenhauer, J. Hardke, Y. Wamishe, C. Wilson Jr.,
R. Cartwright, R.J. Norman, D.K. Ahrent, M.M. Blocker, V.A. Boyett,
J.M. Bulloch, E. Castaneda-Gonzalez, D. L. McCarty, C. Kelsey, and S. Belmar

ABSTRACT

The Arkansas rice breeding program has the ongoing goal to develop new long- and medium-grain cultivars as well as specialty cultivars such as Japanese quality short-grains and aromatics. Cultivars are evaluated and selected for desirable characteristics. Those 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, earliness, erect leaves), and superior grain quality (i.e. cooking, processing, and eating). New varieties are continually being released to rice producers for the traditional southern U.S. markets as well as for the emerging specialty markets. This report deals with the long- and medium-grain pure line rice breeding effort at the University of Arkansas.

INTRODUCTION

The rice breeding and genetics program at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) is by nature a continuing project with the goal of producing new, improved rice cultivars for rice producers in Arkansas and the southern U.S. rice-producing region. The Arkansas rice breeding program is a dynamic team effort involving breeders, geneticists, molecular geneticists, pathologists, soil scientists, physiologists, entomologists, economists, systems agronomists, weed scientists, cereal chemists, extension specialists, and in some cases, a statistician. We also encourage input from producers, industry, and consumers.

As breeders, we integrate information from all of the disciplines to make selections. We are always looking for ways to enable the producer to become more economically viable. This team changes through time as breeding objectives shift.

Breeding objectives for improved long-grain and medium-grain cultivars include standard cooking quality, excellent grain and milling yields, improved plant type, and pest resistance. Through the years, improved disease resistance for rice blast and sheath blight has been a major goal, recently bacterial panicle blight has been added to this list. Blast resistance has been addressed through research by visiting scholars, graduate students, and by the development and release of Katy, Kaybonnet, Drew, Ahrent, and Templeton. Banks was also released from this program with blast resistance, but because it was derived from backcrossing it did not contain the minor genes needed to protect it from *IE-1k* in the field. These cultivars are among the first to have resistance to all of the common southern U.S. rice blast races. The first blast-resistant cultivars released were susceptible to *IE-1k,* but they had field resistance which kept the disease at bay. Templeton is the most recently released blast-resistant cultivar which also has resistance to the race *IE-1k*. Sheath blight tolerance also has been an ongoing concern and the cultivars from this program have also had the best sheath blight tolerance of any in the U.S. Rough rice grain yield has become one of the most important characteristics 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, and Roy J.

PROCEDURES

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

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

RESULTS AND DISCUSSION

Roy J, which was released to seed growers in 2010, was available as certified seed and grown on approximately 8.7% of the Arkansas acreage in 2012. It originated from a cross involving LaGrue, Katy, Starbonnet, Newbonnet, Radiated Bonnet73, Lemont, Lebonnet, CI9902, Dawn, and CI9695 (cross no. 20001692). This line has very high yield potential and excellent lodging resistance. The yield of Roy J was 203 bu/acre in the 2010 to 2012 Arkansas Rice Performance Trials (ARPT) compared to Wells and Francis which yielded 197 and 186 bu/acre, respectively, and with its stiff straw did not lodge from hurricane force winds when Isaac went through Arkansas (Table 1).

One experimental line, 81081, is a high yielding short-season long-grain line which will be grown as foundation seed in 2013. This line originated from the cross, no. 20001653, which has LaGrue, Katy, and Starbonnet in its parentage. During the hot weather in 2010, 81081 yielded 194 bu/acre compared to Francis and Roy J at 184 and 179 bu/acre, respectively (Table 1); and in 2011 and 2012 the yield for 81081 was 190 and 210 bu/acre, respectively (Table 1).

There is also a promising Clearfield line 121102 in the program. This line was in the URRN and ARPT for the first time in 2012. It has Drew, CL161, Katy, Starbonnet, Drew sister line, Lemont, Radiated Bonnet 73, and a Francis sister line in its pedigree. In the ARPT in 2012 (Table 2), it yielded 215 bu/acre compared to CL151, CL152, CL162, CL142-AR, CLXL729, CLXL745, and CLXP4534 at 204,192,187,193, 203, 205, and 246 bu/acre, respectively. This line is also resistant to the common blast races in the southern growing region and has a clear translucent kernel with very little chalk. More data will be collected on this line in the ARPT, URRN, and DD50 in 2013 while it is being increased in head rows.

Crosses have been made for high yield, good quality, improved milling, and disease resistance in various combinations. Crosses were made for both long- and medium-grain and conventional and Clearfield in 2012. The medium-grain crosses were completed to advance the medium-grain breeding program while searching for another rice breeder. Xueyan Sha has been hired to fill this position. The F_2 populations from these crosses will be evaluated in 2013 and selections will be grown in the winter nursery during the winter of 2013-2014. Currently, we have 5,100 F_3 lines growing in Puerto Rico. One or two panicles will be harvested to produce F_4 lines grown at the RREC as P panicle rows in 2013.

Marker-assisted selection has been utilized in this program to select the lines which have the 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 (Boyett et al., 2005 and 2009). The data derived from the markers 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 good levels of disease resistance for release to Arkansas rice producers. The release of Taggart, Templeton, Roy J, CL142-AR, and CL181-AR demonstrate that continued improvement in rice varieties for the producers of Arkansas can be realized through this program. Possibly Roy J or the experimental line 81081 could be the next replacement for Wells. Improved lines will continue to be released from this program in the future. They will have the characteristics of improved disease resistance, plant type, rough rice grain and milling yields, and kernel size. In the future, new rice varieties will be released not only for the traditional southern U.S. long- and medium-grain markets but also for specialty markets as they arise.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Arkansas rice producers, and the support of the Arkansas Rice Research and Promotion Board through their continued interest and funding. Thanks also go to the USDA-ARS for their cooperation, interest, and evaluation of materials, and to the other University of Arkansas System Division of Agriculture Research Stations located throughout Arkansas for their continued support.

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.

Table 1. Data from the 2010-2012 Arkansas Rice Performance Trials for a promising experimental line and check cultivars.

Cultivar[a]	Grain type[b]	Yield[c] 2010	2011	2012	Mean	Height	50% heading	Chalky kernels[d]	Milling[e]
		---------------------(bu/acre)			---------------------	(inches)	(days)		(HR:TOT)
Francis	L	184	195	213	197	42	85	1.0	61:69
Wells	L	170	182	205	186	43	86	0.8	57:71
Cheniere	L	160	177	192	176	38	86	0.9	61:71
Templeton	L	166	182	186	173	44	88	0.5	51:64
Taggart	L	180	215	199	198	46	88	0.7	57:70
Roy J	L	179	196	234	203	43	90	0.7	60:70
81081	L	194	190	210	198	44	82	0.9	60:69
XL723	L	231	191	222	215	46	82	3.0	61:70
CL142-AR	L	166	174	193	178	45	85	1.1	55:70
CL151	L	182	142	204	176	40	83	1.2	62:69
CL152	L	----.	178	192	185	39	85	0.9	59:68

[a] CL stands for Clearfield lines.

[b] Grain type L = long-grain.

[c] Yield trials in 2010 consisted of seven locations: Rice Research and Extension Center, (RREC), Stuttgart, Ark.; Pine Tree Research Station (PTRS), Colt, Ark.; Rohwer Research Station (RRS), Rowher, Ark; Northeast Research and Extension Center (NEREC), Keiser,Ark.; Lonoke County Farmer Field, (LC), Lonoke, Ark.; and Newport Research Station (NRS), Newport, Ark.; and Clay County Farmer Field, (CC), Corning, Ark.; and in 2011 the successful trials were grown at CC, NPRS, and PTRS; and in 2012 the trials were at RREC, PTRS, NEREC, NPRS, and CC.

[d] Data for chalk is from 2010-2011 Riceland data.

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

Table 2. Data from the 2012 Arkansas Rice Performance Trials for a promising experimental line and check cultivars.

Cultivar[a]	Grain type[b]	Yield[c] CC	NEREC	NPRS	PTRS	RREC	Mean	Height	50% heading	Milling[d]
		---------------	------	------	(bu/acre)	------	---------------	(inches)	(days)	(HR:TOT)
121102	L	219	227	159	205	262	215	38	85	62-71
CL151	L	224	234	207	188	169	204	39	84	63-71
CL152	L	227	194	159	207	171	192	38	85	63-71
CL162	L	177	201	.	178	190	187	42	82	59-70
CL142-AR	L	244	216	117	211	179	193	44	85	51-70
CL181-AR	L	213	212	139	211	200	195	35	86	61-70
CLXL729	L	253	191	196	183	193	203	43	84	59-70
CLXL745	L	252	164	.	198	206	205	43	79	57-72
CLXP4534	L	261	226	205	262	274	246	37	75	50-70
Roy J	L	222	212	217	260	257	234	41	89	64-72
Wells	L	221	204	155	228	215	205	40	85	54-71

[a] CL stands for Clearfield lines.

[b] Grain type L = long-grain.

[c] Yield trials in 2012 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.; and Newport Research Station (NRS), Newport, Ark.; and Clay County Farmer Field (CC), Corning, Ark.

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

BREEDING, GENETICS, AND PHYSIOLOGY

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

X. Sha, K.A.K. Moldenhauer, B.A. Beaty,
J.M. Bulloch, E. Castaneda-Gonzalez, M.M. Blocker, and C.E. Wilson Jr.

ABSTRACT

The medium-grain rice breeding project at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC) has taken the new direction under the leadership of Xueyan Sha who was hired on 1 October 2012. 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 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 an important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States only behind California. During 2002-2011, an average of 0.16 million acres of medium-grain rice were grown annually, which made up about 11% of total state rice acreage (Childs, 2012). 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, CL152, CL111, and Cheniere. However, locally developed 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 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 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 bacterial 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. Test tube milling, as well as the physicochemical analysis at the USDA Rice Quality Lab at Dale Bumpers National Rice Research Center, will be conducted to eliminate lines with evident quality problems and/or maintain standard U.S. rice quality of different grain types. Yield evaluations include the preliminary yield trial (PYT) and the Stuttgart Initial Test (SIT) at RREC near Stuttgart, Ark., the Arkansas Rice Performance Trials (ARPT) carried out by Jarrod Hardke, the Arkansas Rice Extension Specialist, at six locations in rice growing regions across the state, and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in Louisiana, Mississippi, Missouri, and Texas. Also selected SIT entries were planted at the Pine Tree Research Station near Colt, Ark., under high natural disease pressure using blast "spreader rows." Promising advanced lines will be provided to cooperating projects for further evaluation of the susceptibility to the physiological disorder straighthead and resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the preliminary yield test and beyond will be planted as headrows for purification and seed increase purposes.

RESULTS AND DISCUSSION

During the transition of this project, a number of breeding populations of different stages were planted and harvested by Karen Moldenhauer. Selection was also made by the senior author on space-planted F_2 populations, and the resulting F_3 progenies were advanced in the Puerto Rico winter nursery. A selected number of germplasm were grown in the greenhouse in late November for crossing in early spring of 2013.

Two medium-grain experimental lines were evaluated in the 2012 URRN, meanwhile they were also tested in 2012 ARPT trails along with seven other medium-grain entries (Table 1). Among those, lines STG09PR-80-062, STG09PR-81-087, and STG09PR-82-037 appeared to have good grain quality, acceptable milling yields, and similar or even better yield potential than commercial checks; therefore they were advanced to the 2013 URRN and ARPT trials for further detailed evaluation. Small headrow increases of the three promising lines are currently being grown in the Puerto Rico winter nursery. In the 2012 SIT, 26 lines were evaluated and several of them showed the yield potential similar to the checks (Table 2). After further evaluation on their grain quality and milling yields, five entries were advanced to the 2013 URRN and/or ARPT trials. Out of 1,109 P panicle rows, 116 were selected for re-selection and 18 bulked for preliminary yield trials in 2013.

SIGNIFICANCE OF FINDINGS

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

ACKNOWLEDGMENTS

This research is partially supported by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Childs, N. 2012. 2010/11 Rice Yearbook. USDA-ERS. (Available online at http://usda01.library.cornell.edu/usda/current/RCS-yearbook/RCS-yearbook-04-09-2012.pdf).

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. Average yield, milling, and agronomic characteristics of nine experimental medium-grain lines and four check varieties tested at five Arkansas locations, 2012[a].

Variety/line	Days to 50% heading	Plant height	Yield	Lodging	Milling yields Head rice	 Total rice
		(cm)	(bu/acre)	--------------------	(%)	--------------------
RU1001102	86	92	202	15	60.5	68.8
RU1201124	81	98	201	3	63.4	69.6
STG09PR-80-062	82	91	210	31	63.5	69.9
STG09PR-81-087	82	101	224	40	54.1	68.3
STG09PR-81-092	83	90	207	5	55.9	68.8
STG09PR-82-037	82	96	222	18	55.7	68.8
STG09PR-82-038	82	94	210	2	53.2	68.0
STG10PR-05-022	82	76	209	24	55.8	69.5
STG10PR-08-077	83	93	206	28	42.1	68.7
Bengal	86	92	212	28	61.3	69.7
Caffey	87	96	203	33	59.9	69.3
Jupiter	88	94	205	32	61.0	68.2
CL261	83	100	179	31	59.2	69.1

[a] Yield trials in 2012 consisted of five locations, Rice Research and Extension Center, Stuttgart, Ark.; Pine Tree Research Station, Colt, Ark.; Northeast Research and Extension Center, Keiser, Ark.; Newport Research Station, Newport, Ark.; and Clay County Farmer Field, Corning, Ark.

Table 2. Performance of selected medium-grain experimental lines and check varieties at Pine Tree Research Station, Colt, Ark., and Rice Research and Extension Center, Stuttgart, Ark., 2012.

Variety/line	Days to 50% heading	Plant height	Yield	Lodging	Milling yields Head rice	 Total rice
		(cm)	(bu/acre)	--------------------	(%)	--------------------
STG09PR-80-064	81	93	189	0	61.8	69.1
STG10F4-04-066	80	86	186	2	46.5	72.5
STG10PR-04-011	85	80	185	0	46.8	72.0
STG10PR-04-031	88	82	181	7	47.1	71.7
STG10PR-04-042	86	84	205	0	33.2	69.8
STG10PR-04-068	83	87	210	0	52.6	70.1
STG10PR-04-073	81	84	184	0	49.2	71.7
STG10PR-05-024	82	82	195	0	22.4	70.9
STG10PR-07-059	89	82	197	30	45.6	67.4
STG10PR-10-052	85	95	201	0	53.2	70.2
STG10PR-10-057	93	85	183	2	56.7	69.5
STG10PR-10-059	88	92	190	22	48.5	68.8
STG10PR-14-015	88	99	193	0	53.8	67.7
Caffey	90	94	209	0	65.2	73.3
Jupiter	94	93	200	22	59.9	69.1

BREEDING, GENETICS, AND PHYSIOLOGY

Hybrid Rice Breeding

Z.B. Yan, C.W. Deren, and W.-G. Yan

ABSTRACT

In 2012, testing continued on breeding lines that had been identified as promising parents in previous years as well as new ones generated in 2011. Various hybrid combinations were evaluated for combining ability in yield and other traits such as height, lodging, disease resistance, grain type, and quality. Replicated tests of various 2- and 3-line combinations were evaluated at the University of Arkansas System Division of Agriculture Rice Research and Extension Center (RREC). Eight hybrids were entered in the Uniform Regional Rice Nursery (URRN) and the Arkansas Rice Performance Trials (ARPT). For 87 hybrid combinations, F_1 seed production was also evaluated.

INTRODUCTION

Lines developed for use in 2- and 3-line hybrids were tested in various combinations to evaluate their potential for breeding and commercially important traits. In 2011, several parent lines and hybrid combinations were identified as having good potential. In addition, several new lines were included in 2012 for testing. Evaluation of potential breeding lines requires testing various combinations as F_1 hybrids for yield and a broad array of traits necessary for a rice variety to be commercially acceptable including various agronomic, milling, and disease resistance traits. In addition, potential parent lines must be tested for seed production, which requires evaluating isolation planting schemes, synchronization of flowering, and pollen distribution, etc.

PROCEDURES

Yield Tests

Yield was evaluated on 23 hybrids in a replicated test at RREC, with 3 replications and included the checks Francis, Wells, and Ark-Flor, a newly released aromatic germplasm from Florida. Plots were drilled on 3 May. Seed were planted in 6-row plots, 3-m long and 1.5-m wide. In addition, 8 hybrids that performed well in 2011 were entered into the URRN to be tested in Ark., La., Miss., Texas, Mo., and in the ARPT to be tested around the state.

Hybrid Seed Production

Seed production was tested in 2 locations chosen for maximum isolation from other rice to reduce the chance of pollen contamination. A total of 87 combinations were tested. Site 1 (Woods) was isolated on 3 sides by woods and fallow land, which provided a relatively secluded location with less chance of uncontrolled pollination. It contained 8 bays, with each bay planted with a different restorer. Restorers were planted in single rows, 3-m apart, and 10-m long. Between the restorer rows, male sterile lines were transplanted on dates varying according to the entries' heading dates. The male-sterile lines were 873A, 799s, 800s, 805s, 811s, and 810s. At Site 2 (Soybean), the location was near other rice fields and surrounded by soybean. Isolation was less than ideal, but it was a good contrast to the Woods site for observing uncontrolled outcrossing. Tests were planted with the same methods as in the Woods site, but used only 4 restorers. Corn was planted around the tests and between bays to help reduce chances for pollen contamination.

RESULTS AND DISCUSSION

Yield Tests

In the replicated yield test, Francis was the highest yielding check variety (7,826 lb/acre), so all comparisons are made with that check (Berger et al., 2013). Twenty-two of the hybrids had yields greater than Francis and 2 hybrids yielded less than Francis. Of these, 11 had yields exceeding that of Francis by 20% or more. For some of the tested hybrids, this was the second year in which they exceeded the check in yield. One interesting observation was that by mating a certain restorer with various male-steriles, heading dates could be shifted by about 3 to 4 day increments.

Of the 8 Arkansas hybrids in the URRN, 5 were in the top 25% in yield for the 200 entries in the test (Table 1). Entry 176, which ranked 2nd in the test is a 2-line hybrid with smooth leaf and long grain. In Louisiana, where blast was very bad, all 8 University of Arkansas hybrids exhibited very good resistance.

Seed Production

Seed production was refined after the experience in 2011. Synchronization of flowering was improved. Hybrid seed production is known to have low yield, but seed yields were at acceptable levels in some combinations.

Until F_1 seed are grown, an assessment of the outcrossing at each site cannot be made. Seed production overall ranged from essentially nothing in some combinations to a high of 2,254 lb/acre. Most combinations averaged about 350 lb/acre, and were fairly consistent across restorers and male-steriles. Seed production will improve as we are able to mechanize more and gain more information on the flowering and management of parent lines.

Seed was increased in isolation for male-sterile lines. The lines 236s, 811s, 873s, and 874s produced well in the field at Stuttgart. The fact that environmental male-sterile lines set seed well, may be attributed in part to the origin, development, and selection of those lines all being done at that location.

SIGNIFICANCE OF FINDINGS

This year's tests added valuable information about both the general and specific combining ability of selected lines. Grain yield and other traits were improved over the previous year. The preliminary evaluations of selected hybrids for both yield and seed production in 2012 were very informative. Selected hybrids will be tested in replicated, multi-location tests in 2013. Seed production schemes will continue to develop with improved synchrony between parent lines.

ACKNOWLEDGMENTS

Funding for this project was provided by the taxpayers of Arkansas through general revenues and by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Berger, G.L., Z.B. Yan, and C.W. Deren. 2013. Development of hybrid rice cultivars. *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 609:52-56. Fayetteville.

Table 1. Performance of selected University of Arkansas hybrids in the 2012 Uniform Regional Rice Nursery (URRN) grown at Stuttgart, Ark.; Crowley, La.; Stoneville, Miss.; Campbell, Mo.; and Beaumont, Texas.

Hybrid	Rank[a]	Yield	Milling[b]	Height	Heading
		(lb/acre)	(%)	(cm)	(days)
176	2	10,201	44/66	110	85
JES	5	9,681	58/67	94	89
173	11	9,445	47/66	112	86
170	18	9,256	48/65	113	86
167	43	8,669	53/68	101	88
Francis	63	8,499	59/70	104	86

[a] Rank is relative to 200 entries.

[b] Milling is head rice/total rice.

Efficacy of Fungicide and Insecticide Seed Treatments for Rice Stand Establishment and Growth

B.W. Burrow, C.S. Rothrock, S.A. Winters, and R.L. Sealy

ABSTRACT

Stand establishment problems occur frequently in Arkansas rice fields and are commonly associated with cool soil temperatures (early planting) and saturated soils. There are several factors that affect rice stand establishment including diseases and insects. It is important to understand what pathogens or pests are the cause of stand problems in rice for managing stand establishment problems. In 2012, field trials evaluated a number of fungicide and insecticide seed treatment combinations over several genotypes. Planting into soils that were warmer than normal planting conditions in 2012 rarely showed a seed treatment response, except when fungicides were combined with the insecticide treatment Cruiser. However, controlled environmental tests suggested seedling diseases are a common cause of stand establishment problems in Arkansas. More reliable stand establishment for rice occurs when fungicide seed treatments are applied to control *Pythium*. This data also suggest that fungicide seed treatments improved the health of the surviving seedlings, improving plant vigor, increasing root development, and decreasing root disease.

INTRODUCTION

Stand problems in Arkansas rice fields frequently cause management problems and production losses (Eberle et al., 2008; Rothrock, 2010). Stand problems are more common when early planting occurs where the soil temperatures are not optimum for seedling development (Rothrock, 2010; Rothrock et al., 2002; Rush and Schneider, 1990). Planting rice before the soil temperatures are conducive for plant growth will slow germination and emergence, increasing susceptibility to soilborne pathogens.

Soilborne pathogens which attack seed or seedlings as they begin to germinate and develop are an important factor in stand problems in Arkansas rice fields. Species of *Pythium* which can cause seed rot prior to emergence or pre-emergence damping off are some of the more common pathogens that cause stand problems in Arkansas (Eberle et al., 2008; Rothrock, 2010; Rothrock et al., 2002; Nelson, 1987; Webster et al., 1970). In addition, *Pythium* spp. are some of the main causes of post-emergence damping off (seedlings rot near the soil line and die). *P. arrhenomones* and *P. irregular* have been reported to be the most virulent *Pythium* spp. to rice seedlings in Arkansas (Eberle et al., 2008).

This study evaluated the importance of rice genotypes and chemical seed treatments for developing better management practices to improve stand establishment.

PROCEDURES

Field Studies

A series of field studies were planted at two locations. At the University of Arkansas System Division of Agriculture Northeast Research and Extension Center, Keiser, Ark., the planting dates were 21 March, 28 March, and 12 April 2012. At the Pine Tree Research Station, Colt, Ark., the planting dates were 29 March, 6 April, and 12 April 2012. Four rice genotypes were used; the cultivars Wells, Jupiter, and Francis, and the Plant Introduction PI60247, a genotype that has shown *Pythium* resistance (Rothrock, 2010). The seed treatments used were non-treated, Trilex 2000 (trifloxystrobin and metalaxyl), Allegiance (metalaxyl), Allegiance + Dynasty (azoxystrobin), and Allegiance + Dynasty + Cruiser (thiamethoxam). A factorial treatment arrangement was used in a completely randomized block design with 4 replications for each planting date. Three arbitrary one meter stand counts were taken per plot at the V3 to V5 leaf stage.

Controlled Environmental Studies

Controlled environmental experiments were also conducted to evaluate these seed treatments using a soil collected at the Rice Research and Extension Center, Stuttgart, Ark. The cultivar Wells was treated with the same five seed treatments used in the field studies. Soil was placed into 18 inch by 24 inch by 3 inch (46 cm by 61 cm by 8 cm) plastic containers with perforated floors. After potting, the soil was saturated by placing a container in a tray of water and then placed into growth chambers at 55 °F (12.78 °C) or 65 °F (18.3 °C) to bring the soil temperature to the planting temperature. Twenty seeds of each treatment were planted in rows that were randomized for each container. Soils were watered every three to four days, depending on soil moisture levels for each temperature. The plantings at the cooler temperature were moved to the warmer temperature after about 5 weeks. The experiments were terminated at 10 weeks.

Upon removal from environmental growth chambers, emergence, stand, and vigor ratings were taken. The vigor rating was made on a scale of 1 to 10 with one being the lowest and 10 being the highest vigor. Root ratings were on a 1 to 5 scale with 1 = no root discoloration, 2 = 1% to 10%, 3 = 11% to 25%, 4 = 26% to 50%, and 5 = 51% to 100% root discoloration.

RESULTS AND DISCUSSION

Soils for 2012 were unseasonably warm and dryer than normal for the field studies. Warm planting temperatures made it difficult to evaluate seedling disease across a range of soil temperatures typical for rice planting. Lack of rainfall also contributed to poor seedling emergence. The only seed treatment to perform consistently across cultivars was Allegiance + Dynasty + Cruiser, which increased stand over all genotypes for the first and third planting dates at Pine Tree (Table 1). The only trial that demonstrated efficacy for fungicide seed treatments was the third planting date at Keiser, with stands for Wells being greater for the Trilex 2000 (trifloxystrobin and metalaxyl) and Allegiance (metalaxyl) treatments than non-treated seed (Table 2).

A temperature response was found for emergence, vigor, and root discoloration for the controlled environmental experiments (Table 3). Across seed treatments, emergence was 14.6 at 55 °F and 12.3 at 65 °F (Table 3). Root discoloration was 3.1 at 55 °F and 1.8 at 65 °F. An interaction between seed treatment and temperature was found for vigor. Numerically all treatments had greater vigor ratings at 65 °F than at 55 °F, except for the nontreated seed. Seed receiving the Allegiance or Trilex 2000 treatment had greater vigor at 65 °F than at 55 °F (Table 3). Seed treatment response for emergence and stand were similar across temperatures. All of the fungicide treatments increased emergence, except for the Allegiance treatment compared to the non-treated control (Table 3). However, all seed treatments were similar for emergence. Final stands were increased by all fungicide seed treatments across both temperatures. A decrease between initial emergence and final stand counts was the result of death of some seedlings that had emerged, post-emergence damping-off. Seedling death was much greater for the non-treated seed than seed receiving a fungicide treatment. For surviving seedlings, root weight was increased and root discoloration was decreased for the fungicide treatments compared to the non-treated control, with all seed treated with a fungicide being similar (Table 3). *Pythium* spp. were the most common pathogen group isolated from the seed treatments examined.

This research supports the value of the insecticide seed treatment (Cruiser) when combined with fungicide seed treatments. For these field studies, fungicide seed treatments rarely improved stands. The warm environmental conditions could be one factor that can be attributed to lack of consistent treatment response. *Pythium* spp., a major component of the seedling disease complex, is favored by cooler soil temperatures (Eberle, 2008). With the environmental conditions not conducive during the field studies, fungicide treatment efficacy was examined in controlled environmental studies with naturally infested soil. Treatment response for seed treatments were found for stand, vigor, root weight, and root ratings. All fungicide seed treatments had similar efficacy. The treated seedlings overall had lower vigor in the cooler soil temperature than the warmer temperature, but still performed better than the non-treated seedlings in the cooler environment. This indicates that seed treatments are beneficial to overall plant health in addition to increasing stands. This also was evident as increased root weight and reduced root discoloration for seedlings from treated seed compared to non-treated seed.

In the current study, fungicide seed treatments were effective over a range of temperatures. The fungicide Allegiance was shown to significantly increase stands over the non-treated seed and had similar stands compared to other seed treatments. In previous controlled studies at warmer temperatures, Allegiance did not show significant differences between treated and non-treated seed (Eberle, 2008). This current study was conducted over a longer period than previous studies and appreciable post-emergent damping-off was observed. So the Allegiance response may have been due to post-emergence disease not observed in previous studies. This is supported by the lack of Allegiance emergence response. This study suggested that in the proper soil moisture conditions, seedling diseases can occur over a range of temperatures.

SIGNIFICANCE OF FINDINGS

There are several factors that affect rice stand establishment in the field. Factors that can contribute to stand problems include pH, soil fertility, moisture, temperature, diseases, and insects. It is important to understand what pathogens or pests are the cause of stand problems in rice for managing stand establishment problems. The controlled environmental tests conducted are useful in examining seedling disease control. This research suggested seedling diseases are a common cause of stand establishment problems in Arkansas and fungicide seed treatment to control *Pythium* improve stand establishment for rice. In addition, this data suggest fungicide seed treatments improved the health of the surviving seedlings, improving plant vigor, increasing the root system, and decreasing root disease.

ACKNOWLEDGMENTS

This research was conducted with the support of the Rice Research and Promotion Board. The authors want to thank Shawn Clark and Mike Duren for helping to establish the trials.

LITERATURE CITED

Eberle, M. 2008. Importance and characterization of seedling pathogens on stand establishment in rice. M.S. Thesis, University of Arkansas, Fayetteville, 2008.

Eberle, M.A., C.S. Rothrock, and R.D. Cartwright. 2008. *Pythium* species associated with rice stand establishments problems in Arkansas. *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 560:57-63. Fayetteville.

Nelson, E.B. 1987. Rapid germination of sporangia of *Pythium* species in response to volatiles from germinating seeds. Phytopathology 77:1108-1112.

Rothrock, C.S. 2010. Managing seedling disease problems on rice through the development of *Pythium*-resistant cold-tolerant cultivars, fungicides, and cultural practices. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Series 2009. University of Arkansas Agricultural Experiment Station Research Series 581:22-26. Fayetteville.

Rothrock, C.S., R.L. Sealy, F.N. Lee, M.M. Anders, and R.D. Cartwright. 2002. Managing seedling disease problems on rice through fungicides, adapted cultivars, and cropping systems. *In:* R.J. Norman and J.-F. Meullenet (eds.). B.R. Wells Rice Research Series 2001. University of Arkansas Agricultural Experiment Station Research Series 495:237-241. Fayetteville.

Rush, M.C. and R.W. Schneider. 1990. Chemical control of seedling diseases of rice in Louisiana. pp. 53-70. *In:* B.T. Grayson et al. (eds). Pest Management in Rice. Elsevier Applied Science, London and New York.

Webster, R.K., D.H. Hall, J. Heeres, C.M. Wick, and D.M. Brandon. 1970. *Achlya klebsiana* and *Pythium* species as primary causes of seed rot and seedling disease of rice in California. Phytopathology 60:964-968.

Table 1. Effect of seed treatments across cultivars on rice stand establishment at the Pine Tree Research Station, Colt, Ark.

Treatment	Stand 29 March	 13 April
	---------(plants/meter of row)--------	
Metalaxyl, Azoxystrobin, and Thiamethoxam	25.8 A[†]	19.3 A
Metalaxyl	20.3 B	14.2 B
Nontreated	19.4 B	15.9 B
Metalaxyl and Azoxystrobin	18.8 B	13.9 B
Trifloxystrobin and Metalaxyl	17.0 B	15.2 B

[†] Means in a column followed by the same letter are not significantly different, protected least signficiant difference, $P = 0.05$.

Table 2. Effect of cultivar and seed treatment on rice stand establishment at the Northeast Research and Extension Center, Keiser, Ark., for the 3rd planting date, 12 April 2012.

Cultivar	Treatment	Stand
		(plants/meter of row)
Wells	Trifloxystrobin and Metalaxyl	11.7 A[†]
Wells	Metalaxyl	11.7 A
Jupiter	Metalaxyl and Azoxystrobin	10.0AB
Francis	Metalaxyl and Azoxystrobin	8.0 ABC
Jupiter	Metalaxyl, Azoxystrobin, and Thiamethoxam	7.6 ABC
Wells	Metalaxyl and Azoxystrobin	7.4 ABC
Wells	Metalaxyl, Azoxystrobin, and Thiamethoxam	7.2 ABC
Jupiter	Nontreated	6.2 BC
Francis	Metalaxyl, Azoxystrobin, and Thiamethoxam	6.2 BC
Francis	Nontreated	5.7 BC
Jupiter	Metalaxyl	5.4 C
Wells	Nontreated	4.7 C
Francis	Metalaxyl	4.0 C
Francis	Trifloxystrobin and Metalaxyl	3.8 C
Jupiter	Trifloxystrobin and Metalaxyl	3.7 C

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

Table 3. Effect of seed treatment and temperature on rice stand establishment in controlled environments[†].

Treatment	Emergence	Stand	Plant vigor[‡]		Root weight	Root[§] rating
			55 °F	65 °F		
					(g)	
Seed treatment						
Allegiance	13.0 AB[¶]	11.0 A	5.5 CD	7.4 A	1.6 A	2.4 B
Allegiance + Dynasty + Cruiser	13.8 A	12.3 A	6.2 BC	7.2 AB	1.7 A	2.3 B
Allegiance + Dynasty	14.4 A	12.8 A	6.2 BC	7.0 AB	1.8 A	2.1 B
Trilex 2000	14.5 A	12.7 A	5.7 C	7.3 A	1.7 A	2.2 B
Nontreated	11.4 B	7.3 B	4.5 DE	4.2 E	1.1 B	3.5 A
Temperature						
55 °F	14.6 A					3.1 A
65 °F	12.3 B					1.8 B

[†] Twenty seed were planted per experimental unit.

[‡] Vigor rating scale of 1 to 10 with 1 being the lowest and 10 being the highest rating.

[§] Root rating scale of 1 to 5 with 1 = no root discoloration and 5 = 51% to 100% root discoloration.

[¶] Means for a parameter for a main effect or interaction followed by the same letter are not significantly different, protected least significant difference, *P* = 0.05.

PEST MANAGEMENT: DISEASES

Reactions of Selected Rice Cultivars to *Ustilaginoidea virens* in Arkansas

D.O. TeBeest and A. Jecmen

ABSTRACT

False smut, caused by *Ustilaginoidea virens,* was found in Arkansas in 1997 and the disease has now been identified in most counties in which rice is grown. The disease is normally identified by the presence of orange and black sori (= spore balls, pseudomorphs) that appear on the maturing heads or panicles. The disease cycle for this emerging disease of rice is poorly understood and its erratic nature on many different cultivars across locations has hampered the development of effective management strategies for this disease. In 2012, among all of our tests, we conducted a preliminary experiment at one location in Arkansas in which five selected cultivars were planted in replicated plots for the purpose of investigating their reaction to false smut. In this test, we selected a site in which the soil was uniform. We determined the number of infected panicles/m^2 (= incidence) twice after the first appearance of the sori and before harvest from each of the plots. We also determined the number of sori per panicle (= severity) in order to compare the severity and incidence of sori on panicles for the five cultivars over time. The results of these investigations are similar to results we obtained in 2011 with a larger number of cultivars. The data suggest that there are differences in the reaction among the selected cultivars in response to seedborne and soilborne inoculum of the fungus. Resistance or tolerance may be a useful strategy in understanding and managing this emerging disease of rice in Arkansas.

INTRODUCTION

False smut of rice is caused by the fungus *Ustilaginoidea virens*. This pathogen has been in the United States for many years, but was first reported in Arkansas in 1997 (Cartwright and Lee, 2001; Wilson et al., 2005). It has been previously reported that this disease does not typically affect yield, but quality issues remain important due to production of ustiloxin, a microtubule inhibitor toxic to animals (Koiso et al., 1992; Miyazaki et al. 2009). More recently, the literature suggests that yields can be significantly reduced (Hedge and Anahosur, 2000; Zhou et al., 2003).

Knowledge concerning the disease cycle and epidemiology of *U. virens* is minimal and incomplete (Guo et al., 2012; Lee and Gunnell, 1992). Recent research conducted by Ashizawa et al. (2010), Ditmore and colleagues (2006, 2007), Ikegami (1963), Schroud and TeBeest (2006), TeBeest et al. (2011), and Zhou et al. (2003) suggests that rice plants may be colonized from seedborne and/or soilborne inoculum within a few weeks after emergence. There is growing evidence than flowers can be infected by injection of spores into the boots prior to their emergence (Ashizawa et al., 2011; Tang et al., 2012). Fungicides, applied at heading may only suppress the disease from developing.

Disease resistance is an important tool in managing false smut. It has been widely suggested that the number of sori found on mature panicles or the degree of blanking (= chaffing) varies according to cultivar and therefore may be related to the level of resistance in the cultivar (Cartwright et al., 1999a; Hedge and Anahosur, 2000; Lu et al., 2009). The methods used to evaluate resistance have measured the occurrence of sori in several ways, including number of sori per panicle (Branson et al., 2009; Cartwright et al., 1999b; Hedge and Anahosur, 2000), the maximum number of sori per head (Cartwright et al., 1999a), and the number of sori per pound of harvested grain (Brooks et al., 2009, 2010; Parsons et al., 2004). In addition, Hedge and Anahosur (2000) and Lu et al. (2009) developed disease scoring systems that contain several categories based on the number of sori per panicle. The categories generally describe the disease severity from 0 sori/panicle to a category that includes 10 or more sori /panicle.

Brooks et al. (2009, 2010) reported that the severity of disease on several selected cultivars may also depend on soil fertility and flood water depth. In 2011, TeBeest et al. reported that the occurrence of sori on panicles also differed according to location and cultivar. Many rice cultivars grown in Arkansas were evaluated or rated for resistance to false smut between 2001 and 2009. The rating system was largely based on the number of sori produced per panicle, the number of sori per pound of harvested seeds, and/or on historical observations (Branson et al., 2009; Cartwright et al., 2002; Robinson et al., 2010). Many of the cultivars and breeding lines rated for resistance to false smut during these years were rated as very susceptible, susceptible, or moderately susceptible. However, Bengal, CL121, Jefferson, Kaybonnet, Katy, Koshihikari, M201, M202, Newbonnet, and Saber were rated as moderately resistant to false smut (Cartwright et al.,1999a,1999b; Cartwright et al., 2000a,b; Cartwright and Lee 2001; Parsons et al., 2004).

In addition to the cultural effects on disease severity, Lu et al. (2009) suggested that there are six pathogenicity groups among the 59 isolates of *U. virens* they tested. Resistance to false smut expressed by three hybrids differed significantly among the isolates tested. They suggested that disease assessments, based on the ability of the isolates to produce sori on the panicles of these three hybrids, could be used to further differentiate the isolates of *U. virens* for virulence to rice. Clearly, the interactions of disease assessments, cultural conditions, cultivar resistance, and the potential role of pathotypes must be understood before effective management tools can be developed.

The overall goal of our research on false smut is to gain a clearer understanding of the disease cycle as it is expressed in Arkansas and of how the disease spreads and develops on some of the current cultivars grown in Arkansas in order to facilitate improving our current management strategies. As part of this overall goal, the specific objective of the work reported here was to evaluate five selected cultivars that had previously shown differences to infection by false smut with two specific sub-objectives: 1) to quantify the number of heads infected by false smut per unit area over time, and 2) to examine the number of sori produced on the panicles of the selected cultivars.

PROCEDURES

Five rice cultivars were selected for these field tests based on the results previously conducted at the Newport Research Station, Newport, Ark., and the Pine Tree Research Station, Colt, Ark., in 2011. Seeds of the five cultivars (Katy, Kaybonnet, Neptune, Taggart, and CL151) were harvested from our research plots in 2011. All seedlots were visibly infested with sori of *U. virens*. Some seeds were also visibly contaminated (blackened) with false smut spores.

Four, 400-gram samples of seeds of each of the five cultivars were prepared and placed individually in envelopes. Treatments (cultivar) were planted in a field with a history of false smut in a randomized complete block design with 4 replications of each treatment. Plots were 5 ft (1.5 m) wide and 100 ft (30.5 m) long and consisted of 7 rows with 7-inch (17.8-cm) spacing between rows. The design of the test (randomization and length of each plot) was intended to minimize differences that might occur within the area with respect to soil fertility (pH, EC, macro- and micro-nutrient levels) which can affect incidence of disease (Brooks et al., 2009, 2010). These data are shown in Table 1. There were no additional seed treatments or inoculations made at any time. Due to the limited space available within a field in which the soil was uniform and the number of times we were able to quantify the disease after first appearance, we can only consider this data as preliminary in nature.

Plots were planted on 18 May 2012 at Pine Tree and seedlings began to emerge on 25 May 2012. Plots were treated with several herbicides, including 0.5 lb/acre Facet and 2 oz/acre Permit on 18 May 2012 and 4 qt/acre Stam and 0.5 oz/acre Permit on 30 May. In addition, 0.8 oz/acre Clincher and 0.25 lb/acre of Facet were applied on 10 July 2012. In addition, plots were treated 150 units of nitrogen (362 lb/acre urea) applied preflood on 21 June 2012. The plots were put into permanent flood on 22 June 2012. Plots were drained on 1 Oct. 2012 and all plots were harvested on 21 October 2012.

Symptom Development, Disease Incidence and Severity, and Collection of Infected Panicles

In order to determine when signs and/or symptoms of false smut appeared in the tests on the five cultivars, all 20 plots at Pine Tree were examined daily beginning in mid-August, 2012, with the onset of booting of the first cultivar. Data on disease incidence (panicles/m^2) were recorded within one week of first appearance of false smut sori and with a final determination on all cultivars in late September to permit full expression of the disease on all cultivars. Disease surveys of all plots began at booting and the average number of infected panicles/m^2 was determined for each plot by counting the number of infected panicles/m^2 by two experienced investigators. Two random counts were made at six locations within each plot in rows exclusive of edge rows. These counts were averaged for each location within each plot.

Collection of Mature Infected Panicles

After all cultivars reached maturity and after the data on the incidence of false smut were collected, 15 to 20 infected panicles were collected at random from the center rows within each plot. The panicles were pooled as a collection for each plot (treatment) and placed in paper bags, then placed in boxes before transport to the laboratory. In the laboratory, the number of sori/panicle was determined by counting the number of typical sori on 10 randomly selected panicles from each individual bag (plot). Thus, we collected 4 replications of 10 infected panicles from each treatment.

Statistical Analyses

The design for this experiment was a randomized complete block design with four replications of each treatment. An analysis of variance of the means of each treatment was conducted using PROC GLM of SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and a least significant difference test (LSD) of the means was used to separate differences at $P = 0.05$ for the dependent variables (infected panicles/m^2 and across the two sample times and sori/panicle).

RESULTS

Symptom Development

As expected, visible symptoms of infection did not appear on any of the cultivars used in the study at any time until 31 August 2012, when young sori were still encased within a membrane and a few orange sori were found developing on a few panicles already at the flowering stage. The infected plants were distributed throughout the test although there were differences between treatments. There were no indications of disease aggregation at this time.

Reaction of Selected Rice Cultivars Grown in Arkansas to Infection by *U. virens*

The average number of panicles visibly infected by false smut/m^2 was collected twice before harvest, once on 6 September 2012 and again on 24 September, 6 and 24 days after the first appearance of sori, respectively. Disease levels were assessed as described above by counting the number of visibly infected heads at multiple locations within each plot and these data were then averaged for each plot. A panicle was considered infected if it had a clearly identifiable sorus.

Analysis of variance shows that there were very significant differences between the cultivars for the number of infected panicles/m^2 for the data collected for both collection dates (Table 2). In Table 3, the mean numbers of infected panicles/plot show a wide and statistically significant range of incidence of infection by false smut in plots at Pine Tree. On 6 Sept., the incidences of infection ranged from 0.75 panicles/m^2 on Katy to more than 16 infected panicles/m^2, in some plots, on CL151. On 6 Sept., there were no significant differences in disease incidences between Katy, Kaybonnet, and Taggart, and no differences between Taggart and Neptune. In comparison, the incidence of infection was very significantly different for CL151 and all other cultivars.

The results of the survey conducted on 24 Sept. showed that there had been a general increase in the number of infected panicles/m^2 for all cultivars when compared to the levels found 18 days earlier, on 6 Sept. For the data collected on 24 Sept., there were no significant differences between Katy, Kaybonnet, Taggart, and Neptune; although the levels of infection were visibly higher on both Taggart and Neptune than on either Katy or Kaybonnet. This was probably due to variances between replications and samples among the data for Taggart and Neptune. In sharp contrast to these cultivars there were, on average, more than 18 infected panicles/m^2 on CL151, in contrast to only 1.33 to 7.33 infected panicles/m^2 on the other four cultivars.

The data in Table 3 also suggest that there might have been a significant increase in the number of infected panicles/m^2 for four of the cultivars on the second sampling date when the data is compared to the data from the first sampling date. However, statistical evaluation of the data between sampling times for all five cultivars revealed that there was no significant increase in disease over time (Table 2). Examination of the data revealed significant overlapping of the incidence data for the different sampling stations within each plot over time for all cultivars. Taken together, the data suggest that there was a rapid increase in disease incidence between the time of its first appearance in the plots and 6 days later and an insignificant increase in disease between 6 and 24 days after the first appearance of the disease in this test. We also found no evidence of interplot interferences due to dispersal of spores after examining the data according to position in the field plots. Similarly, adjacent field tests in which 12 susceptible cultivars (including these five cultivars) had been planted did not appear to have been affected by the close proximity (3 m) to this test.

The data in Table 1 shows that there were significant differences between treatments (= cultivars) in the average number of sori/infected panicle at $P = 0.05$. In Table 2, the data clearly indicates a significant difference between CL151 and the other four cultivars tested. In addition, Katy and Kaybonnet were the only cultivars with an average of fewer than 2 sori/panicle and these two cultivars were the only two cultivars that satisfied the requirements for a disease rating of 1 according to the Lu et al. (2009) scale. All three of the other cultivars were rated as a 2 although CL151 nearly had a rating of 3 according to this scale. We did observe some panicles with more than 9 sori/head on this cultivar. Despite our precautions in site selection, there may have been replication effects originating from overwintering inoculum or soil characteristics that may have affected the incidence of false smut and the number of sori/panicle (Table 2).

DISCUSSION

To our knowledge, this is the first report on the development of the disease on the basis of the time required for false smut sori to appear and reach a maximum incidence levels on cultivars grown in Arkansas. The disease progress curve for false smut in this test was very steep and different from the disease progress curves we have noted for rice blast or anthracnose diseases of grain sorghum and northern jointvetch and *Alternaria* on *Anoda cristata*, other diseases that have significant secondary dispersal and infection cycles (Li and TeBeest, 2009; Long et al., 2001; Moore et al., 2010; Yang and TeBeest, 1993). The cultivars used in this study were previously described as susceptible or moderately susceptible and all of the cultivars grown developed signs of infection. However, it was visibly and statistically evident that there were widely different levels of incidence and severity of false smut among the cultivars at Pine Tree in 2012. In general, Katy and Kaybonnet appeared to be the more 'resistant' or 'tolerant' of the five cultivars tested under the conditions in which they were grown at Pine Tree in 2012.

In the absence of visible symptoms of infection prior to heading, many of the previous studies described above have estimated the relative resistance of cultivars on the basis of the development of visible signs of infection on the panicles or the number of infected heads/unit area. Others have measured the number of sori found in harvested grain. In this study, we collected data on two dependent variables: the number of infected panicles/m^2 in individual field plots and the number of sori on infected panicles from each of 5 cultivars planted, which were previously described as either susceptible or moderately susceptible to *U. virens*. Analysis of variance indicated that there were significant differences in the incidence of false smut between the treatments (cultivars) when measured within 6 days and 24 days after the initial appearance or emergence of the smut sori. The two data sets, gathered 18 days apart from the same general areas of the same plots, are presented as separate events. Statistical evaluation of the incidence data suggests that there were no significant increases in disease incidence for any cultivar after the initial data taken 6 Sept. It is relatively clear from these preliminary data that additional work on the epidemiology of false smut is necessary. Studies to define the rate of increase in the emergence of sori over time in relation to the emergence of panicles from the boots and relative to the levels of resistance within cultivars, would be beneficial. In addition, since the incidences of infection for these five cultivars were much higher in 2011 than in 2012 when measured with the same techniques, it raises questions concerning the role and source of primary inoculum, cultural conditions, and environmental effects on the final incidence of this disease.

Hedge and Anahosur (2000) and Lu et al. (2009) attempted to describe susceptibility of different cultivars on the basis of the number of spore balls/panicle. In 2011, TeBeest et al. used a similar assessment tool and a larger number of cultivars and found that there were statistically significant differences in the number of false smut sori on panicles for the cultivars used in that study. The data in this report also show statistically significant differences in both the severity (= sori/panicle) and in the incidence (= number infected panicles/m^2) of false smut on the five cultivars tested in 2011 at Newport, a location consistently more conducive to false smut development.

SIGNIFICANCE OF FINDINGS

False smut is an emerging and increasingly significant pathogen of rice in Arkansas. Although first reported in a single field in White County, Ark., in 1997, it is now considered to be widespread within the state. Disease resistance is a mainstay of managing many plant diseases. Finding germplasm that demonstrates resistance or tolerance to false smut across the different soil and environmental conditions in the state may be crucial toward successful and integrated management practices. Based on the preliminary data in this test and on the evidence already in the literature for false smut and other diseases, we have begun to develop the methodologies necessary to identify and evaluate germplasms across locations and fields with reasonable assurances of success. In that sense, the results of work conducted in 2011 and 2012 continues to warrant further investigation if they remain inconsistent over time and location.

Given that infestations of seed and soil with viable spores can lead to infections, we need to understand the roles that inoculum, cultivar genetics, and soil fertility may have on the general significance of false smut in Arkansas. The possibility that pathotypes of this fungus may already exist in Arkansas, although as yet not described, must not be overlooked. Lastly, the epidemiology of this disease is poorly understood. Further work on the disease progress curves across cultivars and locations in relation to flowering could provide useful information regarding management of this disease with fungicides or disease resistance.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Arkansas Rice Research and Promotion Board and the Director of the University of Arkansas Agriculture Experiment Station. We are grateful for the seeds of the test cultivars provided by R. Cartwright and K.A.K. Moldenhauer and the Arkansas Rice Foundation Seed program. The authors are indebted to J. Velie, Systems Analyst, University of Arkansas Agricultural Statistics Laboratory, for his assistance with the statistical analyses and Jody Hedge for his vigilance and dedication to maintaining our research plots at the Pine Tree and Newport Research Stations.

LITERATURE CITED

Ashizawa, T., M. Takahashi, J. Moriwaki, and K. Hirayae. 2011. A refined inoculation method to evaluate false smut resistance in rice. J. of General Plant Pathology 77:10-16.

Branson, J.D., D.L. Frizzell, C.E. Wilson Jr., J.A. Yingling, C.E. Parsons, R.D. Cartwright, J.W. Gibbons, K.A.K. Moldenhauer, and R.J. Norman. 2009. Utilization of on-farm testing to evaluate rice cultivars for disease reaction and yield. *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 571:93-101. Fayetteville.

Brooks, S.A., M.M. Anders, and K.M. Yeater. 2009. Effect of cultural management practices on the severity of false smut and kernel smut of rice. Plant Disease 93:1202-1208.

Brooks, S.A., M.M. Anders, and K.M. Yeater. 2010. Effect of furrow irrigation on the severity of false smut in susceptible rice varieties. Plant Disease 94:570-574.

Cartwright, R.D. and F.N. Lee. 2001 Management of rice diseases, Chapter 10. *In:* N.A. Slaton (ed). Rice Production Handbook. MP 192:87-100. University of Arkansas System Division of Agriculture Cooperative Extensive Service.

Cartwright, R.D., F.N. Lee, C.E. Parsons, W.J. Ross, S.R. Vann, and R. Overton. 1999a. Monitoring of rice diseases and on-farm evaluation of rice varieties in Arkansas. *In:* R.J. Norman and T.H. Johnson (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:148-156.

Cartwright, R.D., F.N. Lee, W.J. Ross, S.R. Vann, R. Overton, and C.E. Parsons. 1999b. Evaluation of rice germplasms for reaction to kernel smut, false smut, stem rot and black sheath rot of rice. *In:* R.J. Norman and T.H. Johnson (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:157-168. Fayetteville.

Cartwright, R.D., F.N. Lee, T. Beaty, E.A. Sutton, and C.E. Parsons. 2000a. Reaction of rice cultivars/lines to false smut, stem rot, and black sheath rot. *In:* R.J. Norman and C.A. Beyrouty (eds.). B.R. Wells Rice Research Studies 1999. University of Arkansas Agricultural Experiment Station Research Series 476:158-168. Fayetteville.

Cartwright, R.D., F.N. Lee, C.E. Parsons, W.J. Ross, and E.A. Sutton. 2000b. Disease monitoring and on-farm evaluation of rice varieties in Arkansas. *In:* R.J. Norman and C.A. Beyrouty (eds.). B.R. Wells Rice Research Studies 1999. University of Arkansas Agricultural Experiment Station Research Series 476:169-178. Fayetteville.

Cartwright, R.D., C.E. Parsons, B.J. Dodgen, F.N. Lee, and E.A. Sutton. 2002. Rice disease monitoring and on-farm variety evaluation in Arkansas. *In:* R.J. Norman and J.-F. Meullenet (eds.). B.R. Wells Rice Research Studies 2001. University of Arkansas Agricultural Experiment Station Research Series 495:138-147. Fayetteville.

Ditmore, M. and D.O. TeBeest. 2006. Detection of seed-borne *Ustilaginoidea virens* by nested-PCR. *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 540:121-125. Fayetteville.

Ditmore, M., J.W. Moore, and D.O. TeBeest. 2007. Infection of plants of selected rice cultivars by the false smut fungus, *Ustilaginoidea virens*, in Arkansas. *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 550:132-138. Fayetteville.

Guo, Y., Y. Li, J. Fan, L. Li, F. Huang, and W. Wang. 2012. Progress in the study of false smut disease of rice. J. Agric. Sci. Technol. A2:1211-1217.

Hedge, Y.R. and K.H. Anahosur. 2000. Effect of false smut of rice on yield components and growth parameters. Indian Phytopathol. 53:181-184.

Ikegami, H. 1963. Occurrence and development of sclerotia of the rice false smut fungus. Res. Bull. Fac. of Agriculture. Gifu University, No. 20.

Koiso, Y., M. Natori, S. Iwasaki, S. Sato, R. Fujita, H. Yaegashi, and Z. Sato. 1992. Ustiloxin: a phytotoxin and a mycotoxin from false smut balls on rice panicles. Tetrahedron Letters. 33:4157-4160.

Lee, F.N. and P.S. Gunnell. 1992. False Smut. p. 28. *In:* R.K. Webster and P.S. Gunnell (eds.). Compendium of Rice Diseases. American Phytopathological Society, St. Paul, Minn.

Li, Y. and D.O. TeBeest. 2009. Temporal and spatial development of sorghum anthracnose in Arkansas. Plant Disease. 93:287-292.

Long, D.H., J.C. Correll, F.N. Lee, and D.O. TeBeest. 2001. Rice blast epidemics initiated by infested rice grain on the soil surface. Plant Disease 85:612-616.

Lu, D.H., X.Q. Yang, J.H. Mao, H.L. Ye, P. Want, Y.P. Chen, Z.Q. He, and F. Chen. 2009. Characterising the pathogenicity diversity of *Ustilaginoidea virens* in hybrid rice in China. J. Plant Pathol. 91:443-451.

Miyazaki, S., Y. Matsumoto, T. Uchihara, and K. Morimoto. 2009. High-performance liquid chromatographic determination of ustiloxin A in forage rice silage. J. Vet. Med. Sci. 7:239-241.

Moore, J.W., M. Ditmore, and D.O. TeBeest. 2010. Development of anthracnose on grain sorghum hybrids inoculated with recently described pathotypes of *Colletotrichum sublineolum* found in Arkansas. Plant Disease 94:589-595.

Parsons, C.E., C. Wilson, R.D. Cartwright, E.A. Sutton, C. Carpenter, and F.N. Lee. 2004. Evaluation of rice varieties for performance and disease reactions on farms. *In:* R.J. Norman, J.-F. Meullenet and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2003. University of Arkansas Agricultural Experiment Station Research Series 517:79-87. Fayetteville.

Robinson, J.C., J.A. Yingling, C.E. Parsons, F.N. Lee, C.E. Wilson Jr., D. Frizzell, J. Branson, and R.D. Cartwright. 2010. Assessment of disease reaction of advanced southern U.S. Rice germplasms in the field. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station Research Series 581:76-83. Fayetteville.

Schroud, P. and D.O. TeBeest. 2006. Germination and infection of rice roots by spores of *Ustilaginoidea virens* by nested-PCR. *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 540:143-151. Fayetteville.

Tang, Y.X., J. Jin, D.W. Hu, M.L. Yong, and L.P. He. 2012. Elucidation of the infection process of *Ustilaginoidea virens* (teleomorph: *Villosiclava virens*) in rice spikelets. Plant Pathology Doi: 10.1111//j.1365-3059.2012.02629.x.

TeBeest, D.O., A.C. Jecmen, and M. Ditmore. 2011. Infection of rice by the false smut fungus, *Ustilaginoidea virens*. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:70-81. Fayetteville.

Wilson, C.E. Jr., R.D. Cartwright, J.W. Gibbons, A.L. Richards, D.L. Frizzell, J.W. Branson, S. Runsick, and C.E. Parsons. 2005. Evaluation of rice varieties for performance and disease reaction on farms. *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 529:149-158. Fayetteville.

Yang, X.B. and D.O. TeBeest. 1993. An epidemic of endemic alternaria blight of spurred anoda. Plant Disease 77:1164-1167.

Zhou, Y.L., K. Izumitsu, R. Sonada, T. Nakazaki, E. Tanaka, M. Tsuda, and C. Tanaka. 2003. PCR-based specific detection of *Ustilaginoidea virens* and *Ephelis japonica*. Journal of Phytopathology 151:513-518.

Table 1. Results of analysis of soil samples collected from the field plots at the Pine Tree Research Station, Colt, Ark., in 2012.

Location	Sample[†]	pH	EC	P	K	Ca	Mg	S	Na	Fe	Mn
				----------------------------------(mg/kg) -----------------------							
Pine Tree	1	6.9	107	66.1	123	1566	245	18.6	46.5	560	111
	2	6.5	114	79.5	138	1565	230	28.0	47.7	587	97
	3	7.0	122	53.3	111	1965	289	21.7	47.6	536	439
	4	6.6	105	70.9	121	1648	265	16.1	43.1	594	98
	5	6.8	128	39.4	115	1708	284	22.1	53.9	535	149
	6	6.8	120	70.2	128	1694	270	20.1	43.1	590	127

[†] All data based upon six replicated samples collected on 6 June 2012 and analyzed by the Agricultural Diagnostic Laboratory, University of Arkansas, Fayetteville. Values for EC and pH (1:2 soil/water ratio), Mehlich-3 (1/10 ratio) Analysis by Spectros Arcos inductively coupled plasma mass spectrometry.

Table 2. Analysis of variance of the number of infected panicles counted per square meter and the number of sori found per panicle for five selected cultivars grown in four replications at the Pine Tree Research Station, Colt, Ark., in 2012.

Date/ variable[†]	Source	DF	Sums of squares	Mean square	F value	Pr > F
5 Sept.						
No. panicles	Rep	3	51.6625	17.220	4.23	0.0296
	Treatment	4	666.5500	166.637	40.89	<0.0001
	Error (MS)		48.9000	4.075		
24 Sept.						
No. panicles	Rep	3	107.517	35.838	1.89	0.189
	Treatment	4	744.436	186.109	9.80	<0.001
	Error (MS)	12	227.997	18.999		
Infected	Rep * Treatment	12	136.897	11.408	0.93	0.544
Panicles	Time	1	49.506	49.506	4.03	0.063
over time	Treatment* time	4	25.935	6.484	0.53	0.717
	Error: MS (error)	15	184.038	12.484		
Sori/panicle	Rep	3	2.962	0.987	3.18	0.063
	Treatment	4	8.068	2.017	6.49	0.005
	Error (MS)	12	3.728	0.310		

[†] Variables = values for the dependent variable, no. of panicles/m^2, are given as the average number of infected panicles/m^2 found in replicated plots of five cultivars collected at two different times after first appearance. The dependent variable, sori/panicle, was based on the number of sori counted per panicles collected from 10 infected panicles from each replication of each cultivar (= treatment). Analysis of variances evaluations were performed using a general linear models (GLM) procedure in SAS.

Table 3. The mean number of infected panicles counted per square meter and the number of sori found on panicles of selected cultivars planted in field plots grown at the Pine Tree Research Station, Colt, Ark., in 2012.

	Infected panicles[†]		Sori	Rating class[‡]
Cultivar	6 Sept.	24 Sept.	24 Sept.	24 Sept.
	---------- (no./m^2) -----------		(no./panicle)	
Katy	0.75 A	1.52 A	1.65 A	1
Kaybonnet	1.00 A	1.33 A	1.25 A	1
Taggart	1.62 AB	6.42 A	2.00 AB	2
Neptune	4.25 B	7.33 A	2.70 AB	2
Clearfield 151	16.00 C	18.12 C	2.95 B	2

[†] Means followed by the same letter within a column are not significantly different according to Fisher's protected least significant difference test at $P = 0.05$. Data are the averages of multiple samples per plot and 4 replications per treatment. The number of sori per panicle is based on 10 randomly selected infected panicles per plot and 4 replications of each treatment.

[‡] Disease ratings as reported by Lu et al. (2009). Disease rating classes were assigned based on the average of the number of spore balls/10 panicles per replication/cultivar. Class 0 = 0 sori/panicle; class 1, one sorus/panicle; class 2, two sori/panicle; class 3, three sori/panicle; class 4, six to nine sori/panicle; and class 5, greater than ten sori/panicle.

Fig. 1. Signs of infection of rice by *Ustilaginoidea virens* found on panicles of one of the more susceptible cultivars in our field plots at Pine Tree in 2012. The nine sori are beginning to turn from their initial orange color to dark green before they become blackened at maturity.

Development of Short-Term Management Options for Rice Bacterial Panicle Blight Disease

Y. Wamishe, S. Belmar, C. Kelsey, and D. McCarty

ABSTRACT

Field trials were conducted in 2012 at the University of Arkansas System Division of Agriculture Rice Research and Extension Center near Stuttgart, Ark., to evaluate the effects of planting date, water stress, seeding rate, and nitrogen (N) fertilizer on bacterial panicle blight disease of rice. In addition, preliminary tests were conducted both in the laboratory and greenhouse to develop an artificial seed inoculation technique for the study of chemical and non-chemical seed treatments. Late-planted plots had significantly higher disease incidence on both Bengal (susceptible variety) and Jupiter (moderately resistant variety) resulting in considerable yield and milling quality losses. Water stress showed more of a negative effect on yield than bacterial panicle blight disease for both inoculated and non-inoculated plots. Seeding rate and N fertilizer in split-plot tests showed no significant treatment effects on disease incidence, yield, or milling quality. The artificial seed inoculation method developed in the laboratory was effective for field study. Ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds were screened for their antibacterial activity on inoculated seeds. These screenings are at preliminary level and tests on seed germination are not complete.

INTRODUCTION

Bacterial panicle blight (BPB) has been observed in rice production fields of Arkansas and other southern states with increasing frequency since 1995 (Cartwright, pers. comm.). Extended hot summer nights are favorable to this disease which is thought to be primarily seedborne. The BPB was severe in 2010 and 2011 causing up to 60%

yield loss under environmental conditions favorable for the disease (Cartwright, pers. comm.) Panicle symptoms typically develop late in the season, which makes predicting disease occurrence difficult. Infected panicles have mostly blighted florets which first appear white to light gray with a dark-brown margin on the basal third of the tissue. Later, these florets turn straw-colored and may further darken toward the end of the season with growth of other opportunistic microorganisms. Heavily infected panicles remain upright due to lack of grain fill. There are no chemical options registered in the U.S. to protect or salvage the crop from the disease. This disease, which is dependent on weather and environmental conditions, is sporadic in nature and the causal agents survive in the soil, crop residues, and seeds. The purpose of this research is to examine cultural, chemical, and non-chemical management options that may be used solely or in combination to reduce BPB of rice until resistance is identified and incorporated into high yielding and adapted cultivars.

PROCEDURES

Land Preparation and Planting

Test fields which were cropped the previous year in rice and reported to have BPB were tilled and prepared in the early spring. A preplant fertilizer of Triple Super Phosphate (65 lb/acre), potassium chloride (100 lb/acre), and CoZinco (30 lb/acre) was applied. A burn down application of Gramoxon Inteon was applied to kill weeds and off-type rice. The area was then roto-tilled to loosen the soil and ensure a good seed bed. Planting was done with a Hege 1000 seed drill set to plant 8 rows on 8-inch row spacing approximately one inch deep. The plots were approximately 5 ft by 14 ft. After planting, the plots were rolled to ensure good soil-to-seed contact and to seal in moisture.

Evaluation of the Effects of Planting Date on Bacterial Panicle Blight Disease

Although more than one species of *Burkholderia* are involved in causing rice BPB disease, tests were carried out using only *B. glumae* because it was more frequently isolated from infected kernels in Arkansas. To obtain uniformly infected seeds and to ensure the survival of the bacteria until cotyledon emergence, an artificial inoculation method was developed. *B. glumae* from at least a 4-d old culture, grown on non-selective King's B medium at 104 °F, was washed from a petri dish to obtain a 1-ml suspension. The bacterial suspension was mixed with 4 ml salt-sugar buffer (1 g yeast extract, 2.36 g NaCl, and 3.4 g sucrose/liter of distilled water) (Streeter, 2007). The mixture was infiltrated into 40 g of rice seed by applying a vacuum (25 in. Hg vacuum) for 5 min followed by restoring atmospheric pressure before repeating the vacuuming process a second time. Seeds were then covered with 8 g of talc (powder) to absorb excess liquid and to ease planting. The talc shield also was meant to serve as a buffer between soil and seeds until germination. After emergence, samples of cotyledons were tested for the presence of *B. glumae* on partially selective medium designated, CCNT (Kawaradani et al., 2000). The CCNT agar is a medium containing 2 g of yeast extract, 1 g of polypepton, 4 g of inositol, 10 mg of cetrimide, 10 mg of chloramphenicol, 1 mg of novobiocin, 100 mg of chlorotharonil, and 18 g of agar in 1000 ml of distilled water, and adjusted to pH 4.8. Artificially inoculated seeds of Bengal (susceptible variety) and Jupiter (moderately resistant variety) were planted at the recommended seeding rate of 88 lb/acre on 20 March, 24 April, and 24 May as early, normal, and late planting dates (1st, 2nd, and 3rd), respectively. Plots were replicated four times using a completely randomized design (CRD). To obtain objective measurement on the disease, upright panicles with typical disease symptoms were counted as 100% infected and those that bent down slightly and with typical symptoms on the younger florets as 50%. The counts for 50% were later divided by two to maintain uniformity, and percentage disease incidence was calculated. This disease rating method was used for all field tests in this study.

Evaluation of Water Stress on Bacterial Panicle Blight Disease

Plots were planted on 22 May with Bengal, a BPB-susceptible variety, at the rate of 88 lb/acre. To further improve the chances of observing BPB, plots in two bays were planted with artificially inoculated seeds while plots in the other two bays were planted with non-inoculated seeds. Water treatments consisted of a conventional permanent flood or intermittent flood applied per bay. Intermittent flood treatment plots were allowed to dry down to a soil moisture content of approximately 40% before being re-flooded. Soil moisture was monitored and recorded by soil moisture sensors (Irrometer Co., Riverside, Calif.) placed at depths of 2 in. and 4 in. Water usage was recorded with flow meters (McCrometer, Hemet, Calif.) installed in each of the four bays of the test. The permanent flood bays remained flooded throughout the growing season until drained for harvest. The intermittent bays were allowed to dry down a total of three times during the growing season. All bays were drained on 28 September and allowed to dry for harvest. The test was harvested on 17 October.

Evaluation of Effect of Seeding Rate and Nitrogen Fertilizer on Bacterial Panicle Blight Disease

Seeding rate and N fertilizer effects on BPB disease incidence and severity were tested using a split plot design. *B. glumae*-inoculated seeds of Bengal and Jupiter were planted at a recommended seeding rate (88 lb/acre) and a high seeding rate (176 lb/acre) on 27 April. Two N rates were investigated: the NST*R recommended rate 150 lb N/acre and a rate of 180 lb N/acre. The fertilizer was applied at preflood.

Evaluation and Testing of Chemical and Non-Chemical Seed Treatments

Ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds were screened on artificially inoculated seeds with *B. glumae*. Seed germination testes were carried out for those that showed some level of positive results in their antibacterial activity.

RESULTS AND DISCUSSION

With March and April planting dates, the average percent infected panicles per plot in Jupiter were 0.37% and 0.43% compared to Bengal 0.44% and 0.69%, respectively (Fig. 1). The latest planting date (24 May) appeared to have an extremely high effect on BPB disease incidence and severity on both varieties. The average percent of infected panicles in Jupiter was 49.4% while Bengal had 99%. Most of the panicles in Jupiter showed 50% infections (lower part of the panicles) while Bengal showed 100% (whole panicle).

Grain yield and milling quality also were adversely affected in the latest planting date. Although, the extent of the bird damage was not measured, grain yield in March-planted plots was influenced by bird feeding both before emergence and after heading. Therefore, parameter comparisons were made between April-planted and May-planted plots. In May planting, Bengal showed a 41% yield loss when compared to the yield from April planting. Likewise, Jupiter showed a 33% yield loss (Fig. 2). In both varieties, the yield losses were large. Head rice yields were similarly reduced in May-planted plots compared to April-planted plots causing 25% and 22% reductions in Bengal and Jupiter, respectively (Table 1).

Historically, early planting is generally encouraged to allow adequate time for plant development and grain fill and to escape some rice diseases such as blast. This study indicated March to April planting dates minimized BPB disease incidence resulting in lower effects on yield and grain quality. Observations in previous years showed BPB disease of rice to be severe with high temperatures, particularly extended nighttime air temperatures above 78 °F (D. Groth and R.D. Cartwright, pers. comm.). It is not yet well understood at which stage of the crop that temperature plays the greatest role and what other factors are involved. High humidity, together with prolonged high night temperatures could be key factors. It is likely that favorable temperature and humidity during the earlier crop stages up until boot or boot split allows the survival of the bacteria as an epiphyte if the inoculum source is in seed or soil. These bacteria then move up the crop canopy and eventually become established in the florets. Under lab conditions, *B. glumae* grows well on CCNT or King's B media at temperatures between 98 °F to 104 °F. These bacteria also grow at room temperature but at a slower rate.

Bengal and Jupiter took nearly three months to reach boot stage. Stuttgart weather data indicated the average air maximums from 78.2 °F to 88.4 °F and the average minimums from 55.4 °F to 68.6 °F for the months of April to June, respectively. The average maximum for July and August was 93.6 °F and 87.1 °F while the minimum was 74.5 °F and 70.9 °F, respectively. Average minimum soil temperatures for July and August were 81 °F and 77.7 °F. Soil temperature may play a role in raising the humidity under the canopy creating a favorable microenvironment for the bacteria. However, there is no report on the role of soil temperature in the survival or multiplication of the bacteria. Seeds in all the three planting dates were inoculated similarly and hence, low disease incidence in the first two planting dates cannot be attributed to the absence of inoculum. The seed inoculation method was proven effective with the 3rd planting date where Bengal and Jupiter showed severe disease levels.

Observations from the field test in 2012 indicated that BPB disease on the third planting date became distinct within a week after tropical storm Isaac brought 2.53 inches of rain on 31 August. The non-inoculated border variety (Wells), on the west side of the inoculated plots, showed noticeable BPB disease pressure compared to the Wells planted on the east side of the inoculated plots. The rainy wind that blew east to west drove the bacteria from inoculated plots to the susceptible plants. This suggested windy rain as a possible dispersal mechanism and as an indicator of new infection after heading. The planting date experiment will be repeated for two more seasons.

In the water stress test, BPB incidence was greater in conventionally flooded plots than in intermittent flooded plots (data not shown). However, grain yields were lower in the intermittent flooded plots (data not shown) due to water stress. The soil moisture was lowered up to 40% causing the soil surface to crack and we waited a few days to re-establish the flood. This low level moisture resulted in rolled leaves because the plants were too stressed and possibly the stress condition was too extreme. This test will be conducted for the next two seasons with intermittent flushing instead of intermittent flooding.

Seeding rate and N fertilizer in a split-plot tests showed no treatment effects on disease incidence (data not shown). The lack of differences may be due to the planting time (26 April). Based on the planting date experiment described above, the disease pressure was much higher on late-planted (late May) than April-planted plots. The experiment will be repeated separating the fertility level and seeding rate treatments in randomized complete design. Planting will be in May after the 2nd week.

Preliminary tests of seed treatment for antibacterial activity on artificially inoculated seeds with *Burkholderia glumae* using ultraviolet light, microwave, household antimicrobial agents, hot water, freezing, an industrial sanitation chemical, plant extracts, competitor bacteria, silver, and copper compounds are still being screened.

SIGNIFICANCE OF FINDINGS

Bacterial panicle blight has been the most important disease in Arkansas rice causing millions of dollars loss in 2010 and 2011. While the development of resistant cultivars will offer the best long-term control, short-term disease management options such as adequate planting time, seeding rate, fertilizer amount, water management, and seed treatment options that we hypothesized may have effect on BPB disease intensity needed to be explored. Among these, the planting date experiment has shown clear indication that late-planted material had more incidence of disease.

ACKNOWLEDGMENTS

Special appreciation is extended to the Rice Research and Extension Board for providing funding and support for these projects; to Cartwright of University of Arkansas System Division of Agriculture and Don Groth of Louisiana State University for their technical help; Jarrod Hardke of University of Arkansas for reviewing the manuscript; and Chris Henry and Merle Anders of University of Arkansas for their advice in setting up the water stress test.

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.

Streeter, J.G. 2007. Factors affecting the survival of *Bradyrhizobium* applied in liquid cultures to soya bean [*Glycine max* (L.) Merr.] seeds. J. Applied Microbiology 103:1282-1290.

Table 1. Effect of planting date on milling quality for Bengal (a susceptible variety) and Jupiter (a moderately resistant variety) as a result of bacterial panicle blight disease of rice.

	Milling	
Planting date	Bengal	Jupiter
	----------(% head/% total)----------	
20 March	58/68	59/67
24 April	64/71	62/71
24 May	48/66	48/70
LSD (0.05)[a]	3.96/1.12	

[a] LSD = least significant difference.

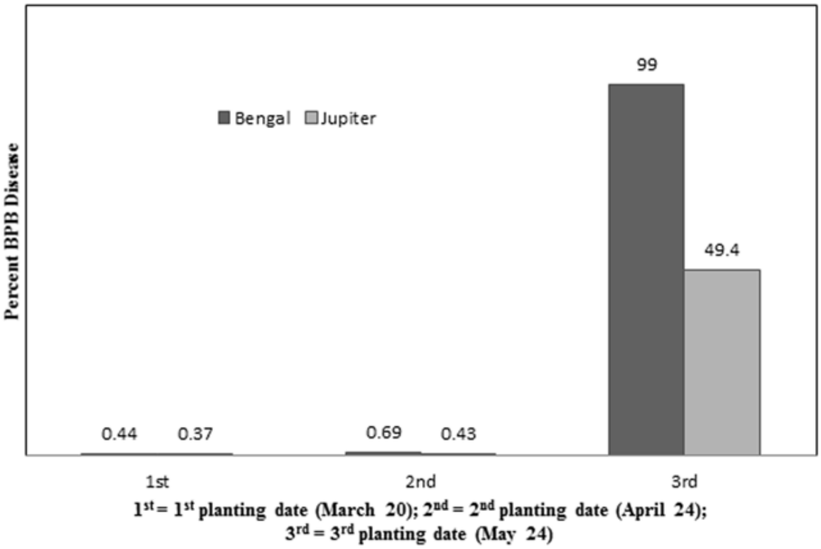


Fig. 1. Percent bacterial panicle blight (BPB) incidence in three planting dates on Bengal (a susceptible variety) and Jupiter (a moderately resistant variety) 2012.

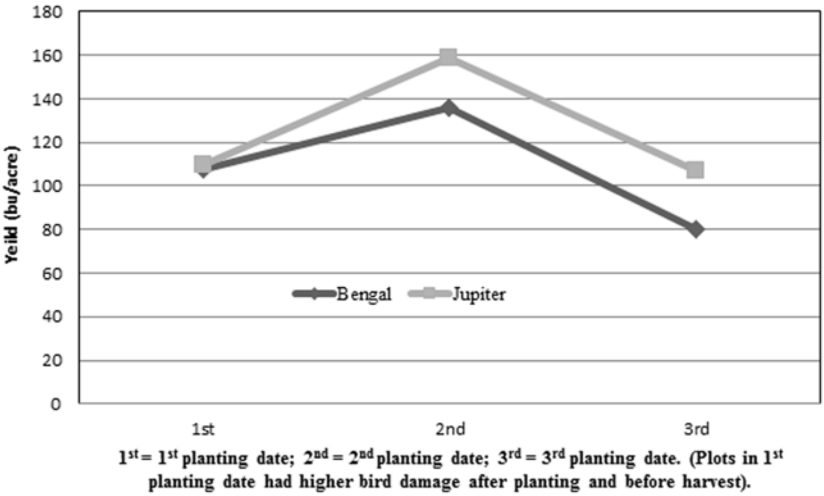


Fig. 2. Grain yield (bu/acre) of Bengal (a susceptible variety) and Jupiter (a moderately resistant variety) as affected by bacterial panicle blight of rice in three planting dates.

Development of Practical Diagnostic Methods for Monitoring Rice Bacterial Panicle Blight Disease and Evaluation of Rice Germplasm for Resistance

Y. Wamishe, Y. Jia, C. Kelsey, S. Belmar, and M. Rasheed

ABSTRACT

A study was initiated to understand *Burkholderia glumae,* the major causal agent for bacterial panicle blight disease of rice; to develop practical diagnostic methods for monitoring the disease; and to evaluate rice germplasm for resistance. *Burkholderia glumae* was frequently isolated from infected panicles on semi-selective medium, designated CCNT. Selected isolates were assessed for virulence by using a hypersensitivity reaction on wild tobacco leaves and pathogenicity tests on rice seedlings. *B. glumae* isolates found positive for tests in hypersensitivity and pathogenicity were used to inoculate seedlings and adult rice plants (at heading) in the greenhouse, and germplasm screening for resistance in the field. Three hundred entries from the Uniform Regional Rice Nursery (URRN) and Arkansas Rice Performance Trials (ARPT) were inoculated between the boot-split and flowering growth stages of rice. Of 300 entries, 14 entries showed no symptom of the disease and 30 entries showed moderate resistance. These entries rated from 1 to 4 on a disease scoring scale of 0 to 9 where 0 is no disease and 9 is severe bacterial panicle blight disease. The remaining entries rated between 5 and 9 and were grouped as moderately susceptible to very susceptible. Greenhouse inoculation on adult rice plants at heading showed discoloration on a few florets in the susceptible variety Bengal. None of the seedling inoculations were definitive enough to separate relative resistance levels among the varieties tested. This study reports preliminary findings only from one season and additional tests, including molecular markers will continue for two more years.

INTRODUCTION

Bacterial panicle blight (BPB) of rice has been observed for many years in Arkansas and other southern rice-producing areas of the United States as a disorder of unknown cause. Until the devastation of Bengal in the mid-1990s, the disease was not considered to be a major problem. In 1996-97 it was discovered at Louisiana State University that *Burkholderia glumae* (formerly known as *Pseudomonas glumae*) was the major biotic agent causing BPB disease of rice. The disease has been increasing in rice production fields in Arkansas and other southern rice-producing states since 1995 and was very severe in 2010 and 2011 (Cartwright, pers. comm.). Although *B. glumae* is the major species of bacteria frequently isolated from symptomatic rice panicles, the disease can be caused by more than one species of bacteria with different and/or overlapping habits. For instance, *B. glumae* is mainly seedborne while other bacteria are seedborne and residueborne. The complexity of the bacterial species could contribute to the difficulty in BPB disease management.

So far, there are no dependable cultural management options to reduce bacterial panicle blight. It has been reported that fields receiving less applied nitrogen (N) had a reduced incidence of BPB and studies are ongoing to confirm this observation. Preliminary data from 2012 field tests showed that water stress impacted yield more than BPB. Early plantings of rice showed little to no symptoms of the disease. The disease seems to favor extended hot summer nights; however, the role of weather factors that encourage bacterial activity remain unclear. Fields cropped to continuous rice appear to have more severe disease symptoms. Overall, disease occurrence appears unpredictable due to insufficient information on the effect of crop rotation, how long the bacteria may survive in soil or on crop residues and favorable weather conditions.

The disease cycle for BPB is not fully understood and chemical control options used in Asia have not been registered in the U.S. Current fungicides used on rice in the U.S. have no activity on bacterial panicle blight and the development of antibiotic resistance in Asia to products used there have raised concern about their successful use here. The ultimate solution to manage BPB would be use of resistant varieties. Therefore, the objectives of this study include (1) understanding the biology of the bacteria that cause BPB; (2) developing suitable methods for screening and selecting resistant germplasm in the greenhouse and field; and (3) identifying rice lines with reliable resistance for use in breeding programs. If successful with greenhouse seedling inoculation, we will work on identifying molecular markers based on gene expression. These markers would enable more efficient screening of advanced breeding lines prior to variety release.

PROCEDURES

Burkholderia glumae was isolated from infected kernels collected from symptomatic rice florets during the 2011 crop season on CCNT agar medium. The CCNT agar is a selective medium containing 2 g of yeast extract, 1 g of polypepton, 4 g of inositol, 10 mg of cetrimide, 10 mg of chloramphenicol, 1 mg of novobiocin, 100 mg of chlorotharonil, and 18 g of agar in 1000 ml of distilled water, and adjusted to pH

4.8. Only isolates that produced yellow pigment diffused in CCNT agar medium were selected and tested for hypersensitivity reaction on wild tobacco (*Nicotania rustica*) leaves and for pathogenicity on rice seedlings. The yellow pigment diffused in the agar is a characteristic toxin produced by *B. glumae*. Pure isolates were stored at -80 °F in 25% glycerol. For greenhouse and field inoculations, two isolates were combined equally to form a mixture.

Evaluation of a greenhouse seedling inoculation method to identify levels of resistance included: spraying, injection, dipping, toothpick transfer, direct agar-plug contact with detached leaf or stem base, tissue cutting/wounding, and soil inoculation with a bacterial suspension. Three 6-wk-old seedlings per pot were tested with needle and spray inoculation. Germinated seeds were transferred into the soil infested with the bacterial suspension, whereas three 4-wk-old seedlings were used for other tests. Bacterial concentration for these tests varied from ~10^6 to 10^9 colony-forming units per milliliter (cfu/ml). To maintain high humidity for 24 h after spray treatments, a dew chamber and plastic bags were used. Rice varieties Bengal (susceptible variety) and Jupiter (moderately resistant variety) were used in all tests except for needle injection where LM1, NPB/CCDR, LR2065/CCDR (resistant lines), and CL181-AR (susceptible variety) were also included.

To test spray inoculation in the greenhouse on adult plants at heading, the rice varieties Bengal and Jupiter were used. Plants were spray-inoculated using an airbrush sprayer (Badger Air-Brush Co., Franklin Park, Ill.) to apply a bacterial suspension of ~10^8 cfu/ml on panicles. The greenhouse was set at 86 °F and 74 °F average day and night temperature, respectively.

To screen rice germplasm for bacterial panicle blight resistance, 200 URRN and 100 ARPT entries were planted in fields at the Rice Research and Extension Center (RREC) near Stuttgart, Ark. Four sets of all the 300 entries were planted: two on 17 April and two on 15 May in a row plot of 5 ft. A set from each planting date was spray-inoculated artificially twice between boot-split and early flowering using a backpack sprayer (Solo, Newport News, Va.) to apply a bacterial suspension of approximately 10^6 cfu to 10^8 cfu/ml following the procedure adopted from LSU (Groth, pers. comm.) and our greenhouse preliminary test. A set from each planting was kept non-inoculated to serve as a control.

B. glumae for field inoculation was grown on petri dishes of King's B medium. King's B medium is a non-selective medium and is used to subculture known bacteria. A culture of 24 h to 48 h old was washed with 10 ml of water and mixed in 1.5 l of water. The solution was slowly stirred using a magnetic mixer for 30 min. Plants in each entry row were inoculated from boot-split to flowering and flagged for each of two consecutive inoculations. During the inoculation period, growth stage was checked twice weekly. Disease data were recorded three weeks after the last inoculation using a 0 to 9 scale, where 0 is no disease and 9 is severe disease. Non-inoculated control entry rows were also evaluated similarly.

RESULTS AND DISCUSSION

All *Burkholderia glumae* isolates obtained from symptomatic infected kernels produced yellow pigment (known as flavotoxin) on CCNT medium. They also showed a strong positive hypersensitive reaction when tested in the greenhouse on wild tobacco leaves and for pathogenicity on rice seedlings.

None of the inoculation methods attempted on seedlings in the greenhouse showed differences in disease resistance between Bengal and Jupiter. Seedlings of Bengal and Jupiter were sprayed with a bacterial suspension after first gently rubbing the leaves with sandpaper to wound them. Plants incubated in a dew chamber showed tiny necroses but differences in varietal resistance were not evident. Needle injection on the stem consistently showed long and noticeable lesions that extended to the mid-veins of the leaves. However, both Bengal and Jupiter responded similarly making the method erratic. Furthermore, it was a lengthy process and hard to maintain consistency in the injected volume of the bacterial suspension because of variability in stem thickness between varieties and even among plants of the same variety. Dipping sprouted seeds in bacterial suspension and transferring the sprouts in pots filled with soil did not show any kind of ill-symptom. Toothpick tips immersed in bacterial suspension for half an hour and placed in the collar (between the culm and sheath) produced lesions on the leaf sheath in both Bengal and Jupiter. Lesion sizes were restricted to less than two mm with no measurable differences in reaction between the two varieties. Bacterial agar plugs on detached leaves incubated at 104 °F produced a longer lesion on both Jupiter and Bengal than those kept at room temperature. Lesion size appeared to vary on leaf width rather than varietal resistance levels. Placing bacterial agar plugs at the base of the seedling stem did not produce any lesions. Cutting leaves with scissors, freshly dipped in bacterial suspension, formed a lesion only at the cut margin. Overall, these tests need to be thoroughly repeated using varieties at extreme opposite levels of relative resistance i.e., very susceptible and very resistant since Bengal (susceptible) and Jupiter (moderately resistant) responded similarly.

Greenhouse spray inoculation of Bengal and Jupiter, after heading, produced typical symptoms of bacterial panicle blight on a few florets. When these florets were plated on CCNT medium, bacterial colonies producing yellow-pigmented toxin were obtained. This test was carried out in the greenhouse as a preliminary investigation before the field season to determine a suitable plant developmental stage for artificial inoculation. The test also indicated bacterial suspension up to 10^8 cfu/ml as adequate for artificial inoculation. *B. glumae* produced the symptom of bacterial panicle blight at 86 °F and 74 °F average day and night temperatures of the greenhouse.

Using a 0 to 9 scale where 0 is no infection and 9 severe BPB, 14 among the 300 entries of artificially inoculated URRN and ARPT showed no symptoms of the disease and were rated highly resistant. Thirty entries rated 1 to 4 were grouped as moderately resistant (Table 1). The rest of the entries rated 5 to 9 and were grouped from moderately susceptible to very susceptible. Ten of the entries that rated resistant to moderately resistant were subsets of URRN and ARPT. Overall, 44 of 300 entries showed promising BPB disease resistance level. Less BPB disease was observed in late maturing types.

Germplasm screening for bacterial panicle blight in 2012 was more focused on generating inoculation methodologies rather than the actual screening process. As a result, the early planted URRN and ARPT entries were inoculated with a larger volume of the bacterial suspension to ensure symptom development. Once symptoms appeared on the early-planted plots, lower volumes of the bacterial suspension were sprayed on the later-planted set. The late-planted control set showed BPB symptoms on 126 entries of 300 entries while only 15 showed the typical symptoms of the disease on the early-planted control set. This supports observations that BPB disease incidence can increase with late planting. Therefore, the relative resistance level groupings in this report are based on data collected from the early- and late-planted single-row plots and their control sets. Although this one season evaluation seems to indicate the presence of resistance sources against the disease, the tests and entries need to be repeated to obtain definitive results.

SIGNIFICANCE OF FINDINGS

Plant resistance to bacterial panicle blight would provide long-term control in years of increased disease pressure compared to susceptible plants and thus improve yields. Developing effective resistance screening techniques for discovery of durable resistance in high yielding rice cultivars is a priority in a disease management strategy. The general objective of this project is to identify practical diagnostic methods of screening for resistance and monitoring rice bacterial panicle blight disease. This will enable identification of more resistance genes to control the disease and transfer them into new and high yielding cultivars.

ACKNOWLEDGMENTS

The support of extension rice pathology research by the Arkansas Rice Research and Promotion Board is highly appreciated. We are grateful to Rick Cartwright of University of Arkansas System Division of Agriculture for his technical help, Jarrod Hardke of University of Arkansas for reviewing the manuscript, Don Groth of Louisiana State University and Karen Moldenhauer of University of Arkansas for their collaboration. We appreciate the cooperation of USDA ARS Dale Bumpers National Rice Research Center for providing excellent facility and technical support.

Table 1. Resistant and moderately resistant entries from 2012 URRN (Uniform Regional Rice Nursery) and ARPT (Arkansas Rice Performance Test) to bacterial panicle blight (BPB) disease of rice rated after artificial inoculation in year 2012 at Rice Research and Extension Center near Stuttgart, Ark.

Rice genotype	Disease score[a]	Resistance group[b]
BCS 01H10010	0	R
RU0903184	0	R
RU0903190	0	R
RU1003101	0	R
RU1103104	0	R
RU1201130	0	R
RU1201145	0	R
RU1201173	0	R
RU1201179	0	R
RU1201182	0	R
RU1201185	0	R
RU1202180	0	R
STG09L-22-053	0	R
STG11HYB-5	0	R
RU1201127	1	MR
RT CLXL729	2	MR
RT CLXL745	2	MR
RT CLXP751	2	MR
RT XL723	2	MR
RT XP753	2	MR
RU0903086	2	MR
RU1003107	2	MR
RU1101108	2	MR
RU1102071	2	MR
RU1201084	2	MR
RU1201148	2	MR
RU1201164	2	MR
RU1201167	2	MR
STG08P-11-023	2	MR
Jupiter	3	MR
RU0801081	3	MR
RU1003178	3	MR
RU1103107	3	MR
RU1103126	3	MR
RU1201050	3	MR
RU1201070	3	MR
RU1201108	3	MR
RU1201136	3	MR
RU0703190	4	MR
RU1101185	4	MR
RU1104122	4	MR
RU1201024	4	MR
RU1201027	4	MR
RU1201061	4	MR

[a] Disease rating scale where 0 = no disease, 9 = severe BPB disease.

[b] R = resistant, MR = moderately resistant.

Efficacy of Rice Insecticide Seed Treatments at Selected Nitrogen Rates for Control of the Rice Water Weevil

M.E. Everett, G.M. Lorenz III, N.A. Slaton, J.T. Hardke,
N.M. Taillon, B.C Thrash, D.L. Clarkson, and L. Orellana-Jiminez

ABSTRACT

The value of insecticide seed treatments in rice has been well documented in recent years, but there have been instances where these treatments have not performed as expected. Soil fertility, nitrogen (N) in particular, is thought to contribute to this variability in performance. Two trials were conducted at the Pine Tree Research Station near Colt, Ark., to examine the response of rice plants receiving different insecticide seed treatments and N-rate combinations. Nitrogen was applied at 0, 45, 90, 135, and 180 lb urea-N/acre to rice plots. Insecticide seed treatments included labeled rates of clothianidin (NipsIt INSIDE®), thiamethoxam (CruiserMaxx® Rice), and a non-treated (fungicide only) control. Both NipsIt INSIDE and CruiserMaxx Rice had significantly fewer rice water weevil larvae compared to the non-treated control with an equivalent level of N; however, no differences were found between the two seed treatments at equal N levels. Nitrogen uptake at panicle differentiation and early heading was not affected by insecticide seed treatments. As N rate increased, grain yield increased up to 90 lb urea-N/acre and then plateaued. Averaged across N rates, both insecticide seed treatments had similar yields that were greater than the grain yields of the control. Preliminary results indicate that N has no effect on the efficacy of rice insecticide seed treatments but does influence the magnitude of leaf scarring and rice water weevil larvae number.

INTRODUCTION

The rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel, has long been considered as the most ubiquitous and injurious pest to rice (*Oryza sativa* L.) crops in most rice-producing areas of the world. Adult RWW are attracted to open water and begin infesting rice fields once the permanent flood is established. Once they have entered the field, adults will immediately begin feeding on plant leaves, causing longitudinal, translucent scarring parallel with the leaf's mid-vein. Although adult feeding does not usually result in yield loss, it is the first indicator of RWW presence and pressure in the field (Bernhardt, 2001). Female RWWs lay eggs vertically in the leaf sheath, just below the water's surface (Saito et al., 2005). Eggs hatch around eight days later, and the legless grubs soon chew through the leaf sheath, sink to the soil, burrow in the mud, and arrive at their true feeding site, the rice root system. Rice water weevil larvae prune the roots when feeding, decreasing the plant's ability to absorb nutrients. If the root system is severely damaged, the plant may become completely dislodged from the soil or demonstrate signs of nutrient deficiency such as yellowing, stunting, and slowed development (Bernhardt, 2001). Due to the rising cost of irrigation and the expense and unpredictability associated with foliar insecticide application for RWW control, many producers have replaced their old pest management practices with more reliable insecticide seed treatments (Lorenz et al., 2012).

A number of insecticide seed treatment options are available to producers, and rice seed treated with these insecticides generally exhibits increased seedling vigor, increased yield, and decreased RWW damage. However, there have been many instances where the selected seed treatment did not perform as expected. It is believed that soil fertility, N in particular, may be a contributing factor to these occurrences. As N rate increases, plant vegetative growth is increased. Therefore, insecticide seed treatments must protect more plant mass with increasing rates of N. This study was done to test the efficacy of seed treatments at various N rates.

PROCEDURES

Two trials were conducted at the Pine Tree Research Station (PTRS-1 and PTRS-2), near Colt, Ark., in St. Francis County to examine the response of rice plants exposed to different combinations of insecticide seed treatments and N rates. Each trial was designed as a randomized complete block with a 3 (seed treatments) × 5 (N rates) factorial treatment structure and included four replications. The first trial (PTRS-1) was established on a Calhoun silt loam soil that followed grain sorghum in rotation. The second trial (PTRS-2) was established on a Calloway silt loam following soybean in rotation. Composite soil samples were collected from the 0- to 4-inch depth of each replicate and analyzed for pH, available nutrients (Mehlich-3 soil test), and soil organic matter content. Selected soil property means were 6.5 pH, 29 ppm P, 88 ppm K, and 2.1% organic matter for PTRS-1 and 7.3 pH, 12 ppm P, 62 ppm K, and 2.5% organic matter for PTRS-2. Triple superphosphate, muriate of potash, and zinc sulfate were applied to supply 50 lb P_2O_5, 80 lb K_2O, and 10 lb Zn/acre to each research site to ensure these elements were not growth limiting.

Rice variety CL152 was planted on 4 April at PTRS-1 and 23 April at PTRS-2 into conventionally-tilled seedbeds at 60 lb/acre. Each plot was 16 ft long and contained nine rice rows (7-inch row spacings) with a 30-inch wide border between the outside rice rows of each plot that contained no rice. Seed treatments were thiamethoxam (CruiserMaxx Rice) at 7 oz/cwt and clothianidin (NipsIt INSIDE) at 1.92 oz/cwt, as well as a non-treated (fungicide only) control. The CruiserMaxx Rice package includes fungicide. NipsIt and the control received the exact fungicide rate and combination that was included in the CruiserMaxx Rice package (0.365 oz/cwt of Apron, 0.046 oz/cwt of Maxim, and 1 oz/cwt of Dynasty). Urea-N was applied at 0, 45, 90, 135, and 180 lb urea-N/acre. The 45 and 90 lb urea-N/acre rates were applied as a single application at the 5-lf stage. The 135 and 180 lb urea-N/acre rates were applied in a split application. The first application consisted of 90 or 135 lb urea-N/acre broadcast onto a dry soil surface at the 5-lf stage followed by 45 lb urea-N/acre broadcast between panicle initiation and panicle differentiation. The permanent flood was established two days after the preflood N was applied on 16 May at PTRS-1 and 23 May at PTRS-2.

Stand density and plant height were measured at the 2- and 3-lf stages to evaluate plant vigor. Stand counts were taken from a 10-ft section of an inner row of each plot. Plant height was measured on five plants randomly selected from one of the seven interior rows in each plot. Height was measured from the soil surface to the outstretched tip of the most recently mature leaf (Y-leaf). To measure adult RWW pressure, the Y-leaf was collected from five rice plants selected at random from an interior rice row of each plot 21 days after flooding, and the number of scars on each leaf were counted and summed. Leaf scarring was measured only at PTRS-1 because little or no leaf scarring was observed at PTRS-2. Rice water weevil larval density was evaluated by taking three soil core samples from each plot 21 days after flooding. Each soil core was taken with a 4-inch diameter sampler to a 3-inch depth, placed in a labeled sealable bag, stored on ice, and transported to the entomology laboratory in Lonoke, Ark. All soil cores were washed over a 40-mesh sieve to remove larvae and excess soil from the roots. The sieve was then immersed in saltwater which caused the larvae to float to the top for counting.

Plant samples were taken at midseason and early heading to measure dry matter and aboveground N uptake. From a 3-ft subsection of an inside row of each plot, rice plants were cut one inch above the soil, bagged, oven dried to a constant moisture, weighed for dry matter, ground, and a subsample analyzed for N concentration by combustion (Elementar rapid N III, Mount Laurel, N.J.). Total N uptake was calculated as the product of dry matter and rice N concentration. Grain was harvested with a small plot combine, weighed, and grain moisture and yield calculated to 12% moisture for statistical analysis. Grain yield data for PTRS-2 was not reported due to extensive damage to the plots from feral hogs.

Analysis of variance was performed by site using SAS v9.2 (SAS Institute; Cary, N.C.). Results were interpreted as significant at the $P < 0.05$ level. Means were separated using Fisher's protected least significant difference tests.

RESULTS AND DISCUSSION

Rice stand density and seedling height at the 2- and 3-lf stages were not affected ($P > 0.05$) by any of the treatments at PTRS-1. The overall average stand density at

PTRS-1 for the 3-lf stage was 98 plants/10 row ft. At PTRS-2, rice stand density at both the 2- and 3-lf stage was affected by the main effect of seed treatment (*P* = 0.0031 and 0.0198 at the 2- and 3-lf, respectively) with both showing similar results. At the 2-lf stage, rice seed treated with CruiserMaxx Rice (99 plants/10 ft, LSD 0.05 = 9) and NipsIt INSIDE (91 plants/10 ft) had greater stand densities than seed that received no insecticide (81 plants/10 ft). At the 3-lf stage, stands were 121 plants/10 ft for Nipsit INSIDE (LSD 0.05 = 9), 114 plants/10 ft for CruiserMaxx Rice, and 109 plants/10 ft for the no insecticide control. The average height of rice seedlings at the 2- and 3-lf stages was 1.6 inch and 6.6 inches, respectively.

Rice water weevil leaf scar number at PTRS-1 was affected only by the main effect of N rate (Table 1). The number of leaf scars on the rice Y-leaf was greatest for rice that received no N, and leaf scar number decreased numerically and sometimes statistically as N rate increased. This result indicates that adult weevils were attracted to the smallest rice and present in higher densities on those plants. Greater plant biomass created by the addition of increasing amounts of N was less attractive to the adult RWW despite the supply of more leaves to feed on. Insecticide seed treatment had no significant effect on leaf scar number (*P* = 0.0711), but the results suggest rice that received no insecticide (2.9 scars) had a tendency to have more leaf scars than rice seed treated with NipsIt INSIDE (2.1 scars) or CruiserMaxx Rice (2.1 scars).

The number of larvae found in the rice root system tended to be greater for rice plots that received preflood N fertilizer when compared to rice that received no N. However, the mean number of larvae for each N rate, averaged across insecticide treatments, showed slightly different trends at the two sites (Tables 1 and 2). At PTRS-1, larva number was affected by the seed treatment by N rate interaction (Table 3). The interaction showed that there was no difference in larva number among preflood N rates within each of the CruiserMaxx Rice or NipsIt INSIDE seed treatments. Rice plants from seed that received no insecticide had mean larva numbers that ranged from 7.6 to 26.2/core with the lowest numbers from rice that received no N. For PTRS-1, both seed treatments tended to have the lowest number of larvae when no N was applied, but differences among rice that received different N rates was not consistent. At PTRS-2, rice that received no N again had the lowest numerical number of larvae. Although not statistically compared, RWW pressure as indicated by leaf scar and larvae numbers was numerically greatest for the earliest planted rice (PTRS-1).

Total aboveground N uptake is reported as a summation of plant N concentration and dry matter production. For both sites and growth stages, seed treatment and the seed treatment by N rate interaction had no significant effect on aboveground N uptake and fertilizer N uptake efficiency. Aboveground N uptake was affected only by N rate, averaged across seed treatments (Tables 1 and 2). At panicle differentiation, aboveground N uptake showed similar trends at each site. Nitrogen uptake was greatest for the highest N rate and decreased incrementally as preflood N rate declined. For rice that received 90 and 135 lb urea-N/acre as the season total application, the preflood N rate was identical (90 lb urea-N/acre) and produced statistically similar N uptake values at each site. Similar results were also observed at the late boot stage (Tables 1 and 2) with a couple of notable exceptions. First, at PTRS-1, the 45 lb urea-N/acre applied at midseason appeared to contribute very little to N uptake at the late boot stage as the N uptake difference between the 90 and 135 lb urea-N treatments differed by only 5 lb N/acre at PTRS-1 (Table 1) compared to 29 lb N/acre at PTRS-2 (Table 2). Second, at the late boot stage, total N uptake between sites was numerically greater for PTRS-1 (ranging from 86 to 241 lb N/acre) than PTRS-2 (ranging from 71 to 216 lb N/acre). Urea-N recovery efficiency, as determined by the slope coefficient from regressing N uptake against the applied urea-N rates, averaged 69% for PTRS-1 and 66% for PTRS-2 at panicle differentiation and 72% for PTRS-1 and 74% for PTRS-2 at the late boot stage.

Rice grain yield was collected only at PTRS-1 due to extensive wildlife damage between heading and maturity at PTRS-2. Averaged across urea-N rates, grain yields were similar for rice that had been treated with CruiserMaxx Rice (172 bu/acre, LSD 0.05 = 8) and NipsIt INSIDE (171 bu/acre) with both producing greater yield than rice that had no insecticide seed treatment (161 bu/acre). Averaged across seed treatments, grain yield increased as N rate increased from 0 to 90 lb urea-N/acre, at which point yields reached a plateau with no further significant increase between 90 and 180 lb urea-N/acre.

SIGNIFICANCE OF FINDINGS

Rice seed treated with CruiserMaxx Rice and NipsIt INSIDE had fewer RWW larvae and produced greater grain yield compared to rice which received no insecticide seed treatment. Preliminary results in this trial indicate that insecticide seed treatments can increase stand density, reduce RWW larvae number, and increase grain yield, but do not influence N uptake or fertilizer recovery efficiency under the conditions of these two trials. The results also indicate that urea-N rate does not influence insecticide efficacy but can influence the number of adult RWW leaf scars. This research will be continued in 2013. Additional trials under a range of RWW pressure should help determine the consistency of results obtained in the 2012 trials.

ACKNOWLEDGMENTS

We wish to thank Nicki Taillon, Ben Thrash, Derek Clarkson, Luis Orellana, Colin Massey, Russ DeLong, and Randy Dempsey for data collection, and Pine Tree Research Station personnel for plot maintenance. Research was supported by Syngenta Crop Protection and Valent U.S.A.

LITERATURE CITED

Bernhardt, J.L. 2001. Insect management in rice. *In:* N.A. Slaton (ed.).Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. Extension Misc. Pub. 192:101-112. Little Rock, Ark.

Lorenz III, G.M., A. Plummer, N. Taillon, B. Thrash, J. Fortner, and K. Colwell. 2012. Comparison of insecticide seed treatments and foliar applications for control of rice water weevil. *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 600:116-119. Fayetteville.

Saito, T., K. Hirai, and M.O. Way. 2005. The rice water weevil, *Lissorhotrus oryzophilus* Kuschel (Coleoptra: Curculionidae). Appl. Entomol. Zool. 40(1):31-39.

Table 1. The effect of nitrogen (N) fertilizer rate, averaged across seed treatments, on rice water weevil leaf scars and larva 21 days after flooding; N uptake at panicle differentiation (PD) and late boot (LB) stages; and grain yield at maturity at Pine Tree Research Station near Colt, Ark. (PTRS-1).

	21 days after flood		N uptake		
N rate	Leaf scars	Larvae	PD	LB	Yield
	------------ (no.)	------------	----- (lb N/acre)	----	(bu/acre)
0	5.7	5.0	21	86	124
45	2.4	13.3	52	134	157
90	1.4	11.4	74	185	182
135	1.3	11.1	75	190	187
180	1.2	9.3	114	241	190
LSD 0.05[a]	1.1	3.1	14	24	11
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] LSD = least significant difference.

Table 2. The effect of N fertilizer rate, averaged across seed treatments, on rice water weevil leaf scars and larvae 21 days after flooding; and N uptake at panicle differentiation (PD) and late boot (LB) stages at Pine Tree Research Station near Colt, Ark. (PTRS-2).

	21 days after flood	N uptake	
N rate	Larvae	PD	LB
	(no.)	-------- (lb N/acre)	--------
0	1.7	18	71
45	2.7	44	115
90	3.7	69	151
135	2.9	68	180
180	3.4	103	216
LSD 0.05[a]	1.2	12	18
P-value	0.0149	<0.0001	<0.0001

[a] LSD = least significant difference.

Table 3. Rice water weevil larva number 21 days after flooding as affected by the insecticide seed treatment by nitrogen (N) rate interaction at the Pine Tree Research Station near Colt, Ark. (PTRS-1).

N rate	No insecticide	NipsIt INSIDE	CruiserMaxx Rice
	(avg larvae no./core)		
0	7.6	3.4	4.1
45	26.2	6.9	6.7
90	17.8	7.5	8.9
135	19.9	5.4	8.1
180	14.3	4.4	9.1
LSD 0.05[a]	5.3		
P-value	0.0026		

[a] LSD = least significant difference.

PEST MANAGEMENT: INSECTS

Efficacy of Selected Compounds for the Control of Rice Stink Bugs in Arkansas Rice, 2012

W.A. Plummer, G.M. Lorenz III, N.M. Taillon,
B.C. Thrash, D.L. Clarkson, M.E. Everett, and L.R. Orellana-Jimenez

ABSTRACT

The rice stink bug (*Oebalus pugnax* F.) is one of the important pests commonly found in Arkansas rice fields. A study was conducted in Lonoke County to determine the efficacy of selected compounds for control of the rice stink bug. This study indicated control could be established with the use of selected compounds in Arkansas rice.

INTRODUCTION

The rice stink bug (RSB) is a common pest of rice in Arkansas. The ability of the rice stink bug to feed and reproduce on a wide range of wild grasses plays a significant role in its status as an economic pest. Feeding on early grasses in the spring enables the rice stink bug to reproduce and increase in numbers before cultivated host plants are available. Rice stink bugs normally do not occur in rice fields until heading has begun, but may occur earlier if heading wild grasses are present in or around field edges. Stink bug feeding on developing seeds causes several different types of damage to rice. Adults and nymphs have piercing-sucking mouthparts. When the RSB pierces the grain of rice it forms a sheath that is visible from the outside of the grain which is called a feeding sheath. Early feeding from pre-fertilization through early milk stages causes the heads to blank or abort resulting in yield reduction. Feeding during the milk to soft dough stages results in kernel shrinkage or slight discoloration commonly referred to as "pecky rice" (Johnson et al., 2002).

PROCEDURES

The trial was located in Lonoke County (Moery Farms). Plot size was 15 ft by 30 ft in a randomized complete block design with four replications. Foliar treatments included: Endigo ZC at 5 oz/acre; Endigo ZCX at 5 oz/acre; Karate Z at 2.56 oz/acre; Centric at 3.5 oz wt/acre; and Tenchu 20 SG at 9 oz/acre. All treatments were compared to an untreated check (UTC). Insecticide treatments were applied with a hand boom on 17 August and 4 September, 2012. Insect ratings were taken 4 and 7 days following treatment one and 3 and 7 days following treatment two. The boom was fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing, spray volume was 10 gal/acre, at 40 psi. Insect density was determined by taking 10 sweeps per plot with a standard sweep net (15-inch diameter) and compared to the economic threshold of 5 rice stink bugs per 10 sweeps. Data was processed using Agriculture Research Manager Version 8, AOV, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

RESULTS AND DISCUSSION

Results indicated at four and seven days after the first (4&7DAT1) application all treatments reduced rice stink bug numbers compared to the UTC (Fig. 1). Although no treatments separated from each other, they did reduce populations below threshold (Fig. 2). All treatments three days after the second application (3DAT2) remained below threshold but no differences were observed from the other treatments (Fig 1).

SIGNIFICANCE OF FINDINGS

The rice stink bug is a common pest that can cause poor milling and yield loss for Arkansas producers. The use of insecticides gives producers the ability to significantly lower rice stink bug numbers. When populations are at moderate levels, like in 2012, many compounds are able to reduce RSB below the economic threshold with just one or two applications. Alternate insecticides such as Tenchu and Centric may help lessen the potential for increasing resistance to pyrethroids. The continued research of selected compounds is necessary for the control of the rice stink bug.

ACKNOWLEDGMENTS

We would like to acknowledge Moery farms, Lonoke County, for their cooperation in this study. Funding for this project was provided by: Rice Check-Off funds, Rice Research and Promotion Board, Syngenta, and Mitsui.

LITERATURE CITED

Johnson, D.R., J. Bernhardt, J. Greene, G. Lorenz, and G. Studebaker. 2002. Rice Stink Bug in Arkansas. Agriculture and Natural Resources Face Sheet. University of Arkansas System Division of Agriculture Cooperative Extension Service. http://www.uaex.edu/Other_Areas/publications/PDF/FSA-7057.pdf

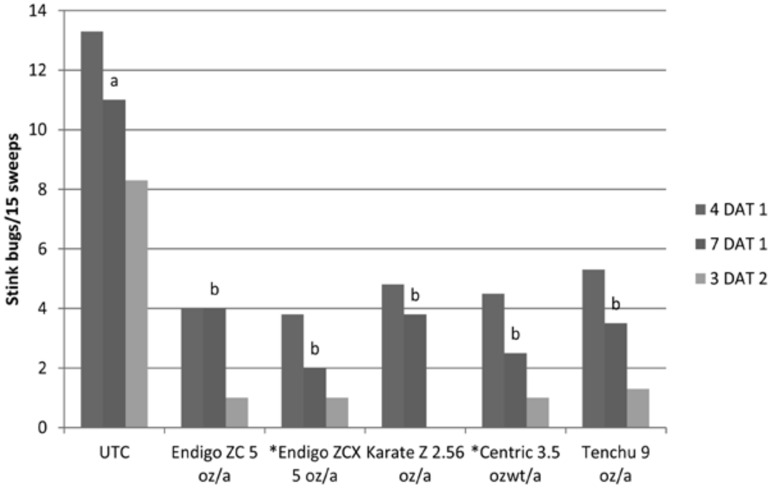


Fig 1. Efficacy of selected compounds for the control of rice stink bugs (RSB) in Arkansas rice, 2012. RSB sweeps. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance treatment P (F) is significant at the mean comparison observed significance level. *Products not currently labeled for use in rice.

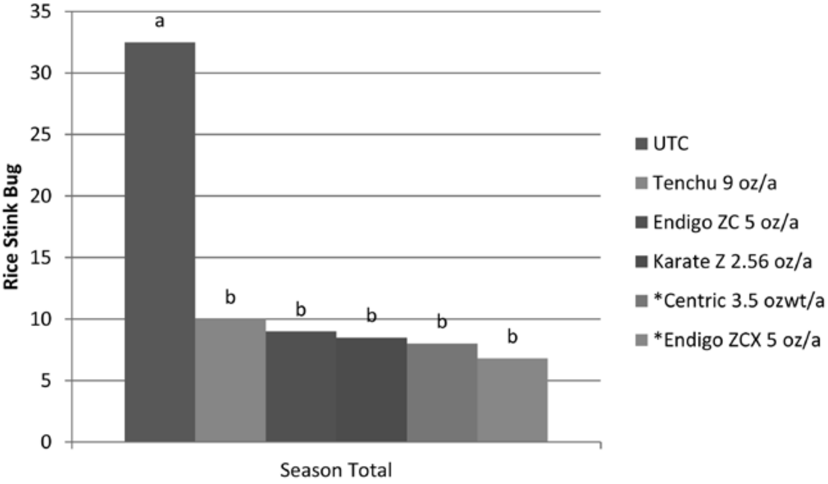


Fig. 2 Efficacy of selected compounds for the control of rice stink bugs in Arkansas rice, 2012. Season total. Means followed by same letter do not significantly differ (*P* = 0.10, Duncan's New Multiple Range Test). Mean comparisons performed only when analysis of variance treatment P (F) is significant at the mean comparison observed significance level. *Products not currently labeled for use in rice.

Comparison of Insecticide Seed Treatments and Foliar Applications for Control of Rice Water Weevil

N.M. Taillon, G.M. Lorenz III, A. Plummer,
M. Everett, B. Thrash, D. Clarkson, and L. Orellana-Jimenez

ABSTRACT

The rice water weevil, *Lissorhoptrus oryzophilus*, is one of the most important insect pests of rice in Arkansas. Prior to the development of the new insecticide seed treatments, growers had few options for control. Foliar insecticide application aimed at the adult before the female could lay her eggs was the most often used option. While draining the field after flood is still one of the most effective options, the high cost of pumping in recent years has deterred growers from exercising this option. The objective of this trial was to evaluate the efficacy of foliar treatments applied at preflood, early postflood and late postflood, compared to insecticide seed treatments. Studies indicated that timing of foliar applications is very critical and compared to seed treatments, residual control may reduce the overall effectiveness.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus*, has historically been a problem to Arkansas rice producers. Weevil adults enter fields at permanent flood and feed on rice leaves along the veins leaving elongated scars. The adults mate and the female lays her eggs in the leaf sheaths of the plant. Larvae hatch and move down to the root and begin to feed. As the larvae feed on root systems the ability of the plant to uptake nutrients is reduced. Deficiency symptoms and stunting become common and delayed maturity and yield decreases can occur. Occasionally, root pruning can be so severe that plants cannot remain anchored in the soil and they will float to the water surface when disturbed (Bernhardt, 2001). Historically, a few costly cultural practices such as increasing seeding rates and drainage of flooded fields were all that was available to combat weevil damage. Foliar applications of pyrethroids at flood became a common practice until insecticide seed treatments became available. The objective of these studies was to evaluate the efficacy of selected insecticide seed treatments compared to foliar applications at preflood, early postflood, and late postflood.

PROCEDURES

This trial was conducted during the 2012 growing season at the Rice Research and Extension Center in Stuttgart, Ark. Plots were 5 ft by 25 ft in a randomized complete block design with four replications. Insecticide applications included two seed-applied treatments as well as foliar treatments Karate Z, Belay, and Declare which were applied preflood, 14 days post flood, and 18 days post flood (Table 1) with a hand boom fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing. Spray volume was 10 gal/ acre, at 40 psi. Rice water weevil samples were taken 21 d after permanent flood. Rice water weevil numbers were determined by taking 3 core samples per plot with a 4-inch cylinder core sampler. All samples were processed at the Lonoke Agricultural Extension and Research Center. 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 saturated salt solution to float the larvae for counting. Yield samples were taken with a small plot combine and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 8, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

Results indicated that Karate (5.12 oz/acre) late postflood, Belay (4.5 oz/acre) early postflood, and Declare (1.54 oz/acre) at the lower rate were no better than the untreated check. Both seed treatments, NipsIt INSIDE (1.9 oz/cwt) and CruiserMaxx Rice (7 oz/cwt), as well as Karate (5.12 oz/acre) preflood and early postflood, Belay (4.5 oz/acre) early preflood and late postflood, and Declare (2.05 oz/acre) preflood and early postflood reduced rice water weevils below the untreated check (Fig. 1).

SIGNIFICANCE OF FINDINGS

With high pumping cost, Arkansas producers cannot afford to drain and reflood rice fields to control rice water weevil. Other means of control are needed like foliar applications. This study indicated control can be achieved by foliar applications but timing is everything. Preflood foliar applications give better control than late postflood applications and in this study are equivalent to the seed treatments.

ACKNOWLEDGMENTS

Funding for this project was provided by: Rice Promotion Board, Syngenta, and Valent.

LITERATURE CITED

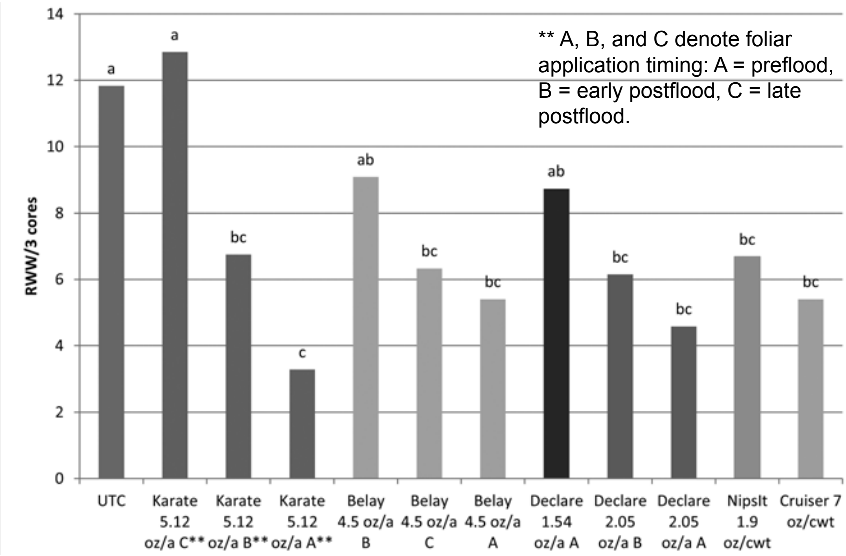
Bernhardt, J.L. 2001. Insect management in rice. pp. 101-112. *In:* N.A. Slaton (ed.). Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. Available at www.uaex.edu/otherareas/publications/PDF/MP/192Chapter11.pdf

---

Table 1. Treatment list and application timing.

Treatments	Application timing
UTC	
Karate 5.12 oz/acre A[†]	Preflood
Karate 5.12 oz/acre B	Early postflood
Karate 5.12 oz/acre C	Late postflood
Belay 4.5 oz/acre A	Preflood
Belay 4.5 oz/acre B	Early postflood
Belay 4.5 oz/acre C	Late postflood
Declare 1.54 oz/acre A	Preflood
Declare 2.05 oz/acre A	Preflood
Declare 2.05 oz/acre B	Early postflood
NipsIt 1.9 oz/cwt	Seed treatment
Cruiser 7 oz/cwt	Seed treatment

[†] A, B, and C denote foliar application timing. A = preflood, B = early postflood, and C = late postflood.



** A, B, and C denote foliar application timing: A = preflood, B = early postflood, C = late postflood.

Fig 1. Foliar treatments compared to seed treatments for control of rice water weevil, core sample data.

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

N.M. Taillon, G.M. Lorenz III, A. Plummer, M. Everett,
B. Thrash, D. Clarkson, and L. Orellana-Jimenez

ABSTRACT

The use of insecticide seed treatments for control of rice water weevil, *Lissorhoptrus oryzophilus*, and grape colaspis, *Colaspis brunnea*, is a viable option for growers. Prior to the development of insecticide seed treatments, growers had few options for control of these key pests and foliar insecticide applications were the most often used. Draining the field after infestation is still one of the most effective options, but the high cost of pumping in recent years has deterred growers from this practice. The objective of this trial was to evaluate the efficacy of selected insecticide seed treatments with new formulations as well as one treatment combined with a foliar application. Studies indicated that new formulations may provide equal or better control when compared to the current standards.

INTRODUCTION

The rice water weevil (RWW), *Lissorhoptrus oryzophilus*, has historically been a problem to Arkansas rice producers. Weevil adults enter fields at permanent flood and feed on rice leaves along the veins leaving elongated scars. The adults mate and the female lays her eggs in the leaf sheaths of the plant. Larvae hatch and move down to the root and begin to feed. As the larvae feed on root systems the ability of the plant to uptake nutrients is reduced. Deficiency symptoms and stunting become common and delayed maturity and yield decreases are observed. Occasionally, root pruning can be so severe that plants cannot remain anchored in the soil and the plants will float to the water surface when disturbed (Bernhardt, 2001).

Another common pest for Arkansas rice producers is the grape colaspis (GC), *Colaspis brunnea*. It is an early season pest most often found in fields that were planted in corn or soybean the previous year (Rolston and Rouse, 1965). Adults are about 0.1875 in. long, oval, golden brown in color, and the elytra (wing covers) have rows of longitudinal ridges. The small larvae are grubs that are "c" shaped, white to tan in color, and have a brown head. Larvae eat away at the rice stem and roots causing a "girdling" effect, which causes the plant to yellow and become stunted and, in many cases, can cause significant stand reduction (Lorenz, 2006).

In the past, a few costly cultural practices such as increasing seeding rates and drainage of flooded fields were all that was available to combat RWW and GC damage. Foliar applications of pyrethroids at flood were a regular practice until insecticide seed treatments became available. As the use of insecticide seed treatments becomes more common, it is necessary for the industry to continue to work to find better formulations and combinations of their products. The objective of this trial was to evaluate the efficacy of insecticide seed treatments with new formulations as well as a seed treatment combined with a foliar application, when compared to current insecticide seed treatments.

PROCEDURES

This trial was conducted during the 2012 growing season at the Rice Research and Extension Center in Stuttgart, Ark. Plots were 5 ft by 25 ft in a randomized complete block design with four replications. Insecticide applications were seed applied, while one treatment included a foliar application of Karate Z early postflood with a hand boom fitted with TX6 hollow cone nozzles at 19-inch nozzle spacing. Spray volume was 10 gal/acre, at 40 psi. Rice water weevil and grape colaspis larvae were evaluated 21 and 28 days after permanent flood by taking 3 core samples per plot with a 4-inch cylinder core sampler. All samples were evaluated at the Lonoke Agricultural Extension and Research Center. 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 saturated salt solution to float the larvae for counting. Yield samples were taken with a small plot combine and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 8, analysis of variance, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

Rice Water Weevil

While no differences were observed at 21 days postflood, samples taken 28 days postflood indicated all treatments were better than the untreated check and Experimental 1 (Table 1). At 35 days postflood, all treatments except for Experimental 1 and NipsIt INSIDE were better than the untreated check. The season total RWW numbers show that all treatments were better than the untreated check. There were significantly fewer RWW in Experimental 2 + Karate than there were in Experimental 1. Cruiser, Dermacor, and Experimental 2 + Dermacor X-100 had significantly fewer RWW than Experimental 2.

Grape Colaspis

No differences were observed at 21 and 28 days postflood; however, at 35 days postflood Experimental 2, Cruiser, NipsIt INSIDE, Dermacor, Experimental 2 + Dermacor, and Experimental 2 + Karate had significantly fewer GC larvae than in the untreated check and fewer larvae than and Experimental 1 (Table 2). Experimental 2 + Karate had significantly fewer GC than Experimental 1. Season total GC numbers show that Experimental 2, Experimental 2 with Dermacor, and Experimental 2 with Karate were significantly better than the untreated check and Experimental 1.

SIGNIFICANCE OF FINDINGS

We continue to evaluate new formulations to determine if they are as good as or better than the current standards.

ACKNOWLEDGMENTS

Funding for this project was provided by: Rice Promotion Board, Syngenta, and Valent.

LITERATURE CITED

Bernhardt, J.L. 2001. Insect management in rice. pp. 101-112. *In:* N.A. Slaton (ed.). Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. Available at www.uaex.edu/otherareas/publications/PDF/MP/192Chapter11.pdf

Lorenz, G.M., III. 2006. Rice insect management. *In:* Agriculture. University of Arkansas System Division of Agriculture Cooperative Extension Service. Available at http://www.aragriculture.org/insects/rice/rice_water_weevil.htm

Rolston, L. H., and P. Rouse. 1965. The biology and ecology of the grape colaspis, *Colaspis flarida* Say, in relation to rice production in the Arkansas Grand Prairie, University of Arkansas System Division of Agriculture Agricultural Experiment Station. Bulletin 694. 31 p.

Table 1. Efficacy of selected insecticides on rice water weevils 21, 28, and 35 days after treatment; with season total rice water weevils.

	Rice water weevils			
Treatment	21 d postflood	28 d postflood	35 d postflood	Season total
	(average no./3 cores)			
UTC	1.83 a	5.65 a	2.58 a	10.05 a
Experimental 1 7 oz/cwt	1.25 a	2.85 b	1.50 ab	5.60 b
Experimental 2 7 oz/cwt	1.08 a	2.00 bc	1.08 bc	4.15 bc
Cruiser 3.6 oz/cwt	1.08 a	0.40 c	0.75 bc	1.80 d
NipsIt INSIDE 1.92 oz/cwt	0.68 a	1.60 bc	1.58 ab	4.25 bc
Dermacor X-100 5.23 oz/cwt	0.65 a	0.93 c	0.15 c	1.73 d
Experimental 2 + Dermacor X-100 4 oz/cwt	0.65 a	0.98 c	0.78 bc	2.43 d
Experimental 2 7 oz/cwt + Karate	0.40 a	1.10 c	1.08 bc	2.58 cd

Table 2. Efficacy of selected insecticides on grape colaspis 21, 28, and 35 days after treatment; with season total grape colaspis.

	Grape colaspis			
Treatment	21 d postflood	28 d postflood	35 d postflood	Season total
	(average no./3 cores)			
UTC	1.6 a	2.8 a	3.0 a	5.4 a
Experimental 1 7 oz/cwt	1.5 a	1.8 a	2.0 ab	5.3 a
Experimental 2 7 oz/cwt	0.3 a	0.3 a	0.5 bc	1.0 b
Cruiser 3.6 oz/cwt	1.5 a	0.8 a	1.0 bc	3.3 ab
NipsIt INSIDE 1.92 oz/cwt	1.3 a	1.0 a	0.5 bc	2.8 ab
Dermacor X-100 5.23 oz/cwt	1.8 a	1.3 a	1.0 bc	4.0 ab
Experimental 2 + Dermacor X-100 4 oz/cwt	0.5 a	0.3 a	0.3 bc	1.0 b
Experimental 2 7 oz/cwt + Karate	1.3 a	0.0 a	0.0 c	1.3 b

Modeling Simultaneous Evolution of Barnyardgrass Resistance to Acetolactate Synthase (ALS)- and Acetyl Coenzyme A Carboxylase (ACCase)-Inhibiting Herbicides in Clearfield® Rice

M.V. Bagavathiannan, J.K. Norsworthy, K.L. Smith, and P. Neve

ABSTRACT

A simulation model was developed to: 1) understand the risk of acetolactate synthase (ALS)-inhibitor-resistant barnyardgrass under a worst-case management scenario in continuous Clearfield® rice, and 2) predict the simultaneous evolution of barnyardgrass resistance to ALS- and acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicides. The model was implemented using the STELLA® modeling software. For each weed management scenario, 1000 model runs were performed over a 30-year period. A population was considered to have evolved resistance when at least 20% of the seedbank consisted of resistant individuals. Under a sole application of ALS-inhibiting herbicides (three applications annually) in continuous Clearfield rice, resistance is predicted within only four years of adopting this program. Model predictions largely corroborate field observations in the mid-South rice production. Cyhalofop applied 14 d postflood helped reduce the risk of ALS-inhibitor resistance. Examination of the seedbank population, however, showed that the number of individuals with resistance to ACCase-inhibiting herbicides steadily increased under this program. When fenoxaprop was applied prior to flooding, the risk of ALS-inhibitor resistance was further reduced; however, there is a risk of simultaneously selecting for multiple resistance. Thus, selection for multiple resistance is possible in barnyardgrass to both ALS- and ACCase-inhibiting herbicides, particularly when ACCase-inhibiting herbicides are heavily relied upon in the Clearfield rice system. There is a need for more diversified barnyardgrass management programs that incorporate all possible herbicide and non-chemical strategies to ensure sustainable weed management in Clearfield rice.

INTRODUCTION

Barnyardgrass (*Echinochloa crus-galli*) is the prime weed in Arkansas rice fields and the evolution of barnyardgrass populations with resistance to a number of herbicide mechanisms of actions (MOAs) makes it challenging for growers to achieve effective, season-long control of this species. In Arkansas rice, barnyardgrass resistance has been confirmed for some of the major herbicides, including propanil (Carey et al., 1995), quinclorac (Lovelace et al., 2000), clomazone (Norsworthy et al., 2009), and imazethapyr (Wilson et al., 2010). The imazethapyr-resistant barnyardgrass populations also exhibit cross resistance to several other acetolactate synthase (ALS)-inhibitor herbicides such as imazamox, bispyribac, and penoxsulam (Wilson et al., 2010).

In the Clearfield rice production system, which has been widely adopted in the mid-South, barnyardgrass resistance to ALS-inhibiting herbicides is a growing concern. As a result, there is an increasing reliance on some of the acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicides such as fenoxaprop and cyhalofop for barnyardgrass control, ultimately increasing selection pressure on these herbicides. If barnyardgrass evolves resistance to the ACCase-inhibiting herbicides, it will be very challenging to control this species because few herbicide options are left to effectively manage barnyardgrass in rice. Specifically, pendimethalin and thiobencarb are the two other herbicide options available for barnyardgrass control in rice; these herbicides do not provide effective barnyardgrass control and not the ones on which a season-long barnyardgrass management program can be developed.

Thus, the prime management goals for barnyardgrass in mid-South Clearfield rice production system are: a) prevent further spread of ALS-inhibitor-resistant barnyardgrass, and b) prevent simultaneous evolution of resistance to ALS- and ACCase-inhibiting herbicides in barnyardgrass. The focus of this research was to address these management goals using a simulation modeling approach.

PROCEDURES

A mathematical model was developed using the visual programming language STELLA (version 9.1; iSee systems, Lebanon, N.H., USA). The general framework and approach of the model follows Neve et al. (2011), but this model is unique in that it simulates the simultaneous evolution of resistance to two herbicide MOAs. It is a stage-structured model with three distinct life-history stages: seeds, emerged seedlings, and mature plants. The model assumes that resistance is endowed by a single gene, completely dominant trait with Mendelian pattern of inheritance. Some variables were considered to be stochastic in nature, with field-to-field or season-to-season variations. Stochastic variables include: the initial frequency of resistance alleles, initial seedbank size, annual seedling emergence proportion, post-dispersal seed loss, and annual seedbank loss. The model also accounts for demographic stochasticity when the population size reaches very low levels (<10 plants).

The model simulates resistance evolution in barnyardgrass across 1000 hypothetical rice production fields in Arkansas over a 30-year period. Resistance is considered to have evolved if at least 20% of the seedbank consisted of resistant individuals for each resistance trait. Banyardgrass emergence was predicted across three important rice growing regions in eastern Arkansas (Stuttgart, Monticello, and West Memphis), based on growing degree days calculated using historical weather data. Each rice field was considered to be 150 acres in size and it was assumed that barnyardgrass was evenly distributed within the field. Barnyardgrass emergence was categorized into five cohorts: cohort 1 (prior to planting on 1 May), cohort 2 (1 May to 14 May), cohort 3 (15 May to 31 May), cohort 4 (1 June to 14 June), and cohort 5 (15 June to 18 June). The final cohort accounts for the seedlings that emerge during the entire duration of flooding, which takes place six weeks after rice seeding.

Management interventions correspond to each cohort, and are timed as: at-plant (1 May), early-post (EPOST) (15 May), mid-POST (MPOST) (1 June), preflood (PREFLD) (15 June) and postflood (POSTFLD) (22 June). In the initial model analyses, three management programs were considered in a continuous Clearfield rice: 1) the worst-case program [tillage at planting followed by (fb) imazethapyr at EPOST fb imazethapyr at MPOST fb imazamox at 7 d POSTFLD]; 2) the worst-case program with cyhalofop [tillage at planting fb imazethapyr at EPOST fb imazethapyr at MPOST fb imazamox at 7 d POSTFLD fb cyhalofop 14 d POSTFLD]; and 3) the worst-case program with fenoxaprop [tillage at planting fb imazethapyr at EPOST fb imazethapyr at MPOST fb fenoxaprop PREFLD fb imazamox at 7 d POSTFLD]. Efficacies for the various management options were determined based on field observations in Arkansas rice production systems.

RESULTS AND DISCUSSION

Preliminary model outputs suggest that there is a high risk for the evolution of ALS-inhibitor-resistant barnyardgrass in the mid-South rice under the worst-case scenario consisting of three applications of imidazolinone herbicides in a continuous Clearfield rice. The model predicts resistance evolution in four years of adopting this program, with about 40% risk by year 10 (Fig. 1). Inclusion of cyhalofop at 14 d POSTFLD in the worst-case program is valuable in reducing the risks of ALS-inhibitor resistance to about 27% by year 10 (Fig. 2), and ACCase-inhibitor resistance does not evolve within the 30-year period. However, examination of the seedbank revealed that the number of ACCase-resistant individuals in the seedbank increased over time (Fig. 3), meaning that they are less likely to be lost from the seedbank. Application of fenoxaprop prior to flooding helps further reduce the risks of ALS-inhibitor-resistant barnyardgrass to about 14% by year 10, but the risks of resistance to ACCase inhibitors also increase by year 20. This can be attributed to the high efficacy of fenoxaprop when applied prior to flooding (on relatively smaller barnyardgrass seedlings), compared to cyhalofop applied at 14 d POSTFLD (as a salvage treatment on larger barnyardgrass plants). The results suggest that when barnyardgrass management heavily relies upon the two herbicide MOAs (ALS- and ACCase-inhibitors), the risks for multiple resistance is high. More diversified management programs, especially with the inclusion of suitable non-chemical strategies, are vital.

SIGNIFICANCE OF FINDINGS

An understanding of the risk of multiple resistance in barnyardgrass will help develop diverse weed management programs and thereby help preserve the long-term utility of available herbicide options in rice production.

ACKNOWLEDGMENTS

Funding for this research was provided by the Arkansas Rice Research and Promotion Board, USDA Southern-Region Integrated Pest Management Grant, BASF, Monsanto, Valent, Dow AgroSciences, Syngenta Crop Protection, and Bayer CropScience.

LITERATURE CITED

Carey, V.F., R.E. Hoagland, and R.E. Talbert. 1995. Verification and distribution of propanil-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas. Weed Technol. 9:366-372.

Lovelace, M.L., R.E. Talbert, L.A. Schmidt, E.F. Scherder, and J.R. Reaper. 2000. Multiple resistance of propanil-resistant barnyardgrass (*Echinochloa crus-galli*) to quinclorac. *In:* Proceedings of the 28th Rice Technical Working Group. Biloxi, Miss. p 153.

Neve, P., J.K. Norsworthy, K.L. Smith, and I. Zelaya. 2011. Modelling evolution and management of glyphosate resistance in *Amaranthus palmeri*. Weed Res. 51:99-112.

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

Wilson, M.J., J.K. Norsworthy, D.B. Johnson, E.K. McCallister, J.D. DeVore, J.M. Griffith, and S.K. Bangarwa. 2010. Herbicide programs for controlling ALS-resistant barnyardgrass in Clearfield rice. RTWG Feb. 24, 2010, Biloxi, Miss.

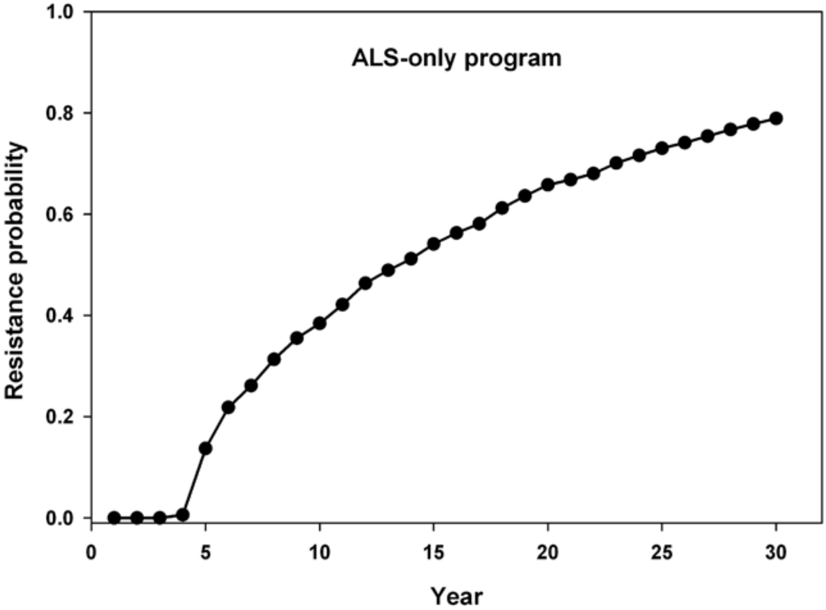


Fig. 1. Risk of barnyardgrass evolving resistance to acetolactate synthase-inhibiting herbicides under a worst-case management scenario in continuous Clearfield rice. The management program consists of tillage at planting followed by (fb) imazethapyr at early-post (EPOST) fb imazethapyr at mid-post (MPOST) fb imazamox at 7 d postflood (POSTFLD).

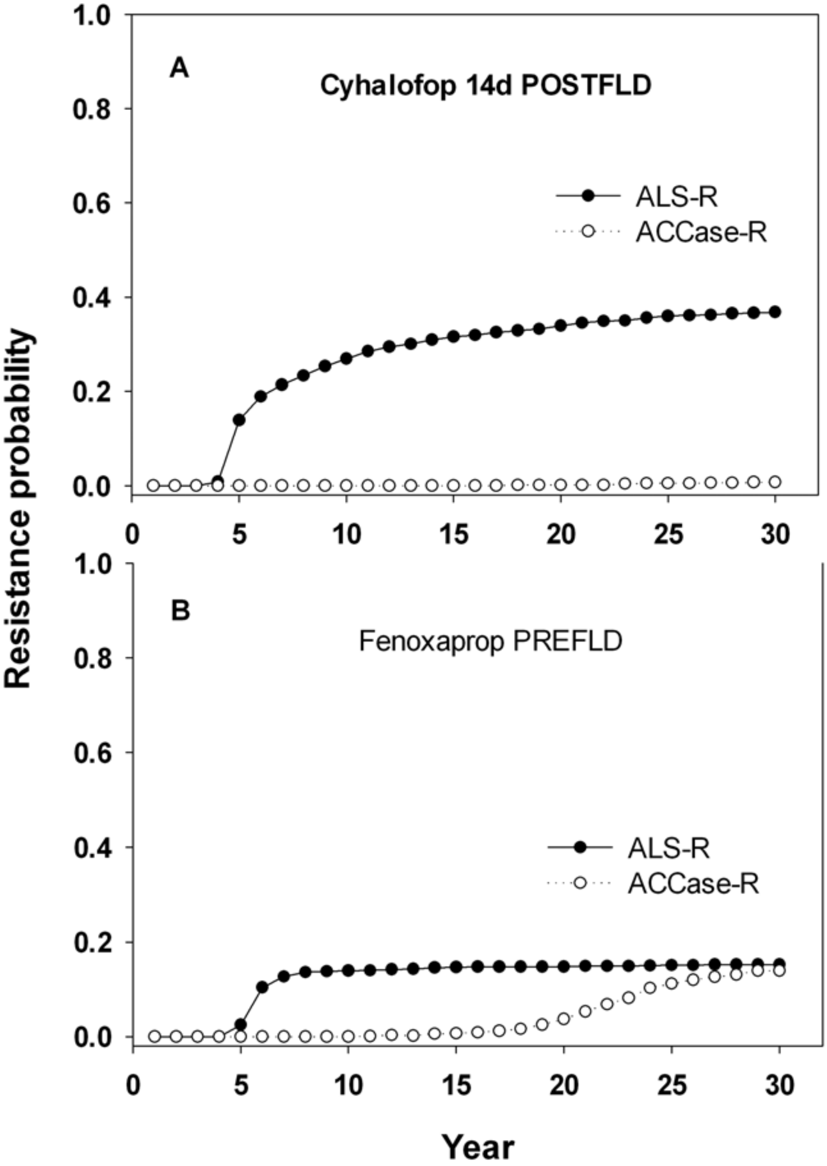


Fig. 2. Risk of simultaneous evolution of resistance to acetolactate synthase (ALS)- and acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicides in barnyardgrass: A) under a management program consisting of tillage at planting followed by (fb) imazethapyr at early-post (EPOST) fb imazethapyr at mid-post (MPOST) fb imazamox at 7 d postflood (POSTFLD) fb cyhalofop at 14 d postflood (POSTFLD) and B) under a program consisting of tillage at planting fb imazethapyr at EPOST fb imazethapyr at MPOST fb fenoxaprop PREFLD fb imazamox at 7 d POSTFLD.

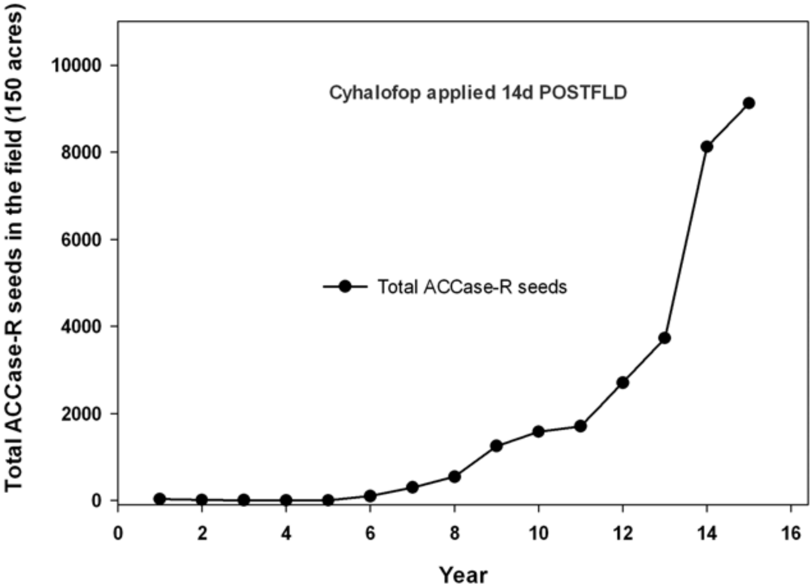


Fig. 3. The number of acetyl coenzyme A carboxylase (ACCase)-resistant individuals in the seedbank under a management program consisting of tillage at planting followed by (fb) imazethapyr at early-post (EPOST) fb imazethapyr at mid-post (MPOST) fb imazamox at 7 d postflood (POSTFLD) fb cyhalofop at 14 d postflood (POSTFLD).

Influence of Rate and Application Timing on Rice Tolerance to Acetochlor and S-Metolachlor

M.T. Bararpour, J.K. Norsworthy, D.B. Johnson, and R.C. Scott

ABSTRACT

Two separate field studies were conducted at the Northeast Research and Extension Center (NEREC; Keiser, Ark.) and at the Rice Research and Extension Center (RREC; near Stuttgart, Ark.) in 2011 and 2012 to evaluate the influence of rate and application timing of acetochlor (Warrant) and S-metolachlor (Dual II Magnum) on rice tolerance. The experiment was designed as a three (application timings) by five factorial (three acetochlor rates and two S-metolachlor rates) along with a nontreated weed-free control in a randomized complete block design. Acetochlor was applied at 0.375, 0.75, and 1.125 lb ai/acre and S-metolachlor was applied at 0.75 and 1.25 lb ai/acre at spiking, 2-lf, and 4-lf stage of rice. On a clay soil at NEREC at 5 wk after emergence, there was no rice injury when acetochlor was applied at the 2-lf stage of rice, regardless of rate. Rice injury was only 4% and 3% following acetochlor at 1.125 lb/acre at spiking and 4-lf rice stage, respectively. On a silt loam soil at RREC, rice injury caused by acetochlor at 0.375, 0.75, and 1.125 lb/acre was 28%, 43%, and 62% when applied at spiking; 4%, 16%, and 18% when applied at 2-lf rice; and 1%, 3%, and 3% when applied at 4-lf rice. At both locations, yields in plots treated with acetochlor at 0.375 and 0.75 lb/acre were comparable to the nontreated check, averaged over years and timings. However, rice yield was reduced 7% from acetochlor at the highest rate of 1.125 lb/acre. S-metolachlor caused unacceptable levels of rice injury when applied at 0.75 lb/acre at spiking, 2-lf, and 4-lf stages of rice.

INTRODUCTION

Weed management programs are an essential component of rice production, and Arkansas has been the nation's leading rice-producing state since 1973. In 2011, barnyardgrass (*Echinochloa crus-galli*) was listed by crop consultants as the most problematic weed of rice in Arkansas and Mississippi (Norsworthy et al., 2007 and 2012). Season-long interference of barnyardgrass at a density of even one plant/10.9 ft^2 can reduce rice yield up to 230 lb/acre (Stauber et al., 1991). In Arkansas, reduced rotation of rice with other crops along with frequent use of propanil, quinclorac, and clomazone has led to the evolution of barnyardgrass biotypes resistant to propanil, quinclorac, and clomazone. Therefore, finding and testing a new herbicide to use in rice fields is essential. Warrant is a new encapsulated formulation of acetochlor that may have potential for postemergence applications in rice if rice exhibits sufficient tolerance. This family of herbicides is not currently used in the United States for rice weed control and would essentially represent a new mode of action for rice producers. The objective of this research was to evaluate the influence of rate and application timing of acetochlor (Warrant) and S-metolachlor (Dual II Magnum) on rice tolerance.

PROCEDURES

Field studies were conducted at the Northeast Research and Extension Center, Keiser, Ark. (NEREC, Sharkey clay soil) and the Rice Research and Extension Center near Stuttgart, Ark. (RREC, Dewitt silt loam soil) in 2011 and 2012 to evaluate the influence of rate and application timing of acetochlor on rice tolerance. The experiment was designed as a three (application timing) by three (acetochlor rates) factorial along with a nontreated weed-free control in a randomized complete block design with four replications. Acetochlor was applied at 0 (nontreated check), 0.375, 0.75, and 1.125 lb ai/acre at spiking, 2-lf, and 4-lf stage of rice. A separate field study was conducted at the NEREC and RREC in 2011 to evaluate the influence of rate and application timing of S-metolachlor on rice tolerance. The experiment was designed as a three (application timings) by two (S-metolachlor rates) factorial along with a nontreated weed-free control in a randomized complete block design with four replications. S-metolachlor was applied at 0 (nontreated check), 0.75, and 1.25 lb ai/acre at spiking, 2-lf, and 4-lf stage of rice. Rice (Clearfield 152) was seeded with a 9-row drill on 7-inch spacing. The plots were 6 ft wide by 20 ft long. The entire experimental site was treated with clomazone (Command) at 0.3 lb ai/acre plus quinclorac (Facet) at 0.3 lb ai/acre preemergence followed by imazethapyr (Newpath) at 0.063 lb ai/acre (pre-flood) for weed control (to keep the test area clean). All herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. Visible estimates of rice injury were taken weekly throughout the growing season to evaluate rice tolerance to acetochlor and S-metolachlor. Data were subjected to analysis of variance, and means were separated by Fisher's Protected Least Significant Difference test at the 5% level of significance. Due to differences between locations, all data are presented by location.

RESULTS AND DISCUSSION

On a clay soil at NEREC, 5 weeks after emergence, there was no rice injury when acetochlor was applied at the 2-lf stage of rice, regardless of rate. Rice injury was only

4% and 3% from 1.125 lb/acre of acetochlor at spiking and 4-lf rice stage, respectively (Table 1). Rice yield was 151, 146, and 155 bu/acre (averaged over years and rates) when acetochlor was applied at spiking, 2-lf, and 4-lf stage of rice, respectively (data not shown). Plots that received acetochlor at 0.375 and 0.75 lb/acre provided comparable yield to the nontreated check (averaged over years and timings). However, rice yield was reduced 7% compared to nontreated check from the highest rate (1.125 lb/acre) of acetochlor (data not shown).

On a silt loam soil at RREC, rice injury was greatest at the spiking stage (Table 2). Rice injury increased as acetochlor rate increased. Rice injury was 4%, 16%, and 18% when acetochlor was applied at 0.375, 0.75, and 1.125 lb/acre at the 2-lf stage of rice, respectively. Rice injury was only 1% to 3% from acetochlor applied to 4-lf rice, regardless of acetochlor rate. Rice yield was 121, 130, and 125 bu/acre (averaged over years and rates) when acetochlor was applied at spiking, 2-lf, and 4-lf stages of rice (data not shown). Rice yields did not differ significantly from the nontreated check regardless of application timing or acetochlor rate, except for acetochlor applied at 1.125 lb/acre at spiking (Table 3). In general at both locations, plots that received acetochlor at 0.375 and 0.75 lb/acre provided comparable yield to the nontreated check (averaged over years and timings). However, rice yield was slightly reduced from the highest rate of acetochlor. Overall, rice tolerance was greatest when acetochlor was applied at 0.75 lb/acre at the 2- to 4-lf stage of rice without yield loss.

At the NEREC, as S-metolachlor rate increased from 0.75 to 1.25 lb/acre, the level of rice injury increased (Table 4). Rice tolerance was greatest when S-metolachlor was applied to 2-lf rice. Plots that received a lower rate (0.75 lb/acre) of S-metolachlor at spiking and 2-lf rice and plots that received a high rate (1.25 lb/acre) of S-metolachlor at the 4-lf rice stage had comparable yield to the nontreated check (Table 5). However, plots that received the higher rate (1.25 lb/acre) of S-metolachlor at spiking and 2-lf rice had 64% and a nonsignificant 6% lower yield than the nontreated check, respectively.

At the RREC, the interaction between S-metolachlor rate and application timing was not significant. However, the main effect of S-metolachlor application timing was significant. Rice injury was 1%, 73%, and 37% (averaged over rates) from the application of S-metolachlor at spiking, 2-lf, and 4-lf stages of rice, respectively. Averaged over rates, rice yield was decreased 20% on average from the application of S-metolachlor at the 4-lf stage compared to the application of S-metolachlor at spiking or 2-lf stage (data not shown). Averaged over application timings, plots that received S-metolachlor at 0.75 and 1.25 lb/acre had reduced yield of 32% to 58% compared to the nontreated check. The level of rice injury caused by S-metolachlor at 0.75 lb/acre at spiking, 2-lf, and 4-lf stage of rice and the associated yield loss was unacceptable.

SIGNIFICANCE OF FINDINGS

The Warrant formulation of acetochlor may have promise as an additional mode of action that could be used in rice. Further research is needed to determine if crop maturity is delayed from the applications that did not appear to cause early-season injury and the level and spectrum of weed control with acetochlor will need to be further evaluated. Based on the findings from these trials, it is unlikely that Dual II Magnum (an EC formulation of S-metolachlor) can be used in rice.

ACKNOWLEDGMENTS

We would like to thank the Arkansas Rice Research and Promotion Board for funding this research.

LITERATURE CITED

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, K.L. Smith, and J.A. Bond. 2012. Survey of weed management practices and needs in Arkansas and Mississippi rice. Proc. 34th Rice Tech. Working Group.

Stauber, L.G., R.J. Smith Jr., and R.E. Talbert. 1991. Density and spatial interference of barnyardgrass (Echinochloa crus-galli) with rice (*Oryza sativa*). Weed Sci. 39:163-168.

Table 1. Rice injury from acetochlor (Warrant) applications five weeks after emergence at the Northeast Research and Extension Center, Keiser, Ark.

	Injury		
Treatment	Spiking	2-lf rice	4-lf rice
(lb ai/acre)	----------------------------	(%)	---------------------------
Acetochlor (0.375)	0 c[†]	0 c	0 c
Acetochlor (0.75)	0 c	0 c	2 b
Acetochlor (1.125)	4 a	0 c	3 ab

[†] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 2. Rice injury from acetochlor (Warrant) applications five weeks after emergence at the Rice Research and Extension Center, near Stuttgart, Ark.

	Injury		
Treatment	Spiking	2-lf rice	4-lf rice
(lb ai/acre)	----------------------------	(%)	---------------------------
Acetochlor (0.375)	28 c[†]	4 e	1 e
Acetochlor (0.75)	43 b	16 d	3 e
Acetochlor (1.125)	62 a	18 d	3 e

[†] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 3. Effect of acetochlor (Warrant) applications on rice yield compared to the nontreated check (130 bu/acre) at the Rice Research and Extension Center, near Stuttgart, Ark.[†]

	Yield		
Treatment	Spiking	2-lf rice	4-lf rice
(lb ai/acre)	-------------------------(bu/acre) ------------------------		
Acetochlor (0.375)	129 a[‡]	123 a	125 a
Acetochlor (0.75)	123 a	137 a	121 a
Acetochlor (1.125)	105 b	132 a	125 a

[†] Nontreated check = 130 a.

[‡] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 4. Rice injury from S-metolachlor (Dual II Magnum) applications five weeks after emergence at the Northeast Research and Extension Center, Keiser, Ark.

	Injury		
Treatment	Spiking	2-lf rice	4-lf rice
(lb ai/acre)	---------------------------- (%) ----------------------------		
S-metolachlor (0.75)	56 b[†]	15 d	23 c
S-metolachlor (1.25)	89 a	16 d	35 c

[†] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 5. Effect of S-metolachlor (Dual II Magnum) applications on rice yield compared to nontreated check (109 bu/acre) at the Northeast Research and Extension Center, Keiser, Ark.[†]

	Yield		
Treatment	Spiking	2-lf rice	4-lf rice
(lb ai/acre)	-------------------------(bu/acre) ------------------------		
S-metolachlor (0.75)	113 ab[‡]	119 a	101 b
S-metolachlor (1.25)	39 c	102 b	114 ab

[†] Nontreated check = 109 ab

[‡] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Rotational Options for Reducing Red Rice (*Oryza sativa*) in Clearfield Rice Production Systems

B.M. Davis, R.C. Scott, and J.W. Dickson

ABSTRACT

This trial was initiated in the summer of 2010 at the Rice Research and Extension Center near Stuttgart, Ark. (silt loam soil) and continued over the next 3 years. The study was established in an area with heavy infestations of red rice and a shattered population of Clearfield rice from the previous year. This area is known to contain diverse red rice biotypes. Even though red rice densities were not always significantly lower than the checks throughout the season, all visual estimates of control and red rice seed production of rotational options resulted in a reduction in red rice compared to the checks. There were no statistical differences in red rice control or production of red rice between rotational strategies in year 2, however more red rice was present in the continuous Clearfield rice system than in the other rotational options. Rotational strategies did reduce red rice counts and red rice yields in year 3 and further illustrates the need for crop rotation in reducing the occurrence of acetolactate synthase (ALS)-resistant red rice.

INTRODUCTION

Weedy rice or "red rice" has been one of the most troublesome weeds to control in rice production history. Until the release of imidazolinone-tolerant rice in 2002 there was no selective herbicide that would control red rice in rice. In 2006, Arkansas producers planted 81,200 hectares of Clearfield rice (Burgos et al., 2008). More recently in 2009, 42% of all the rice planted in Arkansas was in the Clearfield technology (Wilson et al., 2010). The Clearfield technology has enjoyed rapid adoption by rice producers with severe infestations of red rice. The imidazolinone herbicides provide excellent control of red rice and other weeds (Steele et al., 2002). However, the continual use and lack of rotation has led to the discovery of imidazolinone-resistant red rice in 2006. In fact, red rice has become resistant to imazethapyr by both traditional selection and out-crossing (Shivrain et al., 2006). Also in 2006, a survey by Norsworthy et al. reported that 56% of the growers were using the Clearfield technology. They also reported red rice to be the second most problematic weed in rice (2007).

Crop rotation and other management practices have also been discussed and implemented in the effort to control red rice. One other technology released in 1996 was the Roundup Ready system that allowed for over the top applications of glyphosate onto soybean. Glyphosate is very effective at controlling red rice, so crop rotation to Roundup Ready soybean has been an effective management tool. Recently the release of Liberty Link Soybean in 2009 has provided growers another tool for red rice control in some rotations. This technology allows for the over the top application of Ignite (glufosinate) onto soybean. Both herbicides have provided effective reduction of red rice in field trials (Eleftherohorinos and Dhima, 2002).

The objective of this research is to evaluate rotational options for Clearfield rice to aid in the prevention of acetolactate synthase (ALS)-resistant biotypes of red rice.

PROCEDURES

This trial was initiated in the summer of 2010 at the Rice Research and Extension Center near Stuttgart, Ark. (silt loam soil) and continued over the next 3 years. The study was established in an area with heavy infestations of red rice and a shattered population of Clearfield rice from the previous year. This area is known to contain diverse red rice biotypes. The design was a split block with treatments randomized within the blocks with three replications. Plots were 40 ft by 40 ft with 20 ft alleys between reps. Multiple parameters were evaluated in this study, the baseline treatment consisted of a conventional tillage practice where the variety Clearfield 142 was drill-seeded at 90 lb/acre and Newpath at 4 oz/acre applied 14 days after planting (DAP), followed by Newpath at 4 oz/acre + Strada at 2.1 oz/acre at 14 days after the first application (DAA). Treatment 2 consisted of a conventional tillage practice where a flush of red rice was allowed to emerge, then 22 oz/acre of Roundup WeatherMax was applied to control the first "flush" of red rice. CL142 was drill-seeded at 90 lb/acre. Newpath at 4 oz/acre was applied 14 DAP, followed by Newpath at 4 oz/acre + Strada at 2.1 oz/acre at 14 DAA. Treatment 3 consisted of a split check where half the plow was under conventional tillage and the other half was no-till. Treatment 4 was not tilled and was kept weed free with 22 oz/acre of Roundup WeatherMax applied as needed, this treatment was considered our chemical fallow. Treatment 5 consisted of tillage followed by 22 oz/acre Roundup WeatherMax as needed. Treatment 6 was crop rotation to Liberty Link soybean with conventional tillage. Halo 4:94 was drill-seeded at 60 lb/acre, and Ignite was applied at 22 oz/acre + Outlook at 16 oz/acre at 14 DAP. A second application of Ignite at 22 oz/acre was applied at 14 DAA. Treatment 7 was crop rotation to Roundup Ready soybean with conventional tillage. TV46R15 soybean was drill-seeded at 60 lb/acre.

Roundup WeatherMax at 22 oz/acre + Outlook at 16 oz/acre was applied at 14 DAP. A second application of Roundup WeatherMax at 22 oz/acre was applied when needed. Year 2 treatments consisted of Clearfield rice, Roundup Ready Soybean, and Liberty Link Soybean. Herbicide rate and application timings were kept consistent with year 1, respectively. Year 3 treatments consisted of Clearfield rice planted in all treatments. Herbicides and rates were kept constant with the 3 previous years, respectively. All applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 10 GPA. Red rice counts per ft^2 were recorded at 5, 9, 11, and 14 weeks after planting (WAP). Total red rice seed production was characterized at maturity by hand harvesting 3, 10-ft^2 quadrants in each plot. Data was subjected to analysis of variance and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISSCUSSION

Year 1

At 3 WAP, the delayed planted and the fallow with tillage had reduced red rice counts compared to the tilled check (Table 1). The delayed-planted treatment resulted in reduced red-rice density compared to the Clearfield baseline program. Check numbers were 13 for the tilled check and 8 for the no-till check, respectively. If this red rice were shattered or out-crossed Clearfield rice, then the delayed-planted would have provided some control versus no action in the baseline program. Similarly at 5 WAP, all treatments with the exception of the tilled check had reduced red-rice counts compared to the no-till check. The delayed planted, chemical fallow, Liberty Link soybean, and the Roundup Ready soybean had the fewest numbers of red-rice plants ranging from 0 to 2 plants/ft^2.

At 9 WAP, all treatments reduced red rice compared to both the tilled and no-till checks with numbers ranging from 0 to 2 plants/ft^2 (Table 1). There was no difference between herbicide treatments and production practices. Red-rice density in the tilled and no-till checks was 15 and 21 plants/ft^2, respectively. All treatments reduced red-rice counts by 12 WAP compared to both the tilled and no-till checks. Fallow with tillage plus glyphosate had higher red-rice counts than the chemical fallow, Liberty Link Soybean, and the Roundup Ready soybean treatments. At this time the no-till check had a lower red-rice density compared to the tilled check.

Although red-rice density counts were similar for the delayed-planted and baseline Clearfield programs, total red rice produced and final visual control data indicated a significant reduction in red rice with delayed planted. This is may be due to reduced tillering and lower seedhead production where delayed planted was used. Only the fallow programs and soybean rotation provided 100% red-rice control.

Year 2

At 4 WAP, the delayed planted, Clearfield rice following chemical fallow, both treatments following fallow with tillage and glyphosate, and all the treatments following soybeans reduced red-rice counts compared to the checks (Table 2). All other treatments had reduced red-rice counts compared to the tilled flooded check but was not different from the other checks. Similarly at 7 WAP, all treatments following fallow, all treatments following soybeans with the exception of Roundup Ready soybeans reduced red-rice counts compared to the checks and but were not different from the no-till non-flooded checks. Also both treatments following the delayed planted Clearfield rice, and the Clearfield rice following Clearfield rice reduced red-rice counts compared to the flooded check.

At 9 WAP, all treatments with the exception of Roundup Ready soybean following Clearfield rice reduced red-rice counts compared to both tilled checks but were not different from the no-till checks (Table 2). All treatments following the fallow treatments, Liberty Link soybeans, and the Clearfield rice following Roundup Ready soybeans reduced red-rice counts compared to the no-till checks. However, by 12 WAP all treatments with the exception of the Clearfield rice following Clearfield rice had reduced red-rice counts compared to all of the checks.

Even though red-rice densities were not always significantly lower than the checks throughout the season, all treatments' visual estimates of control and red-rice seed production showed a reduction in red rice compared to the checks (Table 2). There were no statistical differences in red-rice control or production of red rice between rotational strategies in year 2, however more red rice was present in the continuous Clearfield rice system than in the other rotational options.

Year 3

At 5 WAP, all rotational strategies with the exception of Roundup Ready soybean followed by (fb) Clearfield rice fb Clearfield rice reduced red-rice densities compared to all check scenarios (Table 3). The tilled check that was flooded though out the season during all 3 years had significantly higher (2 times) red-rice densities than the other checks, that were not flooded. At harvest, both tilled checks yielded significantly higher red rice than the no-till checks. This may be due to the distribution and burial of seed in the tilled checks. In comparison, the no-till, flooded checks were subject to harsher environmental conditions, predation, and germination.

By 9 WAP the delayed-planted fb delayed-planted fb Clearfield rice was the only treatment that did not reduce red-rice densities compared to the check (Table 3). At 11 WAP and 14 WAP, the baseline Clearfield rice fb Clearfield rice fb Clearfield rice and delayed-planted fb delayed-planted fb Clearfield rice were the only treatments that had not reduced red-rice densities, 10 and 4 plants/10 ft^2, respectively. These data indicated that although delayed planting may reduce red-rice numbers in the short term (Tables 1 and 2), long term it may not be an effective resistance management tool, especially not as effective as crop rotation. In fact, it is possible that continued delayed planting practices could result in simply selecting for a red rice that germinates later in the growing season.

Although some treatments did contain red rice throughout the season, due to the nature of red rice to shatter and have sporadic maturity, some red rice was shattered at the time of harvest. All efforts were made to harvest the red rice from each plot. All crop rotational programs resulted in 0 bu/acre of red rice at harvest versus 22 to 54 bu/acre in the various checks.

During the course of this work several "weedy rice" biotypes were observed that survived two applications of Newpath. One of these biotypes was a very early maturing plant of short stature with rough leaves and almost white pericarp. The possible development of these types of weedy rice off-types should be of great concern to those who wish to steward the Clearfield technology.

SIGNIFICANCE OF FINDINGS

In the first year, red rice can be reduced by fallow, soybean rotation, and delayed planting. By harvest, all treatments reduced red-rice numbers to 0 to 2 plants/ft^2. However, if resistant, then less control is expected for the Clearfield system. At 5 WAP, red rice was reduced from 9 to 1 plant/ft^2 by delaying planting and controlling the first flush of red rice with glyphosate. At harvest, red rice visual control was lower for no rotation compared to delayed planting. Even though control was 80% or greater, red rice yield for the no rotation was 6 bu/acre compared to 0.5 bu/acre with the delayed planted. If there is a problem with red rice in a particular field, producers can reduce red rice numbers with any of the rotational options evaluated. Both soybean rotation treatments reduced red-rice plant numbers to 0, whereas the rice treatments reduced numbers to 1. Fallowing a field is also a viable option with adequate reductions ranging from 2 to 0 plants/ft^2. To achieve 100% reduction, crop rotation or fallowing a field is the best option. There were no statistical differences in red-rice control or production of red rice between rotational strategies in year 2, however, more red rice was present in the continuous Clearfield systems than in the other rotational options. Year 3 results suggest that crop rotation is key in reducing red-rice counts and shows that respecting the stewardship is vital. This data may illustrate how over time the level of ALS-resistance could increase, if, for example, this study was conducted for an additional 3 years.

ACKNOWLEDGMENTS

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

LITERATURE CITED

Burgos, N.R., J.K. Norsworthy, R.C. Scott, and K.L. Smith. 2008. Red rice (*Oryza sativa*) status after 5 years of imidazolinone-resistant rice technology in Arkansas. Weed Tech 22:200-208.

Eleftherohorinos, I.G. and K.V. Dhima. 2002. Red rice (*Oryza sativa*) control in rice (*O. sativa*) with preemergence and postemergence herbicides. Weed Tech 16:537-540.

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

Shivrain, V.K., N.R. Burgos, K.A. Moldenhauer, R.W. Mcnew, and T.L. Baldwin. 2006. Characterization of spontaneous crosses between Clearfield rice (*Oryza sativa*) and red rice (*Oryza sativa*). Weed Tech 20:576-584.

Steele G.L., J.M. Chandler, and G.N. McCauley. 2002. Control of red rice (*Oryza sativa*) in imidazolinone-tolerant rice (*Oryza sativa*). Weed Tech 16:627-630.

Wilson, C.E. Jr., S.K. Runsick, and R. Mazzanti. 2010. Trends in Arkansas rice production. *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 581:11-21. Fayetteville, Ark.

Table 1. Number red-rice plants per square foot, bushels of red rice produced and percent control of red rice for various Clearfield rice rotational strategies.

Treatment (rotational programs)	Red-rice counts				Red-rice seed	Control at harvest
	3 WAP[a]	5 WAP	9 WAP	12 WAP		
	------------(no./ft^2)------------				(bu/acre)	(%)
Clearfield rice (Baseline)	14	9	1	1	6	80
Delayed planted - Clearfield rice	0	1	2	1	0.5	98
Tilled check	13	14	21	14	134	0
No-till check	8	17	15	7	99	0
Chemical fallow with glyphosate	6	2	1	0	0	100
Fallow with tillage + glyphosate	4	9	2	2	0	100
Liberty Link Soybean	8	1	0	0	0	100
Roundup Ready Soybean	11	0	0	0	0	100
LSD (0.05)[b]	8	7	6	2	15	17

[a] WAP = weeks after planting.

[b] LSD = least significant difference.

Table 2. Number of red-rice plants per square foot, bushels of red rice produced and percent control of red rice for various Clearfield rice rotational strategies.

Rotational programs		Red-rice counts					
Year 1	Year 2	4 WAP[a]	7 WAP	9 WAP	12 WAP	Red rice	Control at harvest
		---------- (no./ft^2)	----------	----------	----------	(bu/acre)	(%)
Clearfield rice (Baseline)	Roundup Ready Soybean	1	1	2	0	0	100
	Clearfield rice	1	0	1	2	1	90
Delayed planted - Clearfield rice	Roundup Ready Soybean	1	0	1	1	0	99
	Delayed planted - Clearfield rice	0	0	1	1	0	93
Tilled check	Tilled check	2	2	3	6	10	0
	Tilled check (flooded)	3	2	3	9	11	0
No-till check	No-till check	2	1	2	4	8	0
	No-till check (flooded)	2	2	1	4	5	0
Chemical Fallow with glyphosate	Roundup Ready Soybean	1	0	0	0	0	100
	Clearfield rice	0	0	0	0	0	100
Fallow with tillage + glyphosate	Roundup Ready Soybean	0	0	0	0	0	100
	Clearfield rice	0	0	0	0	0	100
Liberty Link Soybean	Roundup Ready Soybean	0	1	0	0	0	100
	Clearfield rice	0	0	0	0	0	100
Roundup Ready Soybean	Liberty Link Soybean	0	0	1	0	0	100
	Clearfield rice	0	0	0	0	0	100
LSD (0.05)[b]		1	1	1	2	4	15

[a] WAP = weeks after planting.

[b] LSD = least significant difference.

Table 3. Number of red-rice plants per 10 square foot and bushels of red rice produced for various Clearfield rice rotational strategies.

Rotational programs			Red-rice counts				
Year 1	Year 2	Year 3	5 WAP[a]	9 WAP	11 WAP	14 WAP	Red rice
			------------------(no./10 ft^2)------------------				(bu/acre)
Clearfield rice (Baseline)	Roundup Ready Soybean	Clearfield rice	1	0	0	0	0
	Clearfield rice	Clearfield rice	2	0	6	10	1
Delayed planted - Clearfield rice	Roundup Ready Soybean	Clearfield rice	2	1	0	1	0
	Delayed planted - Clearfield rice	Clearfield rice	2	17	4	4	5
Tilled check	Tilled check	Tilled check	14	20	6	21	45
	Tilled check (flooded)	Tilled check	28	12	6	16	54
No-till check	No-till check	No-till check	14	25	7	13	22
	No-till check (flooded)	No-till check	22	14	8	24	23
Chemical Fallow with glyphosate	Roundup Ready Soybean	Clearfield rice	1	0	1	1	0
	Clearfield rice	Clearfield rice	1	0	1	0	0
Fallow with tillage + glyphosate	Roundup Ready Soybean	Clearfield rice	1	0	1	0	0
	Clearfield rice	Clearfield rice	0	0	1	0	0
Liberty Link Soybean	Roundup Ready Soybean	Clearfield rice	0	0	1	1	0
	Clearfield rice	Clearfield rice	1	0	1	1	0
Roundup Ready Soybean	Liberty Link Soybean	Clearfield rice	1	0	1	1	0
	Clearfield rice	Clearfield rice	4	0	0	2	0
LSD (0.05)[b]			11	14	4	9	20

[a] WAP = weeks after planting.

[b] LSD = least significant difference.

PEST MANAGEMENT: WEEDS

Weed Control Programs with Sharpen Herbicide in Clearfield Rice

J.R. Meier, T. Barber, R.C. Doherty, R.C. Scott, and J.K. Norsworthy

ABSTRACT

Herbicide combinations with Newpath and Beyond in Clearfield rice provide increased weed control and reduced application costs for producers. However, Newpath and Beyond provide minimal control of hemp sesbania. Sharpen is a new herbicide labeled for preplant use in rice, although research studies indicate that Sharpen applied postemergence in rice provides excellent control of hemp sesbania. The purpose of this research was to examine weed control programs with Sharpen for broadleaf weed control in Clearfield rice programs. Sharpen applied to 1-lf rice caused minimal injury (10% to 15%) and was quickly outgrown. Control of barnyardgrass and sprangletop was excellent among all treatments 14 d after 1-lf rice applications (DAA) but control of hemp sesbania with Newpath plus Sharpen was less than that of Newpath plus Facet L and Prowl H_2O plus Clearpath (Newpath plus Facet premix). When applied preflood, Sharpen provided excellent control of hemp sesbania 31 DAA. Control of sprangletop at this time with two applications of Newpath was less than programs with Prowl H_2O plus Clearpath followed by Newpath or Command followed by Beyond. In Clearfield rice programs, Command applied preemergence or Prowl H_2O applied at 1-lf rice in combination with Newpath or Beyond are essential for control of sprangletop.

INTRODUCTION

Newpath and Beyond herbicides effectively control many grass species in rice, including red rice, barnyardgrass, and broadleaf signalgrass. Newpath also provides suppression of sprangletop (Anonymous, 2013a; Anonymous, 2013b). However, previous research indicates that Newpath and Beyond provide minimal control of hemp sesbania (Anonymous, 2013a; Anonymous, 2013b; Webster and Masson, 2001; Scherder et al., 2001; Zhang et al., 2001). Herbicide combinations with Newpath and Beyond in Clearfield rice are a common practice and are beneficial to producers for increased weed control and reduced application costs (Carlson et al., 2011; Hydrick and Shaw, 1994; Pellerin et al., 2003). Sharpen is a new herbicide labeled for preplant use in rice (Anonymous, 2013c), although research studies indicate that Sharpen applied postemergence in rice provides excellent control of hemp sesbania as well as northern jointvetch with minimal injury to rice (Dickson et al., 2008; Smith et al., 2011). The purpose of this research was to examine weed control programs with Sharpen for broadleaf weed control in Clearfield rice programs.

PROCEDURES

A trial was conducted in 2012 at the Southeast Research and Extension Center near Rohwer, Ark., to evaluate barnyardgrass, sprangletop, and hemp sesbania control in Clearfield rice programs using Sharpen postemergence. A randomized complete block design with four replications was used. The cultivar CL151 was drill-seeded into a Sharkey clay soil at 90 lb/acre, and barnyardgrass and hemp sesbania were broadcast-seeded after planting. A natural population of sprangletop in the trial area was sufficient for evaluation. Treatments were applied with a tractor mounted sprayer calibrated to deliver 12 gal/acre. Barnyardgrass, sprangletop, and hemp sesbania control was evaluated throughout the season on a scale of 0% to 100% where 0% equals no control and 100% equals complete control. Data were subjected to analysis of variance and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Sharpen applied to 1-lf rice caused minimal injury (10% to 15%) and was quickly outgrown (data not shown). Control of barnyardgrass and sprangletop was excellent among treatments 14 days after application (DAA, Table 1). Control of hemp sesbania with Newpath plus Sharpen at this time was less than that of Newpath plus Facet L and Prowl H_2O plus Clearpath (Newpath plus Facet premix) because of less residual control from Sharpen compared to Facet. By 22 DAA, control of barnyardgrass and hemp sesbania was similar among treatments although control had diminished from the previous evaluation. Control of sprangletop at this time was greater from Command applied preemergence compared to Newpath applied at 1-lf rice, but no different from Prowl H_2O applied at 1-lf rice.

Preflood applications were made to treatments at the 5-lf rice growth stage. Control of barnyardgrass, sprangletop, and hemp sesbania 10 d after these applications (1 week postflood) was similar among treatments although control of barnyardgrass and sprangletop from some treatments was <100% (Table 2). By 31 DAA (4 weeks postflood), control of hemp sesbania was 98-100% among all treatments. Control of barnyardgrass was also similar among treatments and was 89-95%. However, control of sprangletop at this time with two applications of Newpath was less than programs with Prowl H_2O plus Clearpath followed by Newpath or Command followed by Beyond. Newpath is only labeled for suppression of sprangletop, and Beyond and Facet L provide no control (Anonymous, 2013a; Anonymous, 2013b; Anonymous, 2013d).

SIGNIFICANCE OF FINDINGS

Sharpen applied at 1-lf rice did not provide as long of residual control of hemp sesbania as Facet L or Clearpath. When applied preflood, Sharpen provided excellent control of hemp sesbania when evaluated 4 weeks postflood. In Clearfield rice programs, Command applied preemergence or Prowl H_2O applied at 1-lf rice in combination with Newpath, Clearpath, or Beyond are essential for control of sprangletop.

ACKNOWLEDGMENTS

Special appreciation is extended to the Arkansas Rice Research and Promotion Board, the Arkansas rice growers, and BASF for providing funding and support for this project.

LITERATURE CITED

Anonymous. 2013a. Newpath herbicide label. Research Triangle Park, N.C.: BASF Agricultural Products.

Anonymous. 2013b. Beyond herbicide label. Research Triangle Park, N.C.: BASF Agricultural Products.

Anonymous. 2013c. Sharpen herbicide label. Research Triangle Park, N.C.: BASF Agricultural Products.

Anonymous. 2013d. Facet L herbicide label. Research Triangle Park, N.C.: BASF Agricultural Products.

Carlson, T.P., E.P. Webster, M.E. Salassi, J.B. Hensley, and D.C. Blouin. 2011. Imazethapyr plus propanil programs in imidazolinone-resistant rice. Weed Technol. 25:204-211.

Dickson, J.W., R.C. Scott, K.L. Smith, J.K. Norsworthy, and B.M. Davis. 2008. BAS 800 (Kixor) for Northern jointvetch and hemp sesbania control in rice. *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 571:160-164. Fayetteville.

Hydrick, D.E. and D.R. Shaw. 1994. Effects of tank-mix combinations of nonselective foliar and selective soil-applied herbicides on three weed species. Weed Tech. 8:129-133.

Pellerin, K.J., E.P. Webster, W. Zhang, and D.C. Blouin. 2003. Herbicide mixtures in water-seeded imidazolinone-resistant rice. Weed Tech. 17:836-841.

Scherder, E.F., R.E. Talbert, M.L. Lovelace, and N.W. Buehring. 2001. Weed control programs in herbicide-tolerant rice. Proc. South. Weed Sci. Soc. 54:39-40.

Smith, K.L., J.A. Bullington, R.C. Doherty, and J.R. Meier. 2011. BAS800H efficacy and tank-mixes in Clearfield rice. *In:* K.L. Smith, J.A. Bullington, R.C. Doherty and J.R. Meier (eds.). Weed Science Research Summaries 2011. University of Arkansas Agricultural Experiment Station Research Series 601:186-188. Fayetteville.

Webster, E.P. and J.A. Masson. 2001. Acetolactate synthase-inhibiting herbicides on imidazolinone-tolerant rice. Weed Sci. 49:652-657.

Zhang, W., E.P. Webster, and H.M. Selim. 2001. Effect of soil moisture on efficacy of imazethapyr in greenhouse. Weed Tech. 15:355-359.

Table 1. Barnyardgrass, sprangletop, and hemp sesbania control 14 and 22 days after application, at the Southeast Research and Extension Center near Rohwer, Ark., in 2012.

			14 days after 1 leaf application[a]			22 days after 1 leaf application		
Treatment	Rice growth stage	Rate	ECHCG[b]	LEFPA	SEBEX	ECHCG	LEFPA	SEBEX
			(%)					
Prowl H_2O	1-lf	2 pt	100	100	98	91	90	88
Clearpath	1-lf	0.5 lb						
Newpath	Preflood	4 oz						
Prowl H_2O	1-lf	2 pt	100	100	94	94	93	91
Clearpath	1-lf	0.5 lb						
Sharpen	1-lf	1 oz						
Newpath	Preflood	4 oz						
Newpath	1-lf	4 oz	100	100	86	94	86	85
Sharpen	1-lf	1 oz						
Newpath	Preflood	4 oz						
Facet L	Preflood	32 oz						
Newpath	1-lf	4 oz	100	100	97	96	86	93
Facet L	1-lf	32 oz						
Newpath	Preflood	4 oz						
Sharpen	Preflood	1 oz						
Command	Preemergence	1.33 pt	100	100	0	95	94	0
Beyond	Preflood	4 oz						
Sharpen	Preflood	1 oz						
Command	Preemergence	1.33 pt	100	100	0	91	97	0
Beyond	Preflood	4 oz						
Facet L	Preflood	32 oz						
Sharpen	Preflood	1 oz						
LSD (0.05)[c]			NS	NS	8	7	7	11

[a] Control was evaluated on a scale of 0% to 100% where 0% equals no control and 100% equals complete control.

[b] Abbreviations: ECHCG, barnyardgrass; LEFPA, sprangletop; and SEBEX, hemp sesbania.

[c] LSD = least significant difference.

Table 2. Barnyardgrass, sprangletop, and hemp sesbania control 1 and 4 weeks postflood at the Southeast Research and Extension Center near Rohwer, Ark., in 2012.

			1 week postflood[a]			4 weeks postflood		
Treatment	Rice growth stage	Rate	ECHCG[b]	LEFPA	SEBEX	ECHCG	LEFPA	SEBEX
			(%)					
Prowl H_2O	1-lf	2 pt	100	98	100	93	84	99
Clearpath	1-lf	0.5 lb						
Newpath	Preflood	4 oz						
Prowl H_2O	1-lf	2 pt	100	98	100	95	85	98
Clearpath	1-lf	0.5 lb						
Sharpen	1-lf	1 oz						
Newpath	Preflood	4 oz						
Newpath	1-lf	4 oz	100	100	100	89	71	100
Sharpen	1-lf	1 oz						
Newpath	Preflood	4 oz						
Facet L	Preflood	32 oz						
Newpath	1-lf	4 oz	98	96	100	94	73	100
Facet L	1-lf	32 oz						
Newpath	Preflood	4 oz						
Sharpen	Preflood	1 oz						
Command	Preemergence	1.33 pt	95	98	100	90	96	100
Beyond	Preflood	4 oz						
Sharpen	Preflood	1 oz						
Command	Preemergence	1.33 pt	98	98	100	93	95	100
Beyond	Preflood	4 oz						
Facet L	Preflood	32 oz						
Sharpen	Preflood	1 oz						
LSD (0.05)[c]			7	7	Ns	13	11	4

[a] Control was evaluated on a scale of 0% to 100% where 0% equals no control and 100% equals complete control.

[b] Abbreviations: ECHCG, barnyardgrass; LEFPA, sprangletop; and SEBEX, hemp sesbania.

[c] LSD = least significant difference.

A Six-Year Summary of the Herbicide-Resistance Weed Screening Program in Rice at the University of Arkansas: 2006-2012

J.K. Norsworthy, R.C. Scott, and D.B. Johnson

ABSTRACT

A program set up to allow growers, consultants, and county agents of Arkansas to submit weed samples from rice fields to be evaluated for possible resistance to herbicides was reinitiated in the fall of 2006. Submission of samples to the program is strictly voluntary and there has been no direct charge for submission of samples. This program has been instrumental in helping document the first occurrence of several resistant weeds. Additionally, the program helps producers understand the possible cause of herbicide failure in their fields. Herbicide options are provided to each individual submitting a sample. A data set showing the spread and frequency of resistance occurrence in Arkansas rice fields has been obtained from the submitted samples. Barnyardgrass has been the most frequently submitted weed with 184 samples submitted over the past 6 years, with resistance confirmed to propanil (Stam), quinclorac (Facet), propanil + quinclorac, clomazone (Command), and imazethapyr (Newpath) in 54%, 29%, 23%, 1%, and 4% of samples, respectively.

INTRODUCTION

In Arkansas, propanil was first used in 1959, with resistance to the herbicide by barnyardgrass confirmed in 1990 (Baltazar and Smith, 1994). Prior to 1990, there was no program in place to screen or evaluate plants for resistance. In the early 1990s, a screening program was developed at the University of Arkansas to test for propanil resistance. Shortly thereafter, it was recognized that propanil resistance by barnyardgrass in Arkansas rice was widespread. In 1992, through a Section 18 label, quinclorac became the solution for managing propanil-resistant barnyardgrass, but in 1999, a biotype resistant to both propanil and quinclorac was confirmed (Lovelace et al., 2002). Clomazone was then registered in Arkansas rice in 2000 and has been used on 70% to 80% of the rice acreage annually (Norsworthy et al., 2007).

Many factors contribute to herbicide failure under field conditions of which some may include absence of a prolonged flood, weeds too large at application, poor coverage, and environmental stresses including high temperatures among others. Most often growers attribute the ineffectiveness of a herbicide to resistance, especially the last product applied in the field. Knowledge gained regarding the sensitivity, or the lack thereof, of weeds present in a field to herbicides is invaluable information that can be used by growers and consultants in developing weed control programs in subsequent years. As a result, a program for evaluating weeds for resistance to herbicides was reinitiated at the University of Arkansas beginning in the fall of 2006. In this report, findings from the herbicide-resistance weed screening program are summarized from 2006 through 2012.

PROCEDURES

Weed seed samples are annually collected by growers, consultants, and county agents from fields where herbicides were not effective. During the winter months, progeny from these samples are sent to the University of Arkansas and are evaluated for herbicide resistance. Findings from the evaluations are returned to the sample submitter along with potential recommendations for control. When samples are submitted, it is suggested that a description of the location from which the sample was collected, crop and herbicide history, along with other pertinent information accompany 20 to 30 seedheads in a paper sack (Fig. 1). From 2006 through 2012, a total of 215 weed samples have been submitted for evaluation of herbicide resistance.

Once samples are threshed and categorized, seed from the suspected resistant plants are sown in 4-inch diameter pots, generally two pots per sample, and a known susceptible is included for comparison. If a known resistant biotype is available, the resistant biotype is included as an additional standard. When evaluating postemergence herbicides, all applications are made at the 2- to 3-lf stage of the weed. When assessing weeds such as barnyardgrass for resistance to clomazone, all applications are made immediately following planting. Barnyardgrass is the most common weed of rice for which resistance is evaluated. Because of the widespread resistance to multiple herbicide mechanisms of action, all barnyardgrass samples are screened for resistance to glyphosate (Roundup), propanil (Stam), quinclorac (Facet), clomazone (Command), penoxsulam (Grasp), cyhalofop (Clincher), and imazethapyr (Newpath). All herbicides are applied at the 1× field use rate, except for glyphosate which is applied at the field use rate of 0.5×. Glyphosate is not labeled for use in rice but is a common herbicide applied as a burndown application prior to planting rice; hence, its inclusion in the screening. For other weeds submitted, samples are only screened against the 1× rate of those herbicides for which concerns for resistance are expressed. When resistance is seen for the first time, subsequent experiments are conducted to document the level of resistance in the resistant biotype relative to a known susceptible biotype as well as the possibility of resistance to herbicides having the same mechanism of action.

RESULTS AND DISCUSSION

Barnyardgrass has been the most frequently submitted weed for screening from 2006 to 2012, with 184 samples submitted (Fig. 2). A total of 215 weed samples have been submitted during this timespan. Other weeds of rice that have been screened include sprangletop, rice flatsedge, smallflower umbrellasedge, yellow nutsedge, and red rice. It is not surprising that barnyardgrass is the most frequently submitted weed because it is the most important weed of Arkansas rice based on a recent survey of rice consultants (Norsworthy et al., 2013).

Weeds of Arkansas rice have shown a high tendency to evolve resistance to herbicides. From the samples that have been submitted over the past 6 years, we have been able to confirm the first resistance of several weeds of Arkansas rice, including barnyardgrass resistance to clomazone (2007) and imazethapyr (2009) among other acetolactate synthase (ALS)-inhibiting herbicides (Riar et al., 2012); rice flatsedge resistance to halosulfuron (2010); smallflower umbrellasedge resistance to halosulfuron (2011); and yellow nutsedge resistance to halosulfuron (2011). The frequency of resistance to propanil, quinclorac, and resistance to both propanil and quinclorac should be reason for concern among rice growers considering that 54% of the samples were resistant to propanil, 29% were resistant to quinclorac, and 23% were resistant to both propanil and quinclorac (Fig. 1).

The fact that herbicide resistance within barnyardgrass can be readily transmitted via pollen as demonstrated by Bagavathiannan et al. (2012) should raise concern for the eventual loss of all herbicides to which resistance has already evolved (propanil - Group 7, quinclorac - Group 4, clomazone - Group 13, ALS-inhibitors - Group 2). No new mechanisms of action will be available in rice in the forseeable future. This means that loss of these four mechanisms of action could place undue selection pressure on the remaining labeled herbicides for grass control in rice, which would include pendimethalin (Group 3), thiobencarb (Group 8), and fenoxaprop and cyhalofop (Group 1). For certain, new mechanisms of action are desperately needed in Arkansas rice, and growers, consultants, and county agents must work diligently to understand whether resistance already exists within their fields and select highly effective herbicides with close attention to use of multiple effective mechanisms of action.

SIGNIFICANCE OF FINDINGS

There are only seven mechanisms of action that are currently available for weed control in Arkansas rice. Unfortunately, barnyardgrass has already evolved resistance to four of these mechanisms of action, and the fact that propanil and quinclorac resistance is widespread and extremely common should be cause for concern among producers. Diversified programs that integrate multiple effective modes of action targeting resistant-prone weeds such as barnyardgrass and the annual sedges are of upmost importance.

ACKNOWLEDGMENTS

We would like to thank the Arkansas Rice Promotion Board for its continual support of the University of Arkansas System Division of Agriculture Weed Science

Program. Appreciation is also extended to those growers, consultants, and county agents that routinely submit weed samples for screening.

LITERATURE CITED

Bagavathiannan, M.V., J.K. Norsworthy, K.L. Smith, and P. Neve. 2012. Pollen-mediated movement of herbicide resistance in barnyardgrass. *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 600:142-148. Fayetteville.

Baltazar, A.M. and R.J. Smith. Jr. 1994. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Tech. 8:576-581.

Lovelace, M.L., R.E. Talbert, B.W. Skulman, and E.F. Scherder. 2002. Evaluation of physiological responses in quinclorac-resistant and -susceptible barnyardgrass. Proc. South. Weed. Sci. Soc. 55:114.

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

Norsworthy, J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Tech. *In press*.

Riar, D.S., J.K. Norsworthy, J.A. Bond, M.T. Bararpour, M.J. Wilson, and R.C. Scott. 2012. Resistance of *Echinochloa crus-galli* populations to acetolactate synthase-inhibiting herbicides. Int. J. Agron. doi:10.1155/2012/893953.

SUSPECTED HERBICIDE RESISTANT-WEED SEED INFORMATION SHEET
(To accompany weed seed to be evaluated for herbicide resistance)

Date: ___________________

Producer: ____
Address: ____
Town: _____________________ County ___________________ State: _______
Zip:_________
Field ID and/or location: ____
GPS coordinates (if available): ____
How many acres are infested at this location? _____ acres
What is the weed problem in the field? ________________________
Has this problem occurred in the same field for several years, become progressively worse, or is this a first time occurrence? ____
What specific herbicide(s) was (were) used to manage this weed this year? _________________
____
What crop was grown this year? _____________________
What was the total herbicide program this year? ______________________________________
____
What has the herbicide program been in this field for the past 5 years?

Year	Crop	Herbicide Program

County Extension Contact Person:
Name: _________________________
Address: _______________________
____
____
Tel: ____________________________
E-mail: _________________________

Contact person for testing:
Dr. Jason K. Norsworthy
Weed Scientist
1366 West Altheimer Drive
University of Arkansas
Fayetteville, AR 72704
jnorswor@uark.edu
(479) 575-8740

Fig. 1. Information sheet that should accompany each weed sample submitted for herbicide-resistance screening.

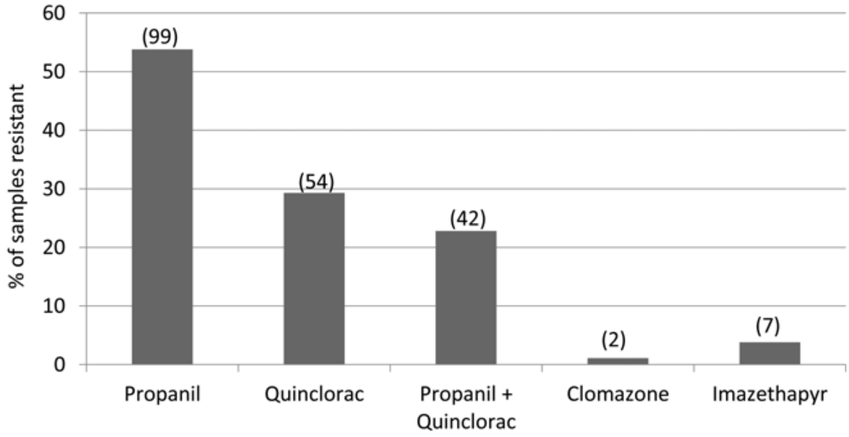


Fig. 2. Confirmation of resistance in barnyardgrass populations screened from 2006 to 2012. A total of 184 populations have been screened. Number of populations confirmed resistant are in parentheses.

PEST MANAGEMENT: WEEDS

Soybean (*Glycine max*) Response to Imazosulfuron Drift from Rice (*Oryza sativa*)

S.S. Rana, J.K. Norsworthy, D.B. Johnson, and R.C. Scott

ABSTRACT

Imazosulfuron is a sulfonylurea herbicide recently labeled in U.S. rice. Soybean is prone to drift of herbicides from rice fields in the southern U.S. because the two crops are often grown in close proximity. Therefore, field trials were conducted at the University of Arkansas Agricultural Research and Extension Station, Fayetteville, and the Pine Tree Research Station, near Colt, Ark., to determine the effect of low rates of imazosulfuron applied at different growth stages of non-sulfonylurea-tolerant (non-STS) soybean. Imazosulfuron is labeled for use in Arkansas rice at a maximum rate of 0.3 lb ai/acre. Soybean was treated at the VC, V2, V6, and R2 growth stages with 1/256, 1/128, 1/64, 1/32, 1/16, 1/8, and 1/4 times (×) the maximum labeled rate of imazosulfuron. Soybean was injured regardless of herbicide rate or application timing. Injury to soybean plants from imazosulfuron was in the form of stunting and purple veins. At 2 weeks after treatment (WAT), imazosulfuron at the 1/256 to 1/4× rates injured soybean 26% to 73%, 44% to 73%, 32% to 65%, and 14% to 46% when applied at the VC, V2, V6, and R2 growth stages, respectively. The highest injury was caused by the highest imazosulfuron rate (1/4×). However, at 20 weeks after planting (WAP), soybean treated with 1/256 to 1/16× rates of imazosulfuron at the VC and V2 growth stages had only 0% to 8% and 8% to 27% injury, respectively. At higher rates (1/8 and 1/4×) of imazosulfuron, soybean treated at the VC growth stage recovered more from injury than did soybean treated at the V2 growth stage. Soybean treated with imazosulfuron at the V6 and R2 growth stages had better recovery from the injury at the lower two rates (1/256 and 1/128×) than at the higher rates (1/64 to 1/4×). Injury to soybean at 2 WAT resulted in higher yield loss if imazosulfuron was applied at V6 and R2 than at VC and V2. At the 1/256 to 1/4× rates, imazosulfuron reduced soybean yields by 0% to

37%, 14% to 50%, 19% to 70%, and 21% to 88% for the VC, V2, V6, and R2 growth stages, respectively. This research indicates that imazosulfuron can severely injure soybean regardless of the growth stage at which drift occurs; however, soybean injured by imazosulfuron at early growth stages (VC and V2) with lower application rates has a better chance of recovery over time compared to later growth stages (V6 and R2).

INTRODUCTION

Imazosulfuron is a new sulfonylurea herbicide labeled for use in rice (Godara et al., 2012; Riar and Norsworthy, 2011). Imazosulfuron acts by inhibiting acetolactate synthase (ALS) (EC 4.1.3.18) activity at very low concentrations and hinders biosynthesis of the branched-chain amino acids valine, leucine, and isoleucine, thereby resulting in rapid cessation of plant cell division and growth (Brown, 1990; Usui, 2001; Riar and Norsworthy, 2011). Imazosulfuron comes into the market with a trade name of League and is being produced by Valent Corporation (Walnut Creek, Calif.) for weed control in drill- and water-seeded rice at a maximum field use rate of 0.3 lb ai/acre. In rice, sequential applications (PRE fb POST) of imazosulfuron at 0.3 lb ai/acre provided excellent control of broadleaf weeds and sedges (Godara et al., 2012; Riar and Norsworthy, 2011).

Rice is one of the most important crops grown in Arkansas. Weed control in rice is highly dependent on use of herbicides; halosulfuron is the current standard of sulfonylurea herbicides used in rice (Nandula et al., 2009). In the southern U.S., soybean is also an important crop and is often grown in close proximity to rice. Halosulfuron, when applied to rice, is reported to injure soybean through off-target movement or drift (Nandula et al., 2009). The normal drift rates of herbicide during application can range from 0.01% to 10% of the applied rate (Al-Khatib and Peterson, 1999; Snipes et al., 1992). However, depending on the crop and the growth stage, injury from the off-target movement of herbicides to non-labeled or susceptible crops ranges from sublethal to severe.

Glyphosate injures non-glyphosate-resistant soybean when applied from vegetative through reproductive stages; however, the vegetative growth stages of soybean had better chances to recover from the injury compared with the reproductive growth stages (Norsworthy, 2004). Therefore, soybean is considered more sensitive to glyphosate applications made later in the season because there is less time to recover from the injury. Halosulfuron at 0.004 to 0.06 lb/acre applied to 4-trifolilate (V4) soybean caused 78% to 89% injury at 28 days after treatment (DAT) (Nandula et al., 2009). At the same rates, halosulfuron applied to full bloom (R2) soybean injured soybean 70% to 75% at 28 DAT. Imazosulfuron at as little as 0.005 lb/acre (1/64×) injured non-STS soybean from cotyledonary (VC) through R2 growth stages; whereas, STS soybean was not injured (Norsworthy et al., 2010). Moreover, imazosulfuron applied at 0.15 lb/acre (1/2×) caused more than 80% injury to soybean. In the same work, soybean treated with 0.005 and 0.009 lb/acre of imazosulfuron at emergence (VE) and at the 3-trifoliolate (V3) soybean growth stages recovered from the injury and resulted in no yield reduction compared with the non-treated control. Recovery of soybean plants treated at early growth stages with lower imazosulfuron rates was because of ample time available for early-season-treated soybean to recover from the injury. For the same reason, the late-maturing soybean varieties have a better chance of recovery from imazosulfuron injury compared with the early-maturing soybean varieties (Davis et al., 2011). Injury from imazosulfuron is generally in the form of chlorosis, purple veins, and stunting that is characteristic of sulfonylurea herbicide (ALS-inhibiting herbicide) injury to soybean (Brown, 1990; Norsworthy et al., 2010). In addition, severely injured soybean fails to produce grain (Norsworthy et al., 2010).

There is little information available for the sensitivity of soybean to drift rates of imazosulfuron. Therefore, it is imperative to conduct research to understand the potential of imazosulfuron to injure soybean via off-target movement from rice.

PROCEDURES

Field trials were conducted at the University of Arkansas Agricultural Research and Extension Station, Fayetteville, and the Pine Tree Research Station, near Colt, Ark., in summer 2011. The experimental arrangement used was a factorial in a randomized complete block design with four replications; factor A was four application timings and factor B was seven imazosulfuron rates. The four application timings were the VC, 2-trifoliolate soybean (V2), 6-trifoliolate soybean (V6), and R2 growth stages. Imazosulfuron was applied at 1/256, 1/128, 1/64, 1/32, 1/16, 1/8, and 1/4 times (×) its labeled rate, 0.3 lb/acre. Treatments also included a non-treated control. Data were recorded for injury at 2 WAT, late-season injury, delay in days to maturity, and yield reduction.

Data were subjected to analysis of variance in SAS JMP v.10 software (SAS Institute, Inc., Cary, N.C.). Data were presented as the percent of non-treated check for all the parameters measured, and data from the nontreated check were not included in the analysis. Data were tested for normality prior to analysis. Data were pooled over the locations with location treated as a random effect. Data were then regressed against imazosulfuron rate using Sigmaplot v. 12 (Systat Software, Inc., San Jose, Calif.) using best-fit regression model.

RESULTS AND DISCUSSION

The response of soybean to imazosulfuron was comparable among response parameters, and there were no significant location interactions for any of the response variables, except for injury at 2 WAT. Therefore, data were pooled across the locations.

Imazosulfuron injury to soybean was noticeable within a week after treatment and peaked at 2 WAT. At 2 WAT, injury symptoms, which were purple veins and stunting, were more severe at higher rates applied at early growth stages. Imazosulfuron at 2 WAT injured early growth stages, VC and V2, more than the later growth stages, V6 and R2. Imazosulfuron at the highest (1/4×) rate resulted in soybean injury of 73% when applied at VC and V2 growth stages, followed by V6 (65%), and R2 growth stages (46%), respectively (Fig. 1, Table 1). The sensitivity of early growth stages of soybean to imazosulfuron is attributed to higher herbicide absorbance by young and rapidly growing plants than mature plants (Devine, 1989; Wanamarta and Penner, 1989).

When observed late in the growing season, soybean injury was greatest for the V6 growth stage followed by R2, V2, and VC growth stages, where imazosulfuron at 1/4× rate caused the highest injury of 68% at the V6 growth stage followed by the R2 (59%), V2 (57%), and VC (17%) growth stages (Fig. 2, Table 1). The higher injury at V6 than at the R2 growth stage may be because of higher sensitivity of vegetative growth stages of soybean to sulfonylurea herbicides than reproductive stages (Bailey and Kapusta, 1993).

Yield loss increased with increasing rates of imazosulfuron, regardless of the application timing. The greatest yield reduction of 88% occurred for soybean treated with the 1/4× rate of imazosulfuron at the R2 growth stage (Fig. 3, Table 1). Across the application timings, the yield reduction is rather higher for the V6 growth stage followed by the R2, V2, and VC growth stages. At the 1/4× imazosulfuron rate, yield reductions of 70%, 50%, and 37% were observed for the V6, V2, and VC growth stages, respectively. The yield reduction data followed the trend of late-season injury data where maximum injury from imazosulfuron occurred at the V6 growth stages followed by the R2, V2, and VC growth stages (Figs. 2 and 3, Table 1).

SIGNIFICANCE OF FINDINGS

The results of this research suggested that non-STS soybean was injured from drift rates of imazosulfuron (1/256 to 1/4×) and at all the application timings (VC, V2, V6, and R2). However, soybean treated with lower imazosulfuron rates at early growth stages recovered better from imazosulfuron injury and resulted in less yield loss compared with higher imazosulfuron rates at later growth stages.

ACKNOWLEDGMENTS

The continued support of weed management research by the Arkansas Rice Research and Promotion Board, Arkansas Soybean Promotion Board, and Valent U.S.A is greatly appreciated.

LITERATURE CITED

Al-Khatib, K. and D. Peterson. 1999. Soybean (*Glycine max*) response to simulated drift from selected sulfonylurea herbicides, dicamba, glyphosate, and glufosinate. Weed Tech. 13:264-270.

Bailey, J.A. and G. Kapusta. 1993. Soybean tolerance to simulated drift of nicosulfuron and primisulfuron. Weed Tech. 7:740-745.

Brown, H.M. 1990. Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides. Pest. Manag. Sci. 29:263-281.

Davis, B.M., R.C. Scott, J.K. Norsworthy, and E. Gbur. 2011. Response of soybean (*Glycine max*) to sublethal rates of glufosinate. Online. Crop Management doi:10.1094/CM-2011-0601-01-RS.

Devine, M.D. 1989. Phloem translocation of herbicides. Rev. Weed Sci. 4:191-213.

Godara, R.K., B.J. Williams, E.P. Webster, J.L. Griffin, and D.K. Miller. 2012. Evaluation of imazosulfuron for broadleaf weed control in drill-seeded rice. Weed Tech. 26:19-23.

Nandula, V.K., D.H. Poston, K.N. Reddy, and K. Whiting. 2009. Response of soybean to halosulfuron herbicide. Int. J. Agron. 2009:1-7.

Norsworthy, J.K. 2004. Conventional soybean plant and progeny response to glyphosate. Weed Tech. 18:527-531.

Norsworthy, J.K., S.K. Bangarwa, J.D. DeVore, E.K. McCallister, and M.J. Wilson. 2010. Corn and soybean response to low rates of imazosulfuron. Proc. South. Weed Sci. Soc. 63:232.

Riar, D.S. and J.K. Norsworthy. 2011. Use of imazosulfuron in herbicide programs for drill-seeded rice (*Oryza sativa*) in the mid-south United States. Weed Tech. 25:548-555.

Snipes, C.E., J.E. Street, and T.C. Mueller. 1992. Cotton (*Gossypium hirsutum*) injury from simulated quinclorac drift. Weed Sci. 40:106-109.

Usui, K. 2001. Metabolism and selectivity of rice herbicides in plants. Weed Biol. Manag. 1:137-146.

Wanamarta, G. and D. Penner. 1989. Foliar absorption of herbicides. Rev. Weed Sci. 4:215-231.

Table 1. Regression parameter estimates and R-square values for regression of injury at 2 WAT, late- season injury, and yield reduction with imazosulfuron rate using Gompertz-3P model.

Variable	Application timing	Regression parameters (± SE)			R-square
		a[†]	b	c	
Injury at 2 WAT	VC	73.05 (1.91)	0.19 (0.03)	0.42 (0.58)	0.8
	V2	73.08 (1.94)	0.17 (0.05)	-2.96 (1.57)	
	V6	64.67 (1.93)	0.18 (0.05)	-1.17 (1.06)	
	R2	45.83 (2.07)	0.14 (0.04)	0.64 (1.05)	
Late-season injury	VC	17.45 (2.95)	0.06 (0.02)	24.58 (6.33)	0.93
	V2	56.78 (3.46)	0.05 (0.01)	17.02 (1.96)	
	V6	67.47 ((1.55)	0.16 (0.02)	5.73 (0.40)	
	R2	59.07 (1.95)	0.09 (0.01)	7.92 (0.83)	
Yield reduction	VC	36.96 (3.87)	0.15 (0.06)	6.83 (1.83)	0.69
	V2	49.66 (5.69)	0.05 (0.03)	0.64 (3.80)	
	V6	70.30 (3.45)	0.17 (0.04)	2.89 (0.79)	
	R2	87.49 (5.72)	0.06 (0.01)	7.70 (1.91)	

[†] Abbreviations: SE = standard error; a, asymptote of the curve; b, growth point of the curve; c, inflection point of the curve; WAT, weeks after treatment. Imazosulfuron was applied with Agri-Dex at 1% v/v.

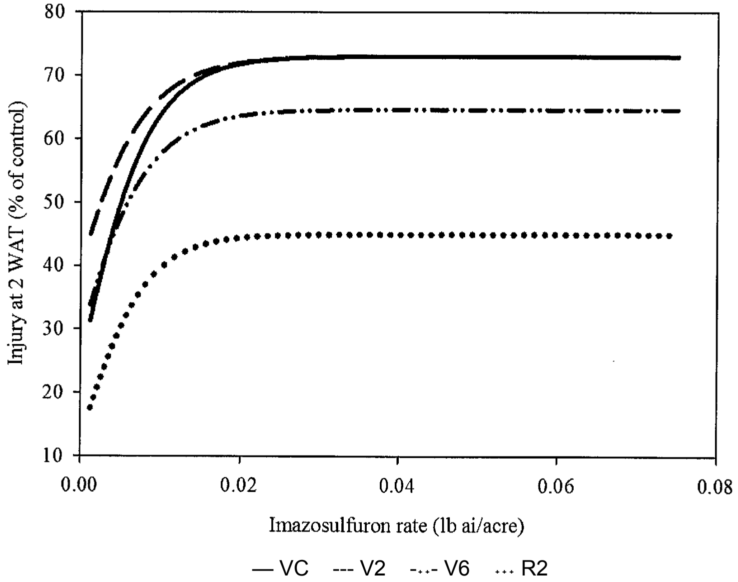


Fig. 1. Soybean injury at 2 weeks after treatment (WAT) as affected by rate of imazosulfuron applied at VC, V2, V6, and R2 growth stages at the University of Arkansas Agricultural Research and Extension Station, Fayetteville, and the Pine Tree Research Station, near Colt, Ark., in 2011.

***Abbreviations: VC, vegetative cotyledonary; V2, vegetative 2nd trifoliate; V6, vegetative 6th trifoliate; R2, reproductive full bloom.**
***The equations and regression parameters of each curve is listed in Table 1.**

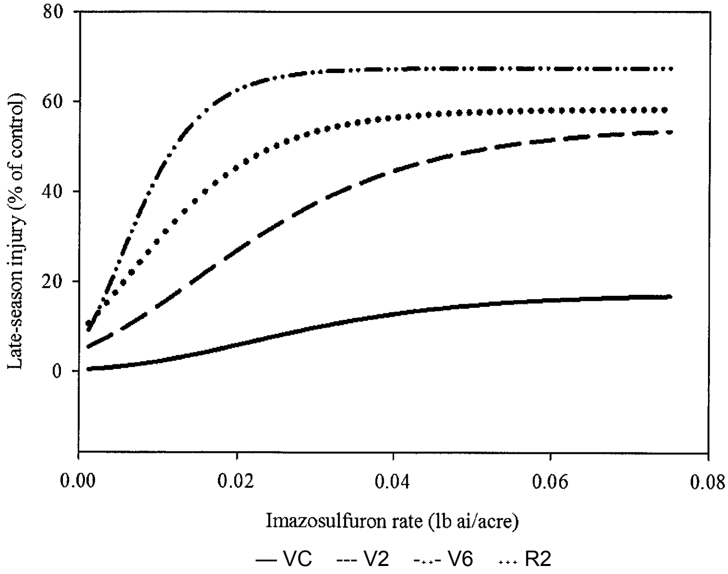


Fig. 2. Soybean late-season injury as affected by rate of imazosulfuron applied at VC, V2, V6 and R2 growth stages at the University of Arkansas Agricultural Research and Extension Center, Fayetteville, and the Pine Tree Research Station, near Colt, Ark., in 2011.

Abbreviations: VC, vegetative cotyledonary; V2, vegetative 2nd trifoliate; V6, vegetative 6th trifoliate; R2, reproductive full bloom.
***The equations and regression parameters of each curve is listed in Table 1.**

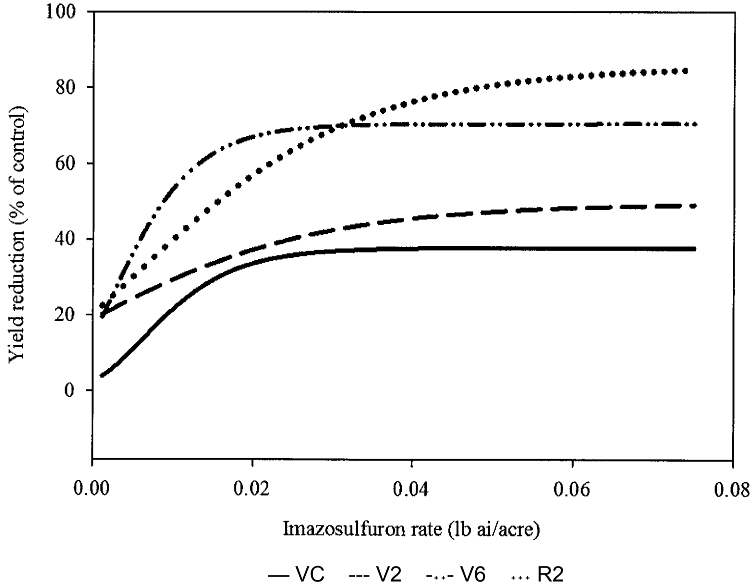


Figure 3. Soybean grain yield reduction as affected by imazosulfuron drift at VC, V2, V6, and R2 growth stages at the University of Arkansas Agricultural Research and Extension Center, Fayetteville, and the Pine Tree Research Station, near Colt, Ark., in 2011.

Abbreviations: VC, vegetative cotyledonary; V2, vegetative 2nd trifoliate; V6, vegetative 6th trifoliate; R2, reproductive full bloom.

***The equations and regression parameters of each curve is listed in Table 1.**

Response of Conventional and Imidazolinone-Resistant Rice and -Susceptible Red Rice to Acetolactate Synthase-Inhibiting Herbicides in Mixture with Malathion

D.S. Riar, J.K. Norsworthy, R.C. Scott, D.B. Johnson, H.D. Bell, and S.S. Rana

ABSTRACT

Malathion in mixture with acetolactate synthase (ALS)-inhibiting herbicides synergizes the control of weed species that have evolved metabolism-based resistance to ALS-inhibiting herbicides. However, the effect of malathion-based herbicide programs on conventional and imidazolinone-resistant (Clearfield) rice systems still need to be evaluated. Studies were conducted to determine the tolerance of conventional (Roy J) and Clearfield (CL152) rice to ALS-inhibiting herbicides in mixture with malathion and to evaluate control of red rice with ALS-inhibiting herbicides in mixture with malathion. Clearfield rice injury at 28 days after treatment (DAT) with bispyribac-sodium (Regiment), imazamox (Beyond), imazethapyr (Newpath), and penoxsulam (Grasp) alone or in mixture with malathion was <5%. In contrast, injury to conventional rice at 28 DAT from bispyribac-sodium, imazamox, and imazethapyr applied in mixture with malathion (10% to 46%, 89% to 93%, and 88% to 89%, respectively) was greater than these herbicides applied alone (2% to 13%, 59% to 74%, and 55% to 71%, respectively). A similar trend was observed for the yield of Clearfield and conventional rice following treatment with ALS-inhibiting herbicides alone and in mixture with malathion. Red rice control (ALS-susceptible) with imazethapyr or imazamox was not improved by the addition of malathion to either of these herbicides due to the high level of control with each herbicide alone.

INTRODUCTION

Concern regarding evolution of metabolism or non-target-site-based resistance (NTSR) that confers cross and multiple herbicide resistance in weeds has increased tremendously (reviewed by Yuan et al., 2007). Because of NTSR, rigid ryegrass (*Lolium rigidum* Gaudin) (Burnet et al., 1994) and black grass (*Alopecurus myosuroides* Huds.) (Délye et al., 2011) have been reported to be resistant to almost all the major herbicides labeled to control these weeds in wheat. After extensive use of acetolactate synthase (ALS)-inhibiting herbicides in Clearfield rice systems, several weed species such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], red rice (*Oryza sativa* L.), rice flatsedge (*Cyperus iria* L.), and yellow nutsedge (*Cyperus esculentus* L.) have evolved resistance to these herbicides in the mid-South U.S. (Norsworthy et al., 2013; Riar et al., 2012a, 2012b). Two barnyardgrass populations from northeast Arkansas and one from Mississippi have been found in rice fields with varying levels of NTSR to bispyribac-sodium, imazethapyr, and penoxsulam (Riar et al., 2012b).

In mixture with ALS-inhibiting herbicides, compounds inhibiting NTSR enzymes such as cytochrome P450 monooxygenase (CYP), glutathione-S-transferases, or hydrolases have been shown to restore sensitivity in ALS-resistant weeds (Délye, 2012). Malathion is one of the known CYP inhibitors; and in mixture with penoxsulam compared to penoxsulam applied alone, reduced dry weight up to 96% and increased mortality up to 90% of penoxsulam-resistant barnyardgrass biotypes from Arkansas and Mississippi (Riar et al., 2012b). Red rice is another important weed of mid-South rice that has evolved resistance to ALS-inhibiting herbicides and is difficult to control because of its morphological similarities with rice. Conventional rice and red rice can metabolize most of the labeled ALS-inhibiting herbicides and, thus, are tolerant to those herbicides. Addition of malathion to herbicide programs for control of metabolism-based ALS-resistant weeds is not useful in conventional rice as injury to conventional rice will result. However, addition of malathion to herbicide programs might be useful in Clearfield rice, which is resistant to imazamox and imazethapyr due to a target-site mutation. Accordingly, experiments were conducted to evaluate the use of malathion-containing ALS-inhibiting herbicide programs for control of red rice and tolerance of conventional and Clearfield rice.

PROCEDURES

Conventional and Clearfield Rice Tolerance Study

Studies were conducted in 2012 at the Northeast Research and Extension Center (NEREC), Keiser, Ark., and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., to determine the tolerance of conventional and Clearfield rice to ALS-inhibiting herbicides in mixture with malathion. Experiments were laid out in split-plot design with two rice varieties [conventional (Roy J) and Clearfield (CL152)] as the main plot and sub plots consisting of 12 herbicide treatments (bispyribac-sodium at 0.032 lb ai/acre, imazamox at 0.039 lb ai/acre, imazethapyr at 0.063 lb ai/acre, and penoxsulam at 0.036 lb ai/acre with and without malathion at 0.6 lb ai/acre; malathion alone at 0.6 lb ai/acre; and nontreated control) applied prior to flooding (PREFLD) at the 5- to 6-lf stage of rice. Rice injury as a percent of the nontreated control was recorded at 28 days after treatment (DAT). Rice grain was harvested for each plot and rice yields in bu/

acre were adjusted to 12% moisture. Injury and yield data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference test at α = 0.05.

Red-Rice Control Study

Studies were conducted at the Pine Tree Research Station (PTRS), near Colt, Ark., and the RREC in 2012 to evaluate the control of red rice in Clearfield rice with ALS-inhibiting herbicides in mixture with malathion. Experiments were laid out in a randomized complete block design with eight herbicide treatments: imazethapyr at 0.063 lb/acre or imazamox at 0.039 lb/acre applied alone or in mixture with malathion at 0.6 lb/acre at mid-POST (MPOST); imazethapyr at 0.063 lb/acre at early-POST (EPOST) followed by (fb) imazethapyr at 0.063 lb/acre at MPOST applied alone or in mixture with malathion at 0.6 lb/acre; malathion alone at 0.06 lb/acre at EPOST fb malathion alone at 0.06 lb/acre at MPOST; and a nontreated control. Red-rice control was recorded at MPOST and 14 days after flooding (DAF). Control data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference test at α = 0.05.

RESULTS AND DISCUSSION

Conventional and Clearfield Rice Tolerance Study

Clearfield rice injury at 28 DAT with all the herbicide treatments was <3% at NEREC and RREC (Table 1). In contrast, injury to conventional rice at 28 DAT from bispyribac-sodium, imazamox, and imazethapyr applied in mixture with malathion (10% to 46%, 89% to 93%, and 88% to 89%, respectively) was greater than these herbicides applied alone (2% to 13%, 59% to 74%, and 55% to 71%, respectively) at both locations. Imazethapyr at 0.013 lb ai/acre caused enough injury to reduce dry weight of conventional rice by 50% in previous studies (Avila et al. 2005). No difference in conventional rice injury was observed between penoxsulam alone (0% to 3%) and penoxsulam in mixture with malathion (5% to 11%).

Data for yield were pooled over locations because of no treatment-by-location interactions (Table 2). Similar to injury, Clearfield rice yield (112 to 124 bu/acre) did not differ among treatments. Yield of conventional rice treated with penoxsulam alone (127 bu/acre) and in mixture with malathion (140 bu/acre) was similar to bispyribac-sodium alone (141 bu/acre), malathion alone (147 bu/acre), and the nontreated (152 bu/acre) control. Conventional rice yield with bispyribac-sodium in mixture with malathion (102 bu/acre) was similar to bispyribac-sodium applied alone, but was less than the nontreated control. Additionally, conventional rice yielded 73 bu/acre when treated with imazamox alone and 62 bu/acre with imazethapyr alone which was less than the nontreated control but was greater than these herbicides applied in mixture with malathion (30% to 35% yield reduction).

In general, addition of malathion to ALS-inhibiting herbicide had no effect on injury and yield of Clearfield rice; but in conventional rice, injury increased and yield decreased with application of bispyribac-sodium, imazamox, and imazethapyr in mixture with malathion compared to these herbicides applied alone.

Red Rice Control Study

Red-rice control following EPOST application of imazethapyr alone (61% to 89%) was similar to imazethapyr applied in mixture with malathion (63% to 88%) (Table 3). Red-rice control with all malathion-containing (98% to 100% at PTRS and 75% to 100% at RREC) and non-malathion (97% to 100% at PTRS and 80% to 98% at RREC) treatments with herbicides was similar at 14 DAF. No increase in control of red rice with herbicide programs containing ALS-inhibiting herbicides in mixture with malathion compared to each herbicide applied alone is likely because of the susceptible red-rice population in these experimental fields, which resulted in a high level of control with imazethapyr or imazamox. Complete control of red rice with imazethapyr applied in pre-emergence and PREFLD programs has been reported (Ottis et al., 2004). Less control with single applications of imazethapyr or imazamox alone or in mixture with malathion at the RREC (61% to 63% at MPOST and 75% to 88% at 14 DAF) compared to PTRS (88% to 89% at MPOST and 97% to 100% at 14 DAF) was because of a higher red-rice density at the time of herbicide application (data not shown). Efficacy of herbicides is often dependent upon on the weed density at application (Hartzler and Roth, 1993).

SIGNIFICANCE OF FINDINGS

This research confirmed that herbicide programs containing ALS-inhibiting herbicides in mixture with malathion can be applied in Clearfield rice systems without injuring rice. Although improved control of ALS-susceptible red rice was not achieved, future research on other weeds, including metabolism-based ALS-resistant barnyardgrass, is underway to determine if CYP inhibitors can be used as part of a resistance management program in Clearfield rice.

ACKNOWLEDGMENTS

The continued support of weed management research by the Arkansas Rice Research and Promotion Board is greatly appreciated.

LITERATURE CITED

Avila, L.A., Do-J. Lee, S.A. Senseman, G.N. McCauley, J.M. Chandler, and J.T. Cothren. 2005. Assessment of acetolactate synthase (ALS) tolerance to imazethapyr in red rice ecotypes (*Oryza* spp.) and imidazolinone tolerant/resistant rice (*Oryza sativa*) varieties. Pest Manag. Sci. 61:171-178.

Burnet M.W.M., Q, Hart, J.A.M. Holtum, and S.B. Powles, 1994. Resistance to nine herbicide classes in a population of rigid ryegrass (*Lolium rigidum*). Weed Sci. 42:369-377.

Délye, C., J.A.C. Gardin, K. Boucansaud, B. Chauvel, and C. Petit. 2011. Non-targetsite-based resistance should be at the centre of herbicide resistance research attention: black-grass (*Alopecurus myosuroides*) as an illustration. Weed Res. 51:433-437.

Délye, C. 2012. Unravelling the genetic bases of non-target-site-based resistance (NTSR) to herbicides: a major challenge for weed science in the forthcoming decade. Pest Manag. Sci. DOI: 10.1002/ps.3318.

Hartzler, R.G. and G.W. Roth. 1993. Effect of prior year's weed control on effectiveness in corn (*Zea mays*). Weed Tech. 7:611-614.

Norsworthy, J.K., J. Bond, and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. Weed Tech. (under review).

Ottis, B.V., J.H. O'Barr, G.N. McCauley, and J.M. Chandler. 2004. Imazethapyr is safe and effective for imidazolinone-tolerant rice grown on coarse-textured soils. Weed Tech. 18:1096-1100.

Riar, D.S., J.K. Norsworthy, A.L. Lewis, and M.T. Bararpour. 2012a. Confirmation, control, and mechanism of ALS-inhibiting herbicide resistance in rice flatsedge. Proc. 2012 Weed Science Society of America annual meeting, Waikoloa, Hawaii. Abstract 154.

Riar, D.S., J.K. Norsworthy, J.A. Bond, M.T. Bararpour, M.J. Wilson, and R.C. Scott. 2012b. Resistance of *Echinochloa crus-galli* populations to acetolactate synthase-inhibiting herbicides. Int. J. Agron. doi:10.1155/2012/893953.

Yuan, J.S., P.J. Tranel, and C.N. Stewart. 2007. Non-target-site herbicide resistance: a family business. Trends Plant Sci. 12:6-13.

Table 1. Injury to conventional (Roy J) and Clearfield (CL152) rice at 28 days after treatment with preflood applications of acetolactate synthase (ALS)-inhibiting herbicides alone and in mixture with malathion at the Northeast Research and Extension Center (NEREC), Keiser, Ark., and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., in 2012.

		Rice injury			
		NEREC		RREC	
Herbicide[†]	Rate	CL152	Roy J	CL152	Roy J
	(lb ai/acre)	(%)			
Bispyribac-sodium	0.032	0 a[‡]	2 d	0 a	13 c
Bispyribac-sodium + Malathion	0.032 + 0.6	3 a	10 c	1 a	46 b
Imazamox	0.039	1 a	74 b	1 a	59 b
Imazamox + Malathion	0.039 + 0.6	0 a	89 a	1 a	93 a
Imazethapyr	0.063	0 a	71 b	1 a	55 b
Imazethapyr + Malathion	0.063 + 0.6	1 a	88 a	0 a	89 a
Penoxsulam	0.036	0 a	3 d	0 a	0 c
Penoxsulam + Malathion	0.036 + 0.6	1 a	5 cd	0 a	11 c

[†] Dyne-A-Pak at 2.5% was added to bispyribac-sodium treatments, whereas Induce at 0.25% was added to all other treatments.

[‡] Means for each rice variety within a column followed by the same lowercase letters are not significantly different according to Fisher's protected least significant difference test (α = 0.05).

Table 2. Yield (averaged over the Northeast Research and Extension Center, Keiser, Ark., and the Rice Research and Extension Center, near Stuttgart, Ark.) of conventional (Roy J) and Clearfield (CL152) rice after treatment with preflood applications of acetolactate synthase (ALS)-inhibiting herbicides alone and in mixture with malathion in 2012.

		Rice yield[‡]	
Herbicide[†]	Rate	CL152	Roy J
	(lb ai/acre)	(bu/acre)	
Bispyribac-sodium	0.032	116 a	141 ab
Bispyribac-sodium + Malathion	0.032 + 0.6	122 a	102 bc
Imazamox	0.039	120 a	73 cd
Imazamox + Malathion	0.039 + 0.6	121 a	35 e
Imazethapyr	0.063	123 a	62 d
Imazethapyr + Malathion	0.063 + 0.6	119 a	30 e
Penoxsulam	0.036	112 a	127 ab
Penoxsulam + Malathion	0.036 + 0.6	124 a	140 ab
Malathion	0.6	115 a	147 a
Nontreated	---	112 a	152 a

[†] Dyne-A-Pak at 2.5% was added to bispyribac-sodium treatments, whereas Induce at 0.25% was added to all other treatments.

[‡] Means for each rice variety within a column followed by the same lowercase letters are not significantly different according to Fisher's protected least significant difference test (α = 0.05).

Table 3. Red-rice control at mid-POST (MPOST) and 14 days after flooding (DAF) with herbicide programs containing acetolactate synthase (ALS)-inhibiting herbicides alone and in mixture with malathion at the Pine Tree Research Station, near Colt (PTRS), Ark., and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., in 2012.

			Red rice control			
			MPOST		14 DAF	
Treatment[‡§]	Application[†] time	Rate	PTRS	RREC	PTRS	RREC
		(lb ai/acre)	----------------------(%)----------------------			
Imazethapyr fb	EPOST fb	0.063 fb	89 a[¶]	61 a	100 a	98 ab
imazethapyr	MPOST	0.063				
Imazethapyr +	EPOST	0.063 +	88 a	63 a	100 a	100 a
Malathion fb		0.06 fb				
imazethapyr +	MPOST	0.063 +				
Malathion		0.06				
Imazethapyr	MPOST	0.063	---	---	97 b	84 c
Imazethapyr +	MPOST	0.063 +	---	---	99 ab	88 bc
Malathion	0.6					
Imazamox	MPOST	0.039	---	---	100 a	75 c
Imazamox +	MPOST	0.039	---	---	98 ab	80 c
Malathion		0.06				

[†] Abbreviations: EPOST, early-POST; and fb, followed by.

[‡] Induce at 0.25% was added to all the treatments.

[§] EPOST fb MPOST treatments at MPOST evaluation time represent only EPOST applications as MPOST applications were not applied at that time.

[¶] Means for each location within a column followed by the same lowercase letters are not significantly different according to Fisher's protected least significant difference test (α = 0.05).

RICE CULTURE

The Effect of Growing Rice with Less Water on Grain Yields, Irrigation Water Efficiency, and Greenhouse Gas Emissions

M.M. Anders, K.B. Watkins, C.G. Henry, T. Siebenmorgen, and K. Brye

ABSTRACT

Rice producers in Arkansas are being called upon to adapt to growing irrigation water constraints and an increasing awareness in the general public of the impacts rice production has on the environment. A study initiated in 2011 to evaluate the potential of producing rice with decreased irrigation water use was continued in 2012 with additional data collected on the impact of reduced water management on greenhouse gas emissions (GHG). Grain yields, averaged over the 2 years were 212 bu/acre for the flooded treatment compared to 198 and 191 bu/acre for the alternate wetting and drying (AWD) 60% and 40% treatments, respectively. The AWD/40%-flood water treatment had a similar grain yield (204 bu/acre) compared to the flood treatment. The two row-watered (RR) rice treatments averaged 143 bu/acre. Total irrigation water applied in the flooded treatment averaged 33 acre-inches and there was an average water savings over the 2 years of 39% in the AWD/40%-flood treatment, 33% in the AWD/60%, and 52% in the AWD/40% treatment. Global warming potential as measured by total methane (CH_4) and nitrous oxide (N_2O), emitted as CO_2 equivalents per bushel of grain over the growing season ranged from 11.2 lb/bu for the flooded treatment to 1.03 lb/bu and 0.62 lb/bu for the AWD/60% and 40% treatments, respectively. The AWD/40%/flood treatment emitted 6.52 lb/bu. These results indicate that AWD flooding not only reduces irrigation water use with minimal yield loss but significantly reduces GHG emissions.

INTRODUCTION

Rice production in Arkansas is dependent on keeping the field flooded throughout the growing season. It is estimated that more than 99% of rice farmers in Arkansas manage their fields under flood irrigation (Wilson and Branson, 2006). The amount of water used in this management was measured as 28 acre-inches, on average, in the 2011 University of Arkansas rice verification studies (Mazzanti et al., 2012). Against this background, the Arkansas Natural Resources Commission (2012) estimated that the alluvial aquifer from which a majority of the water for rice production is pumped, is only 59% sustainable at the rate water is currently being removed. Arkansas has just begun the process of updating its water plan. This process will be complete in 2 years and is likely to show that agriculture, and more specifically rice production, is using more water than is sustainable. Historically farmers have adopted water conservation practices that are focused more on capturing available water rather than adopting practices that involve using less water to grow the crop. This study was initially established to evaluate the potential to grow rice under limited water conditions through changing how the crop was managed.

In recent years there has been global interest in the amount of greenhouse gas (GHG; CH_4, N_2O, and CO_2) emissions generated by agriculture enterprises. This has led to calls for the development of crop management practices that will reduce GHG emissions. Rice production under flooded water management emits both CH_4 and N_2O, while most crops that are not flooded emit only N_2O. It has been estimated that rice has a global warming potential (total GHG emitted for each pound of grain) that is, on average, four times greater than corn or wheat (Linquist et al., 2012). A majority of GHG emitted in rice is in the form of CH_4 which is produced only when the field is flooded. There are studies showing that managing rice under reduced water resulted in lower CH_4 emissions but these were offset by increased N_2O emissions. This is possible because CH_4 and N_2O are 25 and 296 times more toxic than CO_2 to the environment (Houghton et al., 2001). To evaluate the effect of water management on GHG emissions, a select number of treatments were measured in 2012.

PROCEDURES

The same irrigation treatments that were used in 2011 were replicated in 2012. They were: 1) flood, 2) row-water (RR)/40%, 3) RR/60%, alternate wetting and drying (AWD)/40%, AWD/60%, and AWD/40%-flood. Percentage values following irrigation method represent the percent of saturated soil moisture content at the time irrigation water was applied. For the AWD flood treatments, water was applied to a 4-inch depth when the field reached the designated treatment percentage of full water capacity. For the AWD/40%-flood treatment, AWD irrigation was used until the green-ring stage and then a permanent flood established and maintained until maturity. For the RR treatments water was applied in the furrow between 30-inch beds at the time soil moisture reached the designated percent of field capacity. Water application continued until the center of the bed reached field capacity.The two hybrids CLXL745 and XL753 were used in 2012 while CLXL745 and XL723 were used in 2011. Four replications were established with individual plots measuring 14 ft by 100 ft. Rice was planted into 7.5-inch rows at a rate of 30 lb/acre. The RR treatments were planted using the same row spacing onto

30-inch beds. Phosphorus and potassium fertilizer was applied prior to field preparation at rates of 60 and 80 lb/acre, respectively. Nitrogen was applied as urea at a rate of 120 lb/acre as a single preflood application at the 4- to 5-lf stage.

Two of the four replications were fitted with flow meters in the flood, AWD/40%, AWD/60%, and AWD/40%-flood treatments. Static chambers were installed in these same plots to determine GHG emissions. Gas samples were collected no less than twice weekly with additional daily measurements taken when management operations such as fertilizer application, field drying, and field wetting took place. Daily measurements were completed when the flood was removed or when water applications ceased in the flooded and AWD treatments, respectively. For each treatment, an ambient sample was collected when the chamber was installed and subsequent samples at 20, 40, and 60 min. All gas samples were mailed to the University of California, Davis for analysis. We received the results from these samples once the plots hade been harvested. Carbon dioxide analyzes were completed along with NH_4 and N_2O but are not included in this manuscript where we focus on CH_4 and N_2O emissions.

Planting was completed on 12 May in 2011 and 10 April in 2012. In both years, Command (clomazone) and Facet (quinclorac) were applied immediately following planting. Prior to flooding the field at the 4- to 5-lf stage, Clincher (cyhalofop), Permit (halosulfuron), and Facet (quinclorac) were applied and the field flooded. Water was removed from all plots that were flooded on 23 September in 2011 and 12 August in 2012. Harvesting was completed on 28 September in 2011 and 28 August in 2012.

The experiment design was a randomized split block with irrigation treatments as the main plots and varieties as the sub-plots. There were four replications. Harvest weights were collected and analyzed using GLM procedure in Systat 12 (Systat Software, Inc., Chicago, Ill.). Year was regarded as a fixed effect in data presented on grain yield. Data analyses presented on greenhouse gas emissions are data collected only in 2012 over three of the four replications.

RESULTS AND DISCUSSION

Grain yields were numerically lower in 2012 than in 2011 (data not shown). In an analysis of variance test (ANOVA) both water ($P < 0.000$) and variety ($P < 0.008$) differences were significant (Table 1). Of the water treatments, flood, and AWD/40-flood were similar and had the highest grain yields while grain yields were significantly lower for both the RR treatments. The interaction of water and variety was not significant.

Across all water treatments, there was more of a reduction in grain yield in 2012 than in 2011 in the reduced water treatments (data not shown). As flooding times decreased, there was a trend of decreasing grain yields. Water use, averaged over the 2 years for each treatment, was significantly reduced in the AWD and RR treatments compared to the flood treatment. Irrigation water reductions from the flood treatment ranged from 52% in the AWD/40% treatment to 12% in the RR/60% treatment (Table 2). The AWD/40%-flood water treatment had a similar grain yield compared to the flood treatment and resulted in a 39% water savings. Water efficiency values, calculated as the volume of water needed to produce a bushel of rice, were lowest for the AWD/40% treatment indicating that this treatment had the highest water efficiency. Lowest water efficiencies were in the RR treatments even though the values were calculated using the assumption that 30% of the water applied was captured at the bottom of the field. These data indicate a potential to grow rice with significant water savings with a minimal reduction in grain yield. For growers who are limited in their available water, these approaches to water management will allow them to maintain production and/or make more water available for other crop enterprises.

Daily N_2O fluxes closely followed irrigation treatments (Fig. 1). There was a significant increase in N_2O emissions between 16 May and 31 May; a time period corresponding to the first field dry-down in the AWD/60% and AWD/40% treatments. There were corresponding N_2O fluxes with each dry-down; however, each spike was less than the previous. These spikes represent nitrogen losses and were expected. The decreasing amplitude of fluxes as the season progressed is attributed to no more nitrogen fertilizer being applied and a stabilization of the nitrogen added to the soil prior to flooding.

Methane flux patterns also followed irrigation management. Methane emissions began increasing approximately 7 days following flooding in the flood treatment and continued their increase to 15 July; this date represents the plants R5 to R6 growth stage. There was a small increase in the CH_4 flux in the non-flooded treatments prior to the second dry period. For the AWD/40%-flood treatment, CH_4 emissions began at approximately 7 days after the field was flooded and followed the same pattern as the flood treatment. By 30 July, both the flood and AWD/40%-flood treatments were equal in their CH_4 emissions and they followed the same pattern through the remainder of the growing season. Methane production in the AWD/40% and AWD/60% treatments never reached daily flux values more than 100 g/ha/day (Fig. 1).

Increases in N_2O emissions from irrigation practices were more than offset by reductions in CH_4 emissions in this study (Table 3). When the data were yield-scaled, there was a 42% reduction in global warming potential (GWP) in the AWD/40%-flood treatment as compared to the flood treatment. Global warming potential was further reduced in the AWD/60% and AWD/40% water treatments. These results indicate that managing water can not only save water but can significantly reduce greenhouse gas emissions in rice production.

SIGNIFICANCE OF FINDINGS

These findings highlight the potential to produce rice with small reductions in grain yield and, at the same time large reductions in irrigation water used. The results highlight the potential to reduce GHG emissions through improved water management. Reducing irrigation water use in rice will allow farmers to better allocate water across their crop mix while reducing overall production costs. As carbon markets develop, reducing GWP through improved water management will provide Arkansas rice farmers with the opportunity to sell carbon credits.

LITERATURE CITED

Arkansas Natural Resources Commission. 2012. Arkansas ground-water protection and management report for 2011. Arkansas Natural Resources Commission. 101 East Capitol, Suite 350. Little Rock, Ark.

Houghton J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson. 2001. Radiative forcing of climate change. *In:* Climate Change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.881 pp. Cambridge University Press, Cambridge, U.K. and New York, N.Y., USA.

Linquist, B.A., M.A. Adviento-Borbe, C.M. Pittelkow, C. van Kessel, and K.J. van Groenigen. 2012. Fertilizer management practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. Field Crops Research 135:10-21.

Mazzanti, R.S., S.K. Runsick, C.E. Wilson Jr., K.B. Watkins, and T. Hristovska. 2012. 2011 Rice research verification program. *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 600:15-34. Fayetteville.

Wilson, C.E. Jr. and J.W. Branson. 2006. Trends in Arkansas rice production. *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 540:17-26. Fayetteville

Table 1. Analysis of variance mean square grain yield values for water treatment and variety comparisons. Data are from the 2011 and 2012 irrigation management study at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

Water treatment	Grain yield
	(bu/acre)
Flood	212 a[†]
AWD/40-flood	204 ab
AWD/60	198 bc
AWD/40	191 c
RR/60	146 d
RR/40	139 d
Variety	**Grain yield**
	(bu/acre)
XL723	191 a
CLXL745	179 b
XL753	175 b

[†] Treatments with similar letter designations are not significantly different at the $P < 0.05$ level using a Tukey test.

Table 2. Summary of grain yield, irrigation water efficiency, and irrigation water applied to six irrigation treatments in 2011 and 2012 at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

Treatment	Yield	Efficiency	Water used
	(bu/acre)	(gal. H_2O/bu rice)	(acre-inches)
Flood[†]	212	4,224	33
AWD/40%[‡]	191	2,287	16 52%[§]
AWD/40%- Flood[¶]	204	2,685	20 39%
AWD/60%	198	3,036	22 33%
RR/40%[#]	139	4,702	24 27%
RR/60%[#]	146	5,360	29 12%

[†] Flood indicates the treatment was flooded from the 4- to 5-lf stage until maturity.

[‡] AWD represents alternate wetting and drying; /40% represents the percentage of soil water capacity at which water was added.

[§] Represents percent of water savings from the flood treatment.

[¶] AWD/40%-Flood indicates AWD irrigation was used until the green-ring stage and then a permanent flood established and maintained until maturity.

[#] RR indicates a row-water treatment where water is applied in a furrow. Water efficiency values were calculated using the assumption that 30% of irrigation water applied was captured at the bottom of the field.

Table 3. Total methane (CH_4) and nitrous oxide (N_2O) emissions and their global warming potential expressed as CO_2 equivalents, grain yield (bu/acre) and yield-scaled global warming potential (GWP) for four irrigation treatments in 2012 at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

Irrigation	Total CH_4 emissions	Total N_2O emissions	GWP[†]	Grain[‡] yield	Yield-scaled GWP
	(lb CH_4-C/acre/season)	(lb N_2O-N/acre/season)	(lb CO_2 eq/acre/season)	(bu/acre)	(lb CO_2 eq/bu/season)
Flood	63.40 a[§]	0.03	2130 a	190	11.20 a
AWD[¶]/60%	2.50 c	0.20	179 c	174	1.03 c
AWD/40%	1.48 c	0.12	107 c	174	0.62 c
AWD/40%-Flood[#]	33.24 b	0.09	1154 b	177	6.52 b

[†] Grain yield was calculated using plants that were contained in the static chambers used for greenhouse gas measurements.

[‡] Calculated as a total CO_2 equivalent of CH_4 and N_2O emissions with methane adjusted by 25× and nitrous oxide by 296× as per Kyoto Protocol (Houghton et al., 2001).

[§] Values with similar letters are considered similar using a Tukey test at $P < 0.05$ for that particular column.

[¶] Alternate wetting and drying (AWD) consisted of applying irrigation water to a 4-inch depth and allowing the water to evaporate to the designated percent of soil moisture and then applying water again.

[#] AWD/40%-flood treatment AWD was used early in the season until the plant reached the green-ring growth phase at which time the field was flooded until maturity.

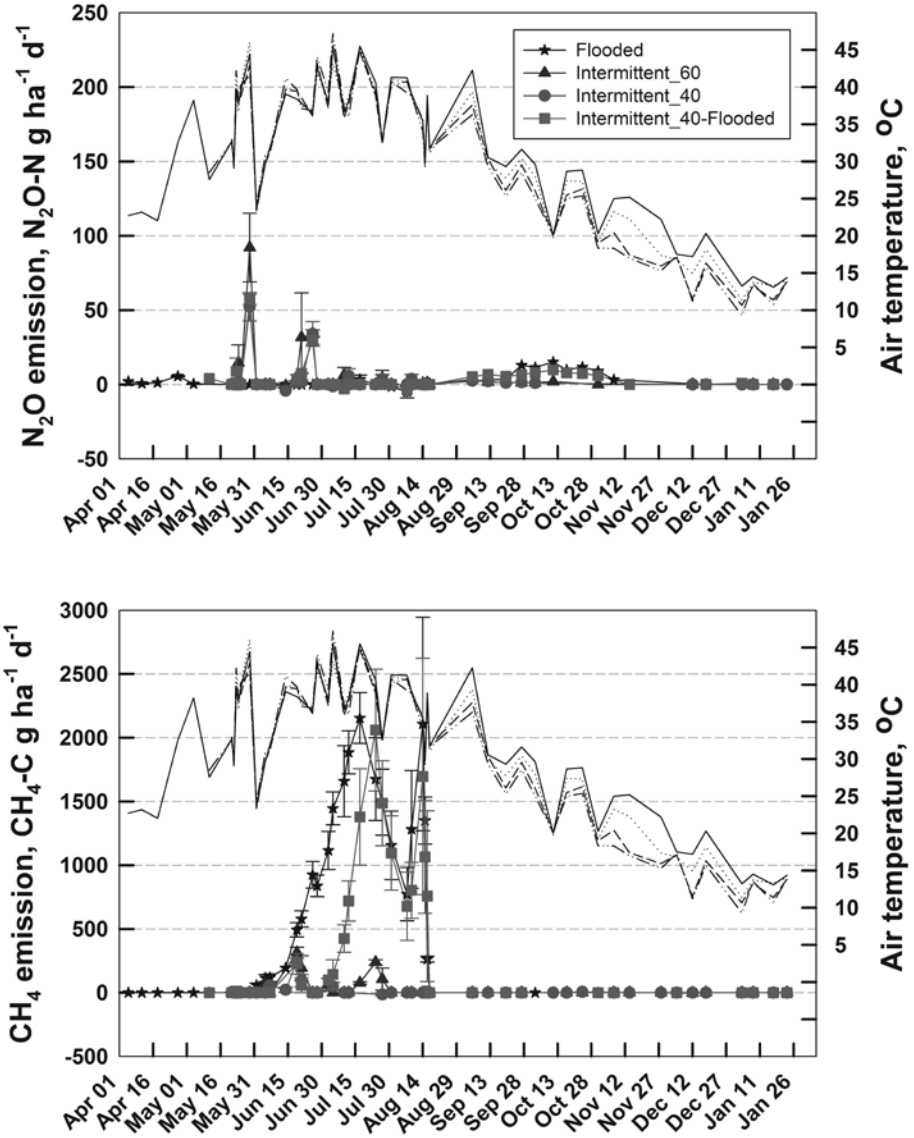


Fig. 1. Daily air temperatures (°C), nitrous oxide (N_2O) and methane (CH_4) fluxes from four irrigation treatments in 2012 at the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark.

Utilization of On-Farm Testing to Evaluate Rice Cultivars

E. Castaneda-Gonzalez, D.L. Frizzell, J.D. Branson,
J.T. Hardke, C.E. Wilson Jr., Y.A. Wamishe, and R.J. Norman

ABSTRACT

Rice diseases reduce grain yield, milling quality, and profit in Arkansas rice production each year. Resistant cultivars are the first line of defense against disease, and the correct cultivar choice for a particular field can reduce production costs and increase profits for the grower by minimizing disease problems. Around the state, rice is grown under diverse field settings with environmental conditions and cultural practices that greatly influence disease pressure. By focusing on reducing disease incidence and buildup, the need for expensive fungicide applications is reduced and profits may be maximized. Therefore, disease performance evaluations across many environments are important to overall cultivar selection. Initiated in 1995, the Disease Monitoring Program (DMP) utilizes studies in grower fields consisting of 25 to 30 commercial cultivars and experimental lines to evaluate disease and yield performance.

INTRODUCTION

Rice diseases are an important constraint to profitable rice production in Arkansas. To reduce disease potential, we recommend the use of host-plant resistance, optimum cultural practices, and fungicides (only when necessary) based on integrated pest management (IPM) methods for disease control. The use of resistant cultivars, combined with optimum cultural practices, provide growers with the opportunity to maximize profit at the lowest disease control expenditure by avoiding the use of costly fungicide applications.

New Arkansas rice cultivars are developed each year under controlled experiment station 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 data set is not complete for many of the environments where rice is grown in the state because diseases or other problems may not be observed in nurseries conducted on experiment stations. With some knowledge of field history, growers can select the cultivar that offers the highest yield potential with the lowest disease risk for their particular situation; however, the knowledge to make these selections accurately each year requires on-going field research. The Disease Monitoring Program (DMP) was designed to better address the many risks faced by newly released cultivars across the rice-growing region of Arkansas. Replicated plots are planted in grower fields across the state and monitored for the development and severity of disease problems, cultivar reaction, and cultivar performance under grower management conditions across different environments. These studies also provide a hands-on educational opportunity for county agents, consultants, and producers.

The DMP has evolved into a major part of the Arkansas rice cultivar development process. The goal of the Arkansas Rice Program is to have a complete production package when cultivars are released, including yield potential, disease reactions, fertilizer recommendations, and DD50 thresholds. The on-farm evaluation of new cultivars allows for development of a complete disease management package and provides better information on yield potential and yield response under various environmental and cultural management conditions.

The objectives of this research, therefore, include: 1) to monitor disease pressure in the different regions of Arkansas, 2) to determine reactions of rice cultivars to diseases not commonly observed on experiment stations, and 3) compare the yield potential of commercially available cultivars and advanced experimental lines.

PROCEDURES

Field studies were conducted in Craighead, Poinsett, Prairie, and White Counties during 2012. Commercial non-Clearfield entries included Antonio, Arize QM1003, Caffey, Cheniere, Colorado, Della-2, Francis, Jazzman, Jazzman-2, Jupiter, Mermentau, Rex, Roy J, Taggart, Wells, a University of Arkansas experimental line (AREXP1), and the RiceTec hybrids XL723 and XL753. Clearfield lines included CL111, CL142-AR, CL151, CL152, CL162, CL261, and the RiceTec hybrids CLXL729 and CLXL745.

Plots were 8 rows (7-inch spacing) wide and 16 ft in length arranged in a randomized complete block design with three replications. Pure-line cultivars (varieties) were seeded at a rate of 40 seed/ft^2 while hybrids were seeded at a rate of 14 seed/ft^2. Since these experiments contained both Clearfield and non-Clearfield entries, all plots were managed as non-Clearfield cultivars. Plots were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control. In most cases, plots did not receive a fungicide application, but if a fungicide was applied, it was considered in the disease ratings. Plots were inspected periodically for disease and rated accordingly then harvested at maturity. At maturity, the center five 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 and percent total white rice (%HR - %TR). Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Averaged across all four locations, RiceTec XL753 and Roy J were numerically the highest-yielding cultivars (Table 1). Roy J, Mermentau, AREXP1, and Wells were numerically the highest-yielding conventional varieties. RiceTec CL XL745 and CL111 were numerically the highest-yielding Clearfield entries. RiceTec XL753 had numerically the highest yield for all three locations at which it was planted. For conventional varieties, Roy J was not only numerically the highest-yielding entry but also performed the most consistently with a yield of at least 191 bu/acre at all locations.

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 2). This is particularly true for minor diseases that may not be encountered frequently, such as narrow brown leaf spot, false smut, and kernel smut.

Diseases in general were not substantial in the 2012 DMP trials and the hot, dry weather in June and July diminished foliar disease development in the state. Yield variability among the study sites represents differences in environments and management practices, but also susceptibility to various diseases present at a specific location.

Cheniere had the highest overall milling yield with an average of 64% head rice and 70% total white rice (Table 3). The cultivars Jazzman-2 and Mermentau averaged 64% head rice and 68% total white rice. CL142-AR and Arize QM1003 had the lowest head rice percentages of all cultivars sampled during 2012.

SIGNIFICANCE OF FINDINGS

The 2012 on-farm rice evaluation and disease monitoring 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 2013.

ACKNOWLEDGMENTS

The authors appreciate the cooperation of all participating rice producers and thank all Arkansas rice growers for financial support through the Rice Check-Off administered by the Arkansas Rice Research and Promotion Board. The authors especially thank the following county agents who made this work possible: Craig Allen, Eric Grant, Brent Griffin, Mike Hamilton, Keith Martin, and Brandon Thiesse.

Table 1. Yield performance of selected rice cultivars in disease monitoring program trials in grower fields in Arkansas in 2012.

	Grain yield by location				
Cultivar	Craighead	Poinsett	Prairie	White	Average
	(bu/acre)				
Antonio	171	240	199	176	196
AREXP1	218	223	219	161	205
Arize QM1003	178	119	72	41	102
Caffey	201	184	197	213	199
Cheniere	174	214	193	165	187
CL111	190	238	213	170	203
CL142-AR	171	230	230	156	197
CL151	194	215	201	187	199
CL152	178	232	213	153	194
CL162	176	204	181	151	178
CL261	187	184	196	165	183
RT CL XL729	.	140	192	161	164
RT CL XL745	.	197	235	197	210
Colorado	144	193	171	142	163
Della-2	159	194	177	139	167
Francis	197	210	232	158	199
Jazzman	161	224	171	158	178
Jazzman-2	175	213	164	118	168
Jupiter	211	169	187	168	184
Mermentau	185	257	214	185	210
Rex	196	188	206	152	186
Roy J	191	234	229	191	211
RT XL723	.	129	229	165	174
RT XL753	.	270	278	268	272
Taggart	189	253	207	165	203
Wells	204	230	222	165	205
Mean	184	211	207	167	194
C.V.[a]	10.2	15.6	8.9	11.5	.
LSD (0.05)[b]	30.4	55.7	29.5	32.7	.

[a] C.V. = coefficient of variation.

[b] LSD = least significant difference.

Table 2. Rice variety reactions to diseases (2012).

Cultivar	Sheath blight	Blast	Straighthead	Bacterial Panicle Blight	Narrow Brown Leaf Spot	Stem Rot	Kernel Smut	False Smut	Lodging	Black Sheath Rot	Sheath Spot
Antonio	S[a]	MS		MS				MS	MS		
AREXP1	MS	S	MS	S	S	S	S	S	MS	MS	S
ArizeQM1003	MS			MR/MS				S	VS		
Caffey	MS			S	R			MS			
Cheniere	S	VS	VS	VS	S	S	S	S	MR	MS	
CL111	VS	MS	S	VS	VS	VS	S	S	MS	S	
CL142-AR	MS	S	MS	S	S	S	S	S	S	S	
CL151	S	VS	VS	VS	S	VS	S	S	MR	S	
CL152	S	S	S	S	R		VS	S			
CL162	VS	S		VS	R		S	S	S		
CL261	MS	VS	S	VS	S	VS	MS	S	MS	MS	
RT CL XL729	MS	R	MS	MR	MS	S	MS	S	S	S	
RT CL XL745	MS	R	R	MR	MS	S	MS	S	S	S	S
Colorado	S	VS		S				S			
Della-2				S							
Francis	MS	VS	MR	VS	S	S	VS	S	MS	S	
Jazzman	MS	S	S	MS	S	S	MS	S	MS	MS	
Jazzman-2	VS	MS		VS	MR			S			
Jupiter	S	S	S	MR	MS	VS	MS	MS	MS	MR	
Mermentau	MS	MS	VS	MS				MS	MS		
Rex	S	S	S	S	MS	S	S	S	MR	S	
Roy J	MS	S	S	S	MR	S	VS	S	MR	MS	
RT XL723	MS	R	S	MR	MS	S	MS	S	MS	S	
RT XL 753	MS			MR				S		S	
Taggart	MS	MS	R	MS	MS	S	S	S	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. Reactions were determined based on historical and recent observations from test plots and in grower fields across Arkansas. In general, these reactions would be expected under conditions that favor severe disease development including excessive nitrogen rates (most diseases) or low flood depth (blast).

Table prepared by Y. Wamishe, Assistant Professor/Extension Plant Pathologist, Stuttgart, Ark., and R.D. Cartwright, Associate Director - Agriculture and Natural Resources, Cooperative Extension Service, Little Rock, Ark.

Table 3. Milling yield performance of selected rice cultivars in disease monitoring program trials in grower fields in Arkansas in 2012.

	Milling yield[a] by location				
Cultivar	Craighead	Poinsett	Prairie	White	Average
	(%HR-%TR)				
Antonio	61-67	66-71	59-67	64-70	63-69
AREXP1	59-68	61-70	52-67	56-70	57-68
Arize QM1003	57-64	50-66	54-63	57-68	54-65
Caffey	59-65	48-67	60-66	59-68	56-66
Cheniere	63-68	67-72	63-70	64-72	64-70
CL111	61-67	64-70	57-67	58-69	60-68
CL142AR	60-66	50-69	50-66	44-70	51-68
CL151	61-66	62-70	59-67	61-70	61-68
CL152	60-65	65-70	59-67	61-69	61-68
CL162	60-66	61-69	54-66	58-69	58-68
CL261	61-67	59-68	61-67	59-69	60-68
RT CL XL729	.	59-69	54-65	55-68	56-67
RT CL XL745	.	57-71	58-68	53-70	56-70
Colorado	59-66	63-70	57-67	58-68	59-68
Della-2	62-67	63-69	59-66	63-69	62-68
Francis	63-68	64-71	58-68	52-70	59-69
Jazzman	62-67	67-70	61-67	60-70	62-68
Jazzman-2	64-66	67-70	61-66	66-70	64-68
Jupiter	55-61	59-68	57-63	61-68	58-65
Mermentau	62-66	65-70	60-68	67-68	64-68
Rex	60-66	61-68	57-66	60-67	60-67
Roy J	62-68	66-72	58-69	61-72	62-70
RT XL723	.	60-69	56-66	60-70	59-68
RT XL753	.	52-69	58-68	54-70	55-69
Taggart	60-67	62-70	55-67	48-69	56-68
Wells	61-68	58-70	52-67	46-70	55-69
Mean	61-66	60-69	57-67	57-69	58-68

[a] (%HR-%TR) = percent head rice - percent total white rice.

Development of Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars: 2011 Study Year

D.L. Frizzell, J.D. Branson, C.E. Wilson Jr., R.J. Norman, and K.A.K. Moldenhauer

ABSTRACT

The Arkansas Rice Degree-Day (DD50) computer program has been one of the most successful programs developed by the University of Arkansas System Division of Agriculture. The program utilizes thermal units accumulated during the growing season to calculate predicted dates the rice will reach critical growth stages. However, the program must be continually updated as new conventional and hybrid rice cultivars are released. To accomplish this objective, DD50 thermal unit thresholds must be established in a controlled research environment. The DD50 thermal unit accumulations, and grain and milling yield performance of each new rice cultivar were evaluated over three seeding dates during 2011 in the dry-seeded, delayed-flood management system that is most commonly used in the southern United States. Rice cultivars evaluated in 2011 included: AREXP1, Arize QM1003, Caffey, CL111, CL142-AR, CL151, CL152, CL162, CL181-AR, CL261, Jazzman, Jazzman-2, Jupiter, Rex, Roy J, Taggart, Wells, and the hybrid RiceTec XP753. Grain and milling yields were measured at maturity to evaluate the influence of seeding date on grain and milling yield potential.

INTRODUCTION

The Arkansas Rice Degree-Day (DD50) computer program was developed in 1978 by the University of Arkansas System Division of Agriculture to assist growers in timing midseason nitrogen (N) fertilizer applications and has been expanded over time to predict at least twenty-six crop management decisions. Grain elevator operators also use this program to predict peak harvest periods. Each DD50 report generated by the program is field and cultivar specific for the current growing season. Timing of practices such as nitrogen (N) fertilizer application, permanent flood establishment, pesticide applications, and reminders for pest scouting and suggested drain dates are included in the report. The program utilizes cultivar-specific data to predict plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. These data are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Each new cultivar remains in the study for a minimum of 3 years. When a new cultivar is released, the data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study were to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition to these objectives, the influence of seeding date on a cultivar's grain and milling yield performance was considered to determine optimal seeding date for new cultivars.

PROCEDURES

The study was conducted during 2011 at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil. Sixteen conventional rice cultivars (i.e., AREXP1, Caffey, CL111, CL142-AR, CL151, CL152, CL162, CL181-AR, CL261, Jazzman, Jazzman-2, Jupiter, Rex, Roy J, Taggart, and Wells) were drill-seeded at a rate of 40 seed/ft^2 in plots nine-rows (7-inch spacing) wide and 17 ft in length. Two hybrid cultivars, Bayer CropScience Arize QM1003 and RiceTec XP753 were sown into the same plot configuration using a seeding rate of 14 seed/ft^2. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates were 31 March, 14 April, and 11 May 2011. Normal cultural practices for dry-seeded, delayed-flood rice were followed. All plots received 120 lb N/acre as a single preflood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied within 2 days following the preflood N fertilization and maintained until the rice reached maturity. Data collected included: maximum and minimum daily temperatures, seedling emergence, and the number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) and 50% heading. At maturity, the center five 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 and percent total white rice (%HR - %TR). Each seeding date was arranged in a randomized complete block design with three replications. Statistical analyses were conducted using PROC GLM of SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's protected least significant difference test ($\alpha = 0.05$) where appropriate.

RESULTS AND DISCUSSION

Generally in seeding date studies, the time between seeding and either emergence or flooding decreases as seeding date is delayed. During 2011, the number of days between seeding and emergence were similar among the three seeding date studies, measuring 7 days when seeded in late March, 6 days when seeded in April, and increasing to 9 days when seeded in May (Table 1). The time between seeding and flooding was longest in the April seeding date at 48 days compared to 40 and 35 days in the March and May studies, respectively. During 2011, the time from emergence to flooding ranged from 26 to 42 days for the three seeding dates in a pattern similar to that measured for days between seeding and flooding.

The time required from emergence to 0.5-inch IE averaged 64 days across all cultivars and seeding dates (Table 2). Average time for all cultivars to reach 0.5-inch IE ranged from 75 days when seeded in late March to 50 days when seeded in May. The number of days required by each cultivar to reach 0.5-inch IE decreased as seeding date was delayed. During 2011, time of vegetative growth, averaged across seeding dates, ranged from 60 days for CL111 and CL151 to 70 days for the aromatic cultivar Jazzman. Thermal unit accumulations between emergence and 0.5-inch IE were generally highest in the late March seeded study and decreased as seeding date was delayed. Average DD50 thermal unit accumulations during vegetative growth ranged from a low of 1451 for CL151 to a high of 1761 for Jazzman.

The time required for development between emergence and 50% heading averaged 92 days across all cultivars and seeding dates during 2011 (Table 3). The number of days required to reach 50% heading declined sharply as seeding date was delayed. Average time for all cultivars to reach 50% heading was 104 days when seeded in March, dropping to 93 and 79 days in the subsequent seeding dates of April and May, respectively. Cool temperatures in May, especially at night, could account for the extended period of time required by the March and April studies to reach 50% heading. When averaged across seeding dates, Wells required 94 days to reach 50% heading. Cultivars that reached 50% heading 5 to 6 days earlier than Wells during 2011 included: AREXP1, CL111, CL151, CL162, CL261, Rex and the RiceTec hybrid XP753. Roy J was 5 days later than Wells to reach 50% heading when averaged across seeding date. Thermal unit accumulation between emergence and 50% heading averaged 2456 units during 2011. Accumulations for each cultivar were highest in the March seeding date and similar between the April and May seeding dates. Across seeding dates, average DD50 thermal unit accumulation ranged from a low of 2320 for RiceTec XP753 to a high of 2691 for Roy J.

Average grain yield for the 2011 study was 119 bu/acre (Table 4). The March seeding date was not used in grain yield determinations because stand density was inadequate at harvest. Average grain yield was higher when seeded in April compared to the May seeding date at 159 and 80 bu/acre, respectively. During 2011, three cultivars, AREXP1, CL142-AR, and Taggart, had grain yields of 190 bu/acre or greater when seeded in April. Only two cultivars, CL142-AR and Jazzman-2, produced grain yields greater than 100 bu/acre when seeded in May. The low grain yields noted in every cultivar seeded in May are likely a result of excessively high night-time temperatures beginning 1 July and continuing until mid-August. High temperatures, especially those at night, can cause sterility resulting in numerous blanks on each panicle.

Grain milling yield, across seeding dates and cultivars, averaged 64-73 in 2011 (Table 5). Percent head rice, averaged across cultivars, was the same when seeded in March or April, but was notably higher for the May seeding date. Percent total rice was similar among the three seeding dates when averaged across cultivars. The highest milling yield occurred for most cultivars when seeded in May. With few exceptions, milling yield was greater than the standard of 55-70 regardless of either seeding date or cultivar during 2011.

SIGNIFICANCE OF FINDINGS

The data from 2011 will be used to refine the DD50 thermal unit thresholds for the new cultivars and hybrids being grown. The grain and milling yield data will contribute to the database of information used by University of Arkansas System Division of Agriculture personnel to help producers make decisions regarding rice cultivar selection, particularly for early and late seeding situations.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board. Special thanks are extended to Emmett “Chuck” Pipkins for his dedication in making the DD50 Program possible.

Table 1. General seeding, seedling emergence, and flooding date information for the Arkansas Rice Degree-Day (DD50) seeding date study in 2011 at the Rice Research and Extension Center, Stuttgart, Ark.

	Seeding Date		
Parameter	31 March	14 April	11 May
Emergence date	7 April	20 April	20 May
Flood date	10 May	1 June	15 June
Days from seeding to emergence	7	6	9
Days from seeding to flooding	40	48	35
Days from emergence to flooding	33	42	26

Table 2. Influence of seeding date on Arkansas Rice Degree-Day (DD50) accumulations and days from emergence to 0.5-inch internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

	Seeding date							
	31 March		14 April		11 May		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
AREXP1	76	1713	67	1586	49	1470	64	1589
ArizeQM1003	73	1607	65	1524	46	1360	61	1497
Caffey	81	1878	70	1685	55	1639	69	1734
CL111	72	1596	64	1502	44	1296	60	1465
CL142-AR	74	1639	66	1565	50	1480	63	1561
CL151	70	1532	63	1481	45	1339	60	1451
CL152	76	1724	67	1585	49	1461	64	1590
CL162	73	1607	66	1555	46	1381	62	1514
CL181-AR	73	1618	65	1543	49	1451	62	1537
CL261	75	1692	67	1596	52	1554	65	1614
Jazzman	81	1877	70	1686	57	1721	70	1761
Jazzman-2	73	1628	65	1533	49	1451	62	1537
Jupiter[a]	.	.	.	.	.	.	.	.
Rex	76	1724	69	1657	51	1522	65	1634
Roy J	77	1744	68	1625	53	1597	66	1655
RT XP753	71	1543	67	1584	46	1381	61	1503
Taggart	76	1702	68	1635	52	1543	65	1627
Wells	78	1765	68	1617	51	1512	65	1631
Mean	75	1685	67	1593	50	1482	64	1587
C.V.[b]	2.2	3.08	2.3	3.01	1.8	1.82	---	---
LSD$_{(\alpha = 0.05)}$[c]	2.8	86.1	2.6	79.6	1.4	44.7	---	---

[a] The cultivar Jupiter was not used in these determinations.

[b] C.V. = coefficient of variation.

[c] LSD = least significant difference.

Table 3. Influence of seeding date on Arkansas Rice Degree-Day (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

	Seeding date							
	31 March		14 April		11 May		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
AREXP1	101	2472	90	2292	76	2322	89	2362
ArizeQM1003	110	2778	100	2611	85	2593	98	2661
Caffey	106	2629	95	2451	81	2456	94	2512
CL111	101	2483	89	2282	75	2290	89	2352
CL142-AR	101	2483	91	2324	78	2376	90	2394
CL151	100	2442	90	2313	77	2333	89	2362
CL152	106	2640	94	2419	79	2397	93	2485
CL162	100	2442	89	2282	76	2322	88	2348
CL181-AR	104	2587	93	2409	79	2397	92	2464
CL261	99	2421	90	2292	77	2344	89	2352
Jazzman	105	2598	92	2377	78	2376	92	2450
Jazzman-2	102	2524	93	2398	78	2376	91	2432
Jupiter	104	2587	93	2409	79	2397	92	2464
Rex	101	2493	90	2292	76	2322	89	2369
RoyJ	114	2894	99	2578	86	2602	99	2691
RT XP753	99	2431	88	2251	75	2280	88	2320
Taggart	108	2693	96	2483	85	2574	96	2583
Wells	107	2661	93	2409	81	2456	94	2509
Mean	104	2578	93	2386	79	2404	92	2456
C.V.[a]	1.3	1.59	1.3	1.56	1.7	1.72	---	---
$LSD_{(\alpha = 0.05)}$[b]	2.2	67.7	1.9	61.4	2.3	68.3	---	---

[a] C.V. = coefficient of variation.

[b] LSD = least significant difference.

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

	Grain yield by seeding date			
Cultivar	31 March	14 April	11 May	Average
	(bu/acre)			
AREXP1	.	195	89	142
ArizeQM1003	.	171	52	111
Caffey	.	153	41	97
CL111	.	109	58	84
CL142AR	.	190	104	147
CL151	.	177	46	111
CL152	.	164	54	109
CL162	.	132	91	111
CL181AR	.	155	83	119
CL261	.	172	83	127
JazzMan	.	135	62	99
JazzMan-2	.	174	124	149
Jupiter	.	154	77	115
Rex	.	180	83	132
Roy J	.	139	84	112
RT XP753	.	110	93	102
Taggart	.	214	89	152
Wells	.	119	69	94
Mean	---	159	80	119
C.V.[a]	---	22.1	16.5	---
LSD$_{(\alpha = 0.05)}$[b]	---	58.0	50.8	---

[a] C.V. = coefficient of variation.

[b] LSD = least significant difference.

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

	Milling yield[a] by seeding date			
Cultivar	31 March	14 April	11 May	Average
	-------------------(%HR - %TR)-------------------			
AREXP1	58-72	59-72	66-75	63-74
ArizeQM1003	57-69	54-70	65-71	60-71
Caffey	65-74	68-76	68-76	68-76
CL111	63-72	64-72	66-74	65-73
CL142-AR	55-72	58-74	61-75	60-75
CL151	61-71	63-72	68-74	66-73
CL152	59-69	56-70	70-73	63-72
CL162	59-70	59-72	68-73	63-73
CL181-AR	60-69	61-71	62-73	62-72
CL261	65-71	64-72	73-75	69-73
Jazzman	64-70	64-71	70-73	67-72
Jazzman-2	67-71	66-72	67-74	67-73
Jupiter	68-72	69-73	64-75	67-74
Rex	58-69	59-70	67-72	63-71
Roy J	62-73	62-73	68-74	65-74
RT XP753	61-72	62-73	64-75	63-74
Taggart	59-71	59-73	67-74	63-74
Wells	58-72	54-73	67-74	61-74
Mean	61-71	61-72	67-74	64-73

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

Development of Degree-Day 50 Thermal Unit Thresholds for New Rice Cultivars: 2012 Study Year

D.L. Frizzell, J.T. Hardke, C.E. Wilson Jr.,
R.J. Norman, J.D. Branson, and K.A.K. Moldenhauer

ABSTRACT

The Arkansas Rice Degree-Day 50 (DD50) computer program has been one of the most successful programs developed by the University of Arkansas System Division of Agriculture. The program utilizes thermal units accumulated during the growing season to calculate predicted dates rice will reach growth stages critical to optimal crop management. However, the computer program must be continually updated as new conventional and hybrid rice cultivars are released. To accomplish this objective, DD50 thermal unit thresholds must be established in a controlled research environment. The DD50 thermal unit accumulations and grain yield performance of each new rice cultivar were evaluated over three seeding dates during 2012 in the dry-seeded, delayed-flood management system that is most commonly used in the southern United States. Rice cultivars evaluated in 2012 included: Antonio, AREXP1, Caffey, CL152, CL162, CL261, Colorado, Della-2, Jazzman-2, Jupiter, Mermentau, Rex, Roy J, Wells, and the hybrid RiceTec XL753. Grain and milling yields were measured at maturity to evaluate the influence of seeding date on grain and milling yield potential.

INTRODUCTION

The Arkansas Rice Degree-Day (DD50) computer program was developed in 1978 by the University of Arkansas System Division of Agriculture for use as a crop management tool for rice. The program has been expanded over time to predict at least twenty-six key management decisions including nitrogen fertilizer timing, permanent flood establishment, timing of pesticide applications, reminders for disease scouting, and suggested harvest timing. Each DD50 file generated is field and cultivar specific for the current growing season. The program utilizes cultivar-specific data to predict rice plant development based on the accumulation of DD50 thermal units from the date of seedling emergence. Thermal units are calculated from a database of 30-year average weather data which has been collected from the National Weather Service weather station closest to a rice producer's location in Arkansas. The cultivar-specific data are acquired from annual studies of promising experimental lines and all newly released conventional and hybrid rice cultivars. Three to four seeding dates are utilized each year to provide thermal unit thresholds within the range of recommended rice seeding dates in Arkansas. When a new rice cultivar is released, data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when specific management practices should be performed. Therefore, the objectives of this study were to develop a database for promising new rice cultivars, to verify the database for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition to these objectives, the influence of seeding date on a cultivar's grain and milling yield performance was considered to determine optimal seeding date for new cultivars.

PROCEDURES

The study was conducted during 2012 at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Arkansas, on a DeWitt silt loam soil. Fourteen conventional rice cultivars (i.e., Antonio, AREXP1, Caffey, CL152, CL162, CL261, Colorado, Della-2, Jazzman-2, Jupiter, Mermentau, Rex, Roy J, and Wells) were drill-seeded at a rate of 40 seed/ft^2 in plots nine rows (7-inch spacing) wide and 17 ft in length. The hybrid rice cultivar RiceTec XL753 was sown into the same plot configuration using a seeding rate of 14 seed/ft^2. General seeding, seedling emergence, and flood dates are shown in Table 1. The seeding dates were 30 March, 13 April, and 11 May 2012. Normal cultural practices for dry-seeded, delayed-flood rice production were followed. All plots received 120 lb nitrogen (N)/acre as a single pre-flood application of urea at the 4- to 5-lf growth stage. The permanent flood was applied within 2 days of pre-flood N fertilization and maintained until rice reached maturity. Data collected included: maximum and minimum daily temperatures, date of seedling emergence, and the number of days and DD50 thermal units required to reach 0.5-inch internode elongation (IE) and 50% heading. At maturity, the center five 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 and percent total white rice (%HR - %TR). Each seeding date was arranged in a randomized complete block design with three replications. Statistical analyses were conducted using PROC GLM of SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's protected least significant difference test ($\alpha = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The time between seeding and emergence ranged from 8 to 12 days (Table 1). Generally in seeding date studies, the time between seeding and emergence decreases as seeding date is delayed. During 2012, thermal unit accumulations were similar among the three seeding dates during the period between seeding and emergence, but days from seeding to emergence were dissimilar as both the March and the May studies emerged 8 days after seeding compared to 12 days for the April study. However, the time between seeding and flooding did decrease as seeding date was delayed, ranging from 42 days for the March seeding date to 35 days for the May seeding date. During 2012, time from emergence to flooding was 34 days for the March seeding date and decreased to 29 and 27 days for the April and May seeding dates, respectively.

The time required from emergence to 0.5-inch IE averaged 54 days across all cultivars and seeding dates (Table 2). When averaged across cultivars, time to reach 0.5-inch IE ranged from 61 days when seeded in late March to 49 days when seeded in May. The number of days required by each cultivar to reach 0.5-inch IE also decreased as seeding date was delayed. During 2012, time of vegetative growth, averaged across seeding dates, ranged from 51 days for Mermentau and RiceTec XL753 to 57 days for Rex and the medium-grain Clearfield variety CL261. Thermal unit accumulations from emergence to 0.5-inch IE were higher for each cultivar in the May seeding date as compared to the other two seeding dates. The DD50 thermal unit accumulations during vegetative growth ranged from a low of 1234 for Mermentau to a high of 1513 for the medium-grain Caffey when averaged across seeding dates.

The time required for plant development between emergence and 50% heading averaged 84 days across all cultivars and seeding dates during 2012 (Table 3). Average time for cultivars in each seeding date to reach 50% heading ranged from 90 days when seeded in late March to 81 days in both the April and May seeding dates. Average time for individual cultivars to reach 50% heading ranged from 80 days for RT XL753 to 91 days for Roy J. Thermal unit accumulation between emergence and 50% heading averaged 2223 units during 2012. For individual cultivars, accumulation was similar between the March and April seeding dates, but was highest in the May seeding date. Across seeding dates, average DD50 thermal unit accumulation ranged from a low of 2096 for RT XL753 to a high of 2443 for Roy J.

The average grain yield for the 2012 study was 176 bu/acre (Table 4). Grain yield was highest when seeded in March, averaging 222 bu/acre across cultivars. With the exception of Roy J, grain yields were notably lower for the April seeding date, averaging 142 bu/acre. This sharp decrease in harvested grain can be attributed to lodging resulting from two significant wind events following Tropical Storm Isaac. Roy J has been rated excellent for straw strength and was able to withstand the winds without lodging and yielded 251 bu/acre for the April seeding date. Several cultivars produced grain yields at or above 200 bu/acre when seeded in May 2012. More extensive planting date studies are needed on the newer cultivars before conclusions can be made concerning the suitability of these cultivars for late-planted situations.

Grain milling yield, across seeding dates and cultivars, averaged 57-67 in 2012 (Table 5). Average percent total rice was similar among the three seeding dates, but percent head rice was notably higher for the May seeding date compared to the two earlier seeding dates. All cultivars in the study had their highest milling yield when seeded in May. The majority of cultivars averaged 55% or greater head rice yields during this study year; however, the long grain aromatic cultivar Jazzman-2 maintained head rice yields at or greater than 60% at each seeding date during 2012.

SIGNIFICANCE OF FINDINGS

The data from 2012 will be used to refine the DD50 thermal unit thresholds for new cultivars and hybrids being grown. The grain and milling yield data will contribute to the database of information used by University of Arkansas System Division of Agriculture personnel to help producers make decisions regarding rice cultivar selection, particularly for early and late seeding situations.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board. Special thanks are also given to Emmett C. “Chuck” Pipkins and Cathi Stoevsand for their dedication to making the DD50 Program possible.

Table 1. General seeding, seedling emergence, and flooding date information for the Arkansas Rice Degree-Day (DD50) seeding date study in 2012 at the Rice Research and Extension Center, near Stuttgart, Ark.

	Seeding Date		
Parameter	31 March	14 April	11 May
Emergence date	7 April	25 April	19 May
Flood date	11 May	24 May	15 June
Days from seeding to emergence	8	12	8
Days from seeding to flooding	42	41	35
Days from emergence to flooding	34	29	27

Table 2. Influence of seeding date on Arkansas Rice Degree-Day (DD50) accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the Rice Research and Extension Center, near Stuttgart, Ark., during 2012.

	Seeding date							
	30 March		13 April		11 May		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
AREXP1	63	1315	51	1283	49	1398	52	1332
Antonio	59	1237	49	1222	48	1345	52	1268
Caffey	68	1482	59	1519	54	1537	61	1513
CL152	63	1315	51	1265	49	1377	54	1319
CL162	58	1204	49	1220	48	1345	52	1256
CL261	64	1353	55	1389	52	1491	57	1411
Colorado	58	1204	49	1220	48	1356	52	1260
Della 2	62	1306	52	1293	52	1482	55	1360
Jazzman-2	60	1254	50	1256	47	1324	52	1278
Jupiter[a]	.	.	.	.	.	.	.	.
Mermentau	57	1187	48	1202	47	1313	51	1234
Rex	66	1401	55	1389	51	1462	57	1417
Roy J[a]	.	.	.	.	.	.	.	.
RT XL753	57	1186	49	1212	47	1324	51	1240
Wells	64	1353	53	1341	51	1451	56	1382
Mean	61	1273	51	1286	49	1386	54	1315
C.V.[b]	2.0	3.12	1.7	1.89	1.6	1.77	---	---
LSD$_{(\alpha = 0.05)}$[c]	2.0	66.0	1.4	40.3	1.3	40.7	---	---

[a] The cultivars Jupiter and RoyJ were not used in these determinations.

[b] C.V. = coefficient of variation.

[c] LSD = least significant difference.

Table 3. Influence of seeding date on Arkansas Rice Degree-Day (DD50) accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the Rice Research and Extension Center, near Stuttgart, Ark., during 2012.

	Seeding date							
	30 March		13 April		11 May		Average	
Cultivar	Days	DD50 units	Days	DD50 units	Days	DD50 units	Days	DD50 units
AREXP1	90	2126	79	2135	78	2274	82	2178
Antonio	90	2126	78	2100	81	2355	83	2194
Caffey	92	2211	86	2333	84	2467	88	2337
CL152	89	2115	84	2260	84	2458	86	2278
CL162	88	2083	78	2100	79	2294	82	2159
CL261	90	2137	82	2210	78	2276	83	2207
Colorado	86	2009	78	2108	80	2337	81	2151
Della 2	91	2179	83	2241	87	2553	87	2325
Jazzman-2	90	2126	81	2181	79	2302	83	2203
Jupiter	96	2317	86	2344	81	2366	88	2342
Mermentau	89	2105	79	2117	84	2468	84	2230
Rex	89	2094	78	2100	80	2334	82	2176
Roy J	96	2309	86	2344	92	2675	91	2443
RT XL753	87	2030	78	2109	74	2149	80	2096
Wells	91	2179	82	2200	85	2486	86	2288
Mean	90	2126	81	2182	81	2362	84	2223
C.V.[a]	1.1	1.38	1.5	1.65	1.9	1.93	---	---
LSD$_{(\alpha = 0.05)}$[b]	1.6	48.6	2.0	59.5	2.5	75.4	---	---

[a] C.V. = coefficient of variation.

[b] LSD = least significant difference.

Table 4. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, near Stuttgart, Ark., during 2012.

	Grain yield by seeding date			
Cultivar	30 March	13 April	12 May	Average
	(bu/acre)			
AREXP1	230	120	125	168
Antonio	219	145	202	189
Caffey	248	113	145	169
CL152	225	108	183	172
CL162	212	135	88	145
CL261	207	120	77	135
Colorado	189	125	122	145
Della 2	195	149	162	169
Jazzman-2	186	102	146	145
Jupiter	254	128	198	193
Mermentau	223	136	209	189
Rex	218	151	171	180
Roy J	255	251	208	238
RT XL753	274	149	214	200
Wells	236	149	214	200
Mean	222	142	165	176
C.V.[a]	6.49	19.2	11.1	---
LSD$_{(\alpha = 0.05)}$[b]	23.8	44.7	30.3	---

[a] C.V. = coefficient of variation.

[b] LSD = least significant difference.

Table 5. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the Rice Research and Extension Center, near Stuttgart, Ark., during 2012.

	Milling yield[a] by seeding date			
Cultivar	30 March	13 April	11 May	Average
	---------(%HR - %TR)---------			
AREXP1	58-72	59-72	66-75	63-74
AREXP1	50-67	52-66	63-69	55-67
Antonio	55-68	58-68	67-71	60-69
Caffey	55-66	50-67	62-69	56-67
CL152	56-67	60-69	67-70	61-69
CL162	53-67	54-67	64-69	57-67
CL261	57-68	56-67	63-69	59-68
Colorado	51-66	51-64	61-68	55-66
Della 2	54-66	59-67	63-67	59-66
Jazzman-2	61-68	60-68	66-68	62-68
Jupiter	56-64	60-67	66-69	61-67
Mermentau	60-68	58-67	67-70	62-68
Rex	55-66	58-68	64-68	59-67
Roy J	53-68	56-70	65-70	58-69
RT XL753	50-67	46-68	65-70	53-68
Wells	46-67	50-68	64-70	53-68
Mean	53-67	54-67	63-69	57-67

Evaluation of the Illinois Soil Nitrogen Test and the Nitrogen-Soil Test for Rice Grown on Clayey Soils

A.M. Fulford, 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

ABSTRACT

Nitrogen (N) fertilizer management based on site-specific N soil testing has become a reality for commercial rice (*Oryza sativa* L.) producers in Arkansas using the Nitrogen-Soil Test for Rice (N-ST*R). The widespread adoption of N-ST*R in the mid-South for rice grown on silt loam soils has stimulated interest in pursuing the development of N-ST*R nitrogen fertilizer rate recommendations specifically for rice grown on clayey soils. Nitrogen response trials were conducted in Arkansas as well as Mississippi from 2007 to 2012 on clayey soils used for rice production. The concentration of alkaline hydrolyzable-N (AHN) was evaluated within 6-inch depth increments as well as depth-averaged soil sampling increments (i.e., 0- to 6-inch, 0- to 12-inch, 0- to 18-inch, and 0- to 24-inches) to a depth of 24 inches. A highly significant ($P < 0.0001$) Illinois Soil Nitrogen Test (ISNT) N fertilizer rate linear regression ($Y = 338.29 - 1.58x$; $R^2 = 0.85$) as well as a highly significant ($P < 0.0001$) N-ST*R nitrogen fertilizer rate linear regression ($Y = 381.79 - 1.77x$; $R^2 = 0.84$) indicated that the 0- to 12-inch sampling depth protocol utilized in Arkansas is appropriate for rice grown on clayey soils in Mississippi. These results suggest either ISNT or N-ST*R could be used to make meaningful adjustments to N fertilizer rate recommendations based on a site-specific estimate of potentially mineralizable-N within the 0- to 12-inch effective rooting depth of rice grown on clayey soils in the mid-South.

INTRODUCTION

Nitrogen fertilizer rate recommendations provided by the Nitrogen-Soil Test for Rice (N-ST*R) soil test method were utilized by commercial rice (*Oryza sativa* L.)

producers in Arkansas beginning in the spring of 2012. This marked the inaugural release of N-ST*R for rice grown on silt loam soils. In order to expand the availability of N-ST*R to an even greater number of rice producers in Arkansas, the next step will be to develop this soil N test for rice grown on clayey soils. It has been well documented that rice grown on clayey soils requires a higher rate of N fertilizer than when grown on silt loam soils (Norman et al., 2003); thus it was believed that perhaps a different calibration curve and depth of soil sampling would be required for rice grown on clayey soils.

The exclusion of subsurface (i.e., > 6 inches) labile N could potentially limit the utility of N-ST*R as a site-specific N soil test. Extensive research in Arkansas indicated that a 0- to 18-inch sampling depth encompassed the effective rooting depth of rice grown on silt loam soils and therefore improved the accuracy of N-ST*R nitrogen rate recommendations compared to a 0- to 6-inch sampling depth (Roberts et al., 2011a). Quantification of alkaline hydrolyzable-N (AHN) has served as the basis for the development of routine soil test methods such as the Illinois Soil Nitrogen Test (ISNT) for corn (*Zea mays* L.; Khan et al., 2001) and N-ST*R for rice (Roberts et al., 2011b). The ISNT utilizes diffusion under mild temperature and alkaline conditions (i.e., 122 °F and 2 *M* NaOH) to quantify AHN, while N-ST*R utilizes direct steam distillation (DSD) of 10 *M* NaOH to quantify AHN. Both ISNT and N-ST*R methods attempt to provide an estimate of potentially mineralizable-N. The objectives of this project were: (1) to correlate the concentration of AHN as determined by ISNT and N-ST*R to percent relative grain yield (%RGY) for clayey soils sampled to a 2-ft depth in Arkansas; and (2) establish N fertilizer rate calibration curves capable of predicting site-specific and yield maximizing N fertilizer rates for use in rice production systems on clayey soils in the mid-South.

PROCEDURES

Nitrogen rate trials were conducted in commercial production and experiment station fields in Arkansas on clayey soils used for rice production from 2007 to 2012 by broadcasting urea (46% N) fertilizer in a two-way split application with the majority of N applied preflood and the remaining 45 lb N/acre applied at beginning internode elongation (i.e., mid-season). At each location, total N rates included: 0, 45, 90, 135, 180, and 225 lb N/acre. The Northeast Research and Extension Center (NEREC) in Keiser, Ark., and the Southeast Research and Extension Center (SEREC) in Rohwer, Ark., are the University of Arkansas System Division of Agriculture locations utilized in this study. With the help of cooperating researchers from Mississippi State University, six additional N rate trials were established in Mississippi from 2007 to 2011. The N rate trials in Mississippi utilized the aforementioned N fertilizer source and rates and were conducted at the Delta Research and Extension Center (DREC) in Stoneville, Miss., on clay soil used for rice production.

Both direct-seeded and water-seeded methods were utilized for stand establishment. At each experiment station trial, 9 rows of the rice cultivar Wells were drill-seeded in 16-ft long rows with 7.5 inches between each drill-seeded row. For the commercial production trials, conventional or hybrid rice cultivars commonly grown in Arkansas were selected based on similar N fertilizer rate requirements (i.e., 150 lb N/acre; Roberts and Wilson, 2012). From each unfertilized plot (0 lb N/acre), soil was sampled to a depth of 24 inches in successive 6 inch increments (i.e., 0- to 6-inch, 6- to 12-inch, 12- to 18-inch, and 18- to 24-inches) using a Dutch Auger probe (AMS Inc., American Falls, Idaho). Information describing the soil series, taxonomic classification, previous crop, as well as the year each N rate trial was established is provided for each location in Arkansas (Table 1). Taxonomic classification was based on official soil series descriptions as provided by the United States Department of Agriculture-Natural Resources Conservation Service (Soil Survey Staff, 2012).

Soil samples were oven-dried at 140 °F, ground, sieved (< 2-mm particle size), and placed in cardboard containers prior to chemical analysis. The concentration of AHN was determined for 6-inch as well as depth averaged soil samples using the ISNT or diffusion method of Khan et al. (2001) and the N-ST*R or DSD method of Roberts et al. (2011a) and Bushong et al. (2008). The sampling protocol utilized in this study allowed for the concentration of AHN to be determined within individual 6 inch sampling increments as well as depth averaged sampling increments of 0- to 6-inch, 0- to 12-inch, 0- to 18-inch, and 0- to 24-inches. To obtain the depth-averaged concentration of AHN, it was necessary to sum the AHN concentration of each 6 inch sample and then divide by the number of depths used in summation. For example, the concentration of AHN from the 0- to 12-inch depth represents the sum of the AHN concentrations from the 0- to 6-inch and 6- to 12-inch depth divided by two.

Grain yield correlation and N fertilizer rate calibration curves were developed based on depth-averaged AHN concentration. The linear grain yield correlation curves were developed by regressing the concentration of AHN on the %RGY. The %RGY for each location was determined by dividing the yield of the unfertilized control by the maximum yield and multiplying by 100. The linear N fertilizer rate calibration curves were developed in order to identify the N rate needed to obtain near maximal rice grain yield and this was achieved by regressing the depth averaged AHN concentration on the 95% RGY N fertilizer rate. Fifteen site-years of N fertilizer rate trials in Arkansas were incorporated into the development of the ISNT correlation and fertilizer calibration curves and 14 site-years were incorporated into the N-ST*R correlation and fertilizer calibration curves using depth averaged soil test values. Six locations from Mississippi were added to the N fertilizer rate calibration curve using the 0- to 12-inch depth sampling protocol first established for Arkansas clayey soils. Therefore, 21 site-years have been used to develop a separate 0- to 12-inch depth N fertilizer rate calibration curve for ISNT while 20 site-years have been used to develop a separate 0- to 12-inch N-ST*R fertilizer calibration curve for Arkansas and Mississippi clayey soils. Linear %RGY correlation curves and 95% RGY N fertilizer rate calibration curves were established for ISNT and N-ST*R. The PROC REG in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) was used to identify the significance (P <0.05) of each linear regression equation.

RESULTS AND DISCUSSION

The correlation between ISNT soil test values and %RGY was significant for each of the soil sampling increments to a depth of 24 inches (Table 2). As sampling depth increased from 0- to 6-inches to 0- to 12-inches, the coefficient of determination increased reaching a maximum ($R^2 = 0.72$) at the 0- to 12-inch depth. This result indicates that 72% of the variation in %RGY can be explained by the ISNT soil test value. Also, the coefficient of determination for the 0- to 18-inch depth and the 0- to 24-inch depth were lower than the coefficient of determination that was observed for the 0- to 12-inch depth indicating that the AHN concentration from within the 0- to 12-inch depth provided the most accurate estimate of potentially mineralizable-N.

Similar to the results obtained for the depth averaged ISNT correlation curve equations, N-ST*R was also significantly and positively correlated to %RGY for the 15 site-years of data collected in Arkansas reaching a maximum ($R^2 = 0.77$) at the 0- to 12-inch depth (Table 3). Nitrogen-Soil Test for Rice linear regression equations had a coefficient of determination range ($R^2 = 0.36$ to 0.77) that was shown to be wider than the coefficient of determination range obtained using the corresponding ISNT soil test values ($R^2 = 0.57$ to 0.72). However, both ISNT and N-ST*R correlation curve equations indicated that the 0- to 12-inch sampling depth provided the most accurate index of the amount of AHN that is available for plant uptake. Also, the greatest increase in the coefficient of determination occurred between the 0- to 6-inch and the 0- to 12-inch depth for both the ISNT and N-ST*R soil test methods. This result indicates that the predictive ability of ISNT and N-ST*R linear regression equations was improved the most by sampling a 0- to 12-inch depth.

The development of N fertilizer rate calibration curve equations based on AHN concentration is needed in order to relate the soil test value, as determined by ISNT or N-ST*R, to the amount of N fertilizer needed to achieve maximum yield. Depth averaged N fertilizer rate calibration curves were established based on the ISNT soil test value and each sampling depth increment produced a significant linear relationship to the N fertilizer rate needed to achieve 95% RGY (Table 4). The 0- to 18-inch sampling depth produced the greatest coefficient of determination ($R^2 = 0.84$) indicating that the 0- to 18-inch sampling depth should provide the most accurate prediction of a yield maximizing N fertilizer rate. However, sampling an additional 6 inches, from 0- to 12-inches to 0- to 18-inches, does not appear to be practical due to the minimal improvement in the coefficient of determination from 0.83 to 0.84.

Nitrogen fertilizer rate calibration curves developed based on N-ST*R analysis indicated that there was a significant and negative linear relationship between N-ST*R soil test values and the N fertilizer rate required to achieve 95% RGY for each sampling depth (Table 5). The coefficient of determination range for the linear regression equations based on N-ST*R analysis ($R^2 = 0.49$ to 0.83) was wider than the coefficient of determination range observed for ISNT analysis ($R^2 = 0.72$ to 0.84). However, the coefficient of determination for N-ST*R nitrogen fertilizer rate calibration exhibited the greatest increase as sampling depth increased from 0- to 6-inches to 0- to 12-inches, similar to the trend that was observed among ISNT nitrogen fertilizer rate calibration curves. Also, similar to the ISNT, the highest coefficient of determination ($R^2 = 0.83$) for N-ST*R soil test values and the N fertilizer rate required to achieve 95% RGY was obtained at the 0- to 12-inch sampling depth.

The development of a 0- to 12-inch sampling depth protocol established for rice grown on clayey soils in Arkansas led to the evaluation of the N-ST*R N fertilizer rate calibration curve for rice grown on clayey soils in Mississippi. A significant ($P < 0.0001$) and negative linear relationship was observed between N-ST*R and the 95% RGY nitrogen fertilizer rate (Fig. 1). The 0- to 12-inch sampling depth protocol was also utilized in order to establish a N fertilizer rate calibration curve for use in conjunction with ISNT analysis. Similar to the N-ST*R nitrogen fertilizer rate calibration curve, ISNT soil test values exhibited a significant ($P < 0.0001$) and negative linear relationship to the N fertilizer rate needed to achieve 95% RGY (Fig. 2). Results from the development of N-ST*R and ISNT N fertilizer rate calibration curves indicated that the predictive ability of these linear regression equations should enable the 0- to 12-inch sampling depth protocol to provide accurate fertilizer rate recommendations for rice grown on clayey soils in Arkansas as well as Mississippi.

SIGNIFICANCE OF FINDINGS

The use of N-ST*R to provide site-specific and yield maximizing N fertilizer rate recommendations has been successful when rice is grown on silt loam soils throughout the mid-South. Successful implementation of N-ST*R nitrogen fertilizer rates for rice grown on clayey soils may require the development of a grain yield correlation and N fertilizer rate calibration curve separate from the correlation and calibration curves developed for rice grown on silt loam soils. The results obtained from N response trials conducted in Arkansas indicated that ISNT and N-ST*R analysis could be used as the basis for the development of a N fertilizer rate calibration curve using a 0- to 12-inch sampling depth. Nitrogen fertilizer response trials in Mississippi were also incorporated into the N fertilizer calibration curves first developed for use in Arkansas rice production systems. These results indicated that the N fertilizer rate calibration curve developed based on ISNT or N-ST*R analysis could be used in Arkansas and Mississippi for clayey soils sampled to a 12-inch depth.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Bushong, J.T., T.L. Roberts, W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2008. Evaluation of distillation and diffusion techniques for estimating hydrolyzable amino sugar-nitrogen as a means of predicting nitrogen mineralization. Soil Sci. Soc. of Am. J. 72:992-999.

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. of Am. J. 65:1751-1760.

Norman, R.J., C.E. Wilson Jr., and N.A. Slaton. 2003. Soil fertilization and rice nutrition in U.S. mechanized rice culture. *In:* C.W. Smith and R.H. Dilday (eds.). Rice: Origin, History, Technology, and Production. Wiley Sciences. Hoboken, N.J. pp. 331-411.

Roberts, T.L. and C.E. Wilson Jr. 2012. University of Arkansas Cooperative Extension Service. 2012 Recommended Nitrogen Rates and distribution for rice varieties in Arkansas. Available online at http://www.aragriculture.org/crops/rice/Publications/nratetable2012.pdf accessed [1/14/2013].

Roberts, T.L., W.J. Ross, R.J. Norman, N.A, Slaton, and C.E. Wilson Jr. 2011a. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1161-1171.

Roberts, T.L., R.J. Norman, N.A. Slaton, C.E. Wilson, Jr., A. Fulford, S. Williamson, J. Branson, and D. Frizzell. 2011b. Field validation of the nitrogen soil test for rice produced on silt loam soils. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:223-228. Fayetteville.

Soil Survey Staff, Natural Resources Conservation Staff, United States Department of Agriculture, "Official soil series descriptions with series extent mapping capabilities," http://soils.usda.gov/technical/classification/osd/index.html (Accessed December 05, 2012).

Table 1. Year of nitrogen fertilizer rate trial, soil series, taxonomic classification, and previous crop for locations sampled in Crittenden, Lawrence, Lonoke, and Mississippi Counties as well as locations sampled at the Northeast Research and Extension Center (NEREC) and Southeast Research and Extension Center (SEREC) in Arkansas from 2007 to 2012.

Location	Year	Soil series	Taxonomic classification	Previous crop
NEREC	2007	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean[a]
NEREC	2008	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
NEREC	2008	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Rice
NEREC	2009	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
NEREC	2009	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Rice
Lawrence Co.	2009	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean
SEREC	2009	Desha	very-fine, smectitic, thermic, Vertic Hapludolls	Soybean
Mississippi Co.	2010	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean
Lawrence Co.	2010	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
NEREC	2010	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
NEREC	2010	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Rice
NEREC	2012	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Rice
Lonoke Co.	2012	Perry	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
Crittenden Co.	2012	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Soybean
Mississippi Co.	2012	Sharkey	very-fine, smectitic, thermic, Chromic Epiaquerts	Rice

[a] *Glycine max* L.

Table 2. Regression equations describing the relationship between the Illinois Soil Nitrogen Test (ISNT) and percent relative grain yield for clayey soils sampled in Arkansas from 2007 to 2012.

Sampling depth	Regression equation	R^2	*P* value
0- to 6-inch	$Y = -34.30 + 0.65x$	0.57	0.001
0- to 12-inch	$Y = -22.35 + 0.61x$	0.72	<0.0001
0- to 18-inch	$Y = -6.14 + 0.51x$	0.65	0.0003
0- to 24-inch	$Y = 184.07 - 3.09x + 0.016x^2$	0.69	0.0009

Table 3. Regression equations describing the relationship between the Nitrogen-Soil Test for Rice (N-ST*R) and percent relative grain yield for clayey soils sampled in Arkansas from 2007 to 2012.

Sampling depth	Regression equation	R^2	*P* value
0- to 6-inch	$Y = -23.59 + 0.53x$	0.36	0.01
0- to 12-inch	$Y = 312.28 - 4.60x + 0.02x^2$	0.77	0.0001
0- to 18-inch	$Y = -15.76 + 0.54x$	0.58	0.0009
0- to 24-inch	$Y = 236.04 - 3.74x + 0.02x^2$	0.66	0.001

Table 4. Regression equations describing the relationship between the Illinois Soil Nitrogen Test (ISNT) and the 95% relative grain yield nitrogen fertilizer rate (lb N /acre) for clayey soils sampled in Arkansas from 2007 to 2012.

Sampling depth	Regression equation	R^2	*P* value
0- to 6-inch	$Y = 393.70 - 1.96x$	0.72	0.0001
0- to 12-inch	$Y = 332.77 - 1.57x$	0.83	<0.0001
0- to 18-inch	$Y = 299.57 - 1.38x$	0.84	<0.0001
0- to 24-inch	$Y = 281.28 - 1.30x$	0.74	<0.0001

Table 5. Regression equations describing the relationship between the Nitrogen-Soil Test for Rice (N-ST*R) and the 95% relative grain yield nitrogen fertilizer rate (lb N /acre) for clayey soils sampled in Arkansas from 2007 to 2012.

Sampling depth	Regression equation	R^2	*P* value
0- to 6-inch	$Y = 383.39 - 1.73x$	0.49	0.005
0- to 12-inch	$Y = 391.88 - 1.89x$	0.83	<0.0001
0- to 18-inch	$Y = 326.08 - 1.47x$	0.75	<0.0001
0- to 24-inch	$Y = 301.79 - 1.35x$	0.67	0.0002

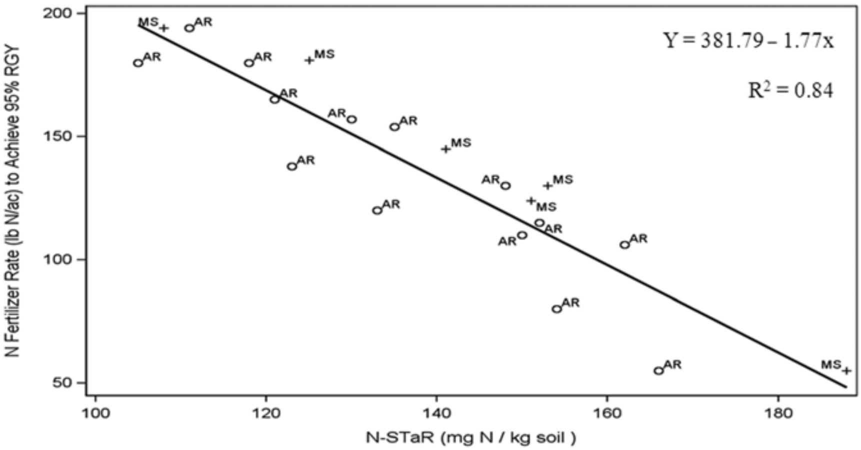


Fig. 1. The 95% relative grain yield nitrogen fertilizer rate (lb N/acre) versus the Nitrogen-Soil Test for Rice (N-ST*R) soil test value (mg N/kg soil) for clayey soils sampled from 0- to 12-inches in Arkansas (AR) and Mississippi (MS) from 2007 to 2012.

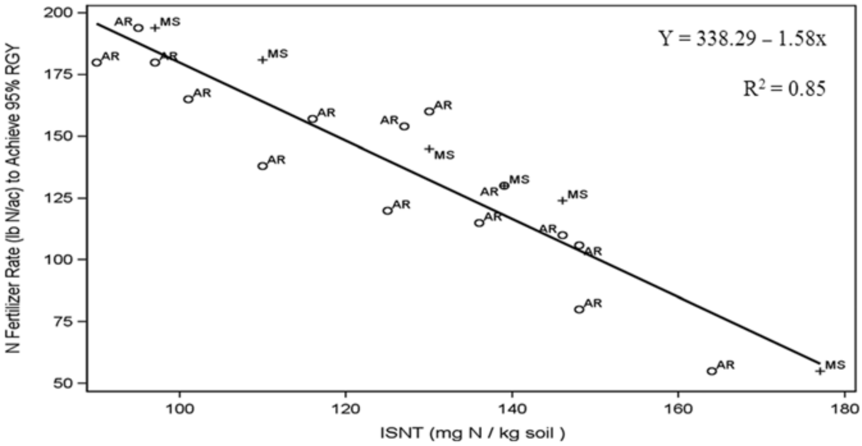


Fig. 2. The 95% relative grain yield nitrogen fertilizer rate (lb N/acre) versus the Illinois Soil Nitrogen Test (ISNT) soil test value (mg N/kg soil) for clayey soils sampled from 0- to 12-inches in Arkansas (AR) and Mississippi (MS) from 2007 to 2012.

Influence of Poultry Litter on Nitrogen-Soil Test for Rice Soil Test Values and Rice Grain Yield

C.E. Greub, T.L. Roberts, N.A. Slaton, R.J. Norman,
A.M. Fulford, J. Shafer, S.M. Williamson, and C.L. Scott

ABSTRACT

An important advancement in predicting field-specific nitrogen (N) fertilizer recommendations for rice (*Oryza sativa* L.) production in Arkansas is the Nitrogen-Soil Test for Rice (N-ST*R). Studies were conducted to evaluate the influence of poultry litter (PL) on N-ST*R soil test values when applied as a fertilizer source on silt loam soils. These studies were conducted at the Pine Tree Research Station (PTRS), Colt, Ark., and Rohwer Research Station (RRS), Rohwer, Ark., where pelletized PL was applied at rates ranging from 0 to 3 ton PL/acre. Poultry litter was applied at two different treatment times including an application of PL 4 weeks (at-planting) and 8 weeks (1-month prior to planting) prior to flooding. Rice grain yield increased as PL rate increased, with maximal yield being reached with the at-planting application time. Poultry litter rate as a main effect significantly increased alkaline hydrolyzable-N (AH-N) as PL application rate increased, with a 7 ppm difference in AH-N values between the untreated control and the highest PL rate application; subsequently resulting in a decrease in the N-ST*R nitrogen rate recommendation as PL rate increased. Alkaline hydrolyzable-N was also significantly influenced by the two-way interaction of soil sample time and location, with the PTRS location having higher AH-N values at each soil sample time when compared to the RRS location. The PL application time by soil sample time interaction resulted in a significant difference between the PL application times only at the 0 wk following planting sample time, with a 6 ppm difference between treatments. Even though these differences were statistically different, they are negligible when assessing a soil test. Results of this study allowed the development of sampling protocols that recommend to rice producers applying PL to wait a minimum of two weeks following application to collect N-ST*R soil samples.

INTRODUCTION

Rice (*Oryza sativa* L.), is grown on approximately 1.2 million acres in Arkansas annually, making Arkansas the leading rice-producing state in the United States. Concurrently, poultry litter (PL) is one of the most nutrient-rich soil amendments with Arkansas producing large amounts of PL and applying it to row-crop acres. Poultry litter is typically applied to satisfy phosphorus and potassium recommendations; however, studies conducted by Wild et al. (2011) and Golden et al. (2006) indicated that approximately 19% and 25% of the total nitrogen (TN) applied as PL was recovered by the rice crop, respectively. A recent improvement for predicting N fertilizer needs for rice production in Arkansas was the correlation and calibration of the Nitrogen-Soil Test for Rice (N-ST*R) developed by Roberts et al. (2011). This is a site-specific soil-based N test that predicts potentially mineralizable soil-N (e.g., amino sugars, amino acids, and NH_4) as AH-N. The N-ST*R method determines AH-N by the direct steam distillation (DSD) procedure developed by Bushong et al. (2008).

The development of N-ST*R to predict field-specific N rates is expected to become a standard procedure for rice produced on silt loam soils; however rice producers in the Delta region receive about 100,000 tons PL/year from Arkansas (Kellogg et al., 2000) and there has been little research concerning the ability of N-ST*R to estimate N credits from PL applications. With N expected to represent roughly 20% of the total operating expenses in rice production (University of Arkansas, 2012), it is important to be able to accurately predict how PL application time and rate influences the N-ST*R soil test values. Therefore, the objective of this research was to quantify PL influences on N-ST*R soil test values and rice grain yield to evaluate the ability of N-ST*R to estimate N credits from fields that have received an application of PL prior to soil sampling for N recommendations.

PROCEDURES

Four field experiments, two in 2011 and two in 2012, were established to evaluate crop and soil responsiveness to pelletized PL as a fertilizer for an estimated N credit in rice using N-ST*R. This experiment has a full factorial randomized complete-block design (2 locations × 2 PL application times × 4 PL rates). The medium-grain rice variety CL261 was drill-seeded at the Pine Tree Research Station (PTRS, Colt, Ark.) and the Rohwer Research Station (RRS), Rohwer, Ark., on Calhoun and Hebert silt loam soils (Table 1), respectively. The two PL application times were 4 weeks (at-planting) and 8 weeks (1-month prior to planting) prior to flooding. The four PL rates were broadcast by hand to a dry, tilled soil surface and mechanically incorporated at rates of 0, 1, 2, and 3 ton PL/acre (N rate equivalent to 0, 76, 152, and 228 lb N/acre) to generate an N response curve and allow quantifiable changes in the soil N status.

Both locations contained plots with rice and plots without rice. Each location had 64 individual plots (2 PL application times with 4 replicates and 8 plots per replicate) that were 6.5-ft wide by 16-ft long. The plots without rice were soil sampled to identify changes in N-ST*R (Roberts et al., 2011) soil test values, with the N rate recommendation being determined from the AH-N values. Soil samples were collected three times from the plots devoid of rice at 2-week intervals; sampling was initiated at planting and continued until flooding. Soil samples were collected using a slide hammer and core tip, then dried at 130 °F (55 °C) and crushed to pass through a 0.0787-inch sieve. The plots with rice were used to determine rice grain yield in response to the PL application. Plots were flooded when the rice reached the 4- to 5-lf stage for each location and remained flooded until the rice was mature. At maturity, the center five rows of each plot were harvested, the moisture content and weight of the grain were collected to determine rice grain yield expressed as bushels (bu)/acre at a 12% moisture content (a bushel weighs 45 lb). All statistical analyses were carried out using JMP (SAS Institute, Inc., Cary, N.C.) and means were separated using the least significant difference (LSD) test, assessing significance at $P < 0.05$.

RESULTS AND DISCUSSION

Rice grain yield was significantly influenced by PL rate and the two-way interaction of PL application time by location, both with a P-value of <0.0001 (Table 2). As PL rate increased, there was an increase in rice grain yield for the 0, 1, and 2 ton PL/acre rates, with the 3 ton PL/acre rate not being significantly different than the 2 ton PL/acre rate in yield (Fig. 1); maximal yield was achieved when PL was applied at a 2 ton PL/acre rate with a yield of 125 bu/acre. When evaluating PL application timing, the PTRS location attained the overall highest yield when PL was applied at planting with a yield of 132 bu/acre (Fig. 2). However, the at-planting PL application time at the RRS location produced the overall lowest yield. The decrease in yield at the RRS location for the at-planting PL application when compared to the PTRS location could have been caused by a high accumulation of salt effecting the germination of the rice seeds at the RRS location. High rates of PL can cause salinity problems for rice due to increasing concentrations of soluble salts (Norman et al., 2003). The effects of salinity on rice occur from the increased osmotic pressure of the soil solution impairing the plant's ability to absorb water at the seedling growth stage. The 1-month prior to at-planting PL application resulted in relatively similar yields for both the RRS and PTRS locations with a yield of 111 and 114 bu/acre, respectively (Fig. 2).

The main purpose of this study was to identify changes in AH-N values within soil samples that were collected following a PL application; identifying if the standard N-ST*R recommendation can be used following a PL application or the extent the N-ST*R rate recommendation needs to adjusted to prevent an over- or under-fertilization with N fertilizer. Poultry litter rate as a main effect significantly increased AH-N as PL application rate increased with a P-value of 0.0096 (Table 3), where treatment values ranged from 54 ppm to 61 ppm (Fig. 3). Even though there was a significant difference in AH-N following PL application, the 7 ppm difference when comparing the 0 and the 3 ton PL/acre application rates is a relatively negligible change in AH-N when evaluating a soil test. Conversely, a significant decrease in the N-ST*R N rate recommendation was detected as PL rate increased; however, there was only an 11 lb N/acre difference in the N recommendation between the 0 and 3 ton PL/acre application rates (Fig. 4).

Alkaline hydrolyzable-N was also significantly influenced by the two-way interaction of soil sample time and location $P < 0.0001$ (Table 3), with the PTRS location having higher numerical values at all three sample times when compared to the RRS location (Fig. 5). Also, within the interaction of soil sample time and location, no significant differences in AH-N were identified within both locations across soil sampling times. Furthermore, the PL application time by soil sample time interaction with a *P*-value of 0.0152 (Table 3) resulted in a significant difference between the PL application times only at the first soil sampling time, with a 6 ppm difference in AH-N (Fig. 6). There were no significant differences in AH-N within a PL application time for all three soil sampling times.

SIGNIFICANCE OF FINDINGS

Results of a 2-year field study, at two locations, indicated that AH-N is significantly influenced by: PL rate, soil sample time by location, and soil sample time by PL application time. A PL application can also significantly increase rice grain yield and decrease N-ST*R nitrogen recommendation. However, even though AH-N is significantly influenced statistically by a PL application, from a practical standpoint the influence is insignificant when variability in the field, fertilizer application, and environment are considered. Poultry litter minimally influences N-ST*R soil test values because we are applying and incorporating PL in the top 4 inches of the soil surface, but the N-ST*R uses an 18-inch deep soil sample. Evaluating the influence of PL on N-ST*R soil test values across time will ensure that the proper N recommendation is determined using N-ST*R following a PL application. The results of this study demonstrate the ability to design soil sampling protocols, recommending that producers applying PL need to wait at least 2 weeks following a PL application before collecting soil samples for N recommendations using the N-ST*R program.

ACKNOWLEDGMENTS

This experiment received financial support from the Arkansas Rice Check-off Program distributed by the Arkansas Rice Research and Promotion Board, which was greatly appreciated. We are also grateful for the assistance from the University of Arkansas N-ST*R Soil Testing Lab for laboratory equipment and analysis and the field and research support personnel at each research location for their help with establishing and maintaining these studies. The personnel that helped include Randy Spurlock, Larry Earnest and Shawn Clark.

LITERATURE CITED

Bushong, J.T., T.L. Roberts, W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2008. Evaluation of distillation and diffusion techniques for estimating hydrolyzable amino sugar-nitrogen as a means of predicting N mineralization. Soil Sci. Soc. Am. J. 72:992-999.

Golden, B.R., N.A. Slaton, R.J. Norman, E.E. Gbur, Jr., K.R. Brye, and R.E. DeLong. 2006. Recovery of nitrogen in fresh and pelletized poultry litter by rice. Soil Sci. Soc. Am. J. 70:1359-1369.

Kellogg, R.L., C.H. Lander, D.C. Moffitt, and N. Gollehon. 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: Spatial and temporal trends for the United States. Pub. No. NPS00-0579. USDA-NRCS, Economic Research Service, Washington, DC. Accessed on September 12, 2012. Available at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_012133.pdf

Norman, R.J., C.E. Wilson Jr., and N.A. Slaton. 2003. Soil fertilization and mineral nutrition in U.S. mechanized rice culture. pp. 331-411. *In:* C.W. Smith and R.H. Dilday (eds.). Rice: Origin, History, Technology, and Production. John Wiley & Sons, Inc. Hoboken, N.J.

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. 75:1161-117.

University of Arkansas. 2012. Crop enterprise budgets for Arkansas field crops planted in 2012. AG-1272. Accessed on August 29, 2012. Available at: http://www.uaex.edu/depts/ag_economics/budgets/2012/Budgets2012.pdf.

Wild, P.L., C.V. Kessel, J. Lundberg, and B.A. Linquist. 2011. Nitrogen availability from poultry litter and pelletized organic amendments for organic rice production. Agron. J. 103(4):1284-1291.

Table 1. Selected soil characteristics at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

Year	Location	Soil series	pH	% Total N	% Total C
2011	PTRS	Calhoun	7.8	0.09	0.81
2011	RRS	Hebert	5.9	0.10	0.93
2012	PTRS	Calhoun	7.7	0.06	0.66
2012	RRS	Hebert	6.2	0.07	0.78

Table 2. Analysis of variance for rice grain yield as influenced by location, poultry litter (PL) application time, PL rate, and soil sample time.

	Rice grain yield	
Source of variance	DF	P-value
Location	1	<0.0001*[a]
PL application time	1	0.2486
PL rate	3	<0.0001*
Location × PL application time	1	<0.0001*
Location × PL rate	3	0.1142
PL application time × PL rate	3	0.4618
Location × PL application time × PL rate	3	0.0522

[a] * indicates significant difference.

Table 3. Analysis of variance for alkaline hydrolyzable-N (AH-N) and Nitrogen-Soil Test for Rice (N-ST*R) nitrogen (N) rate recommendation as influenced by location, poultry litter (PL) application time, PL rate, and soil sample time.

	AH-N	
Source of variance	DF	P-value
Location	1	0.1083
PL application time	1	0.7500
PL rate	3	0.0096*[a]
Soil sample time	2	0.0430*
Location × PL application time	1	0.6244
Location × PL rate	3	0.6569
Location × soil sample time	2	<0.0001*
PL application time × PL rate	3	0.7496
PL application time × soil sample time	2	0.0152*
PL rate × soil sample time	6	0.9873

[a] * indicates significant difference.

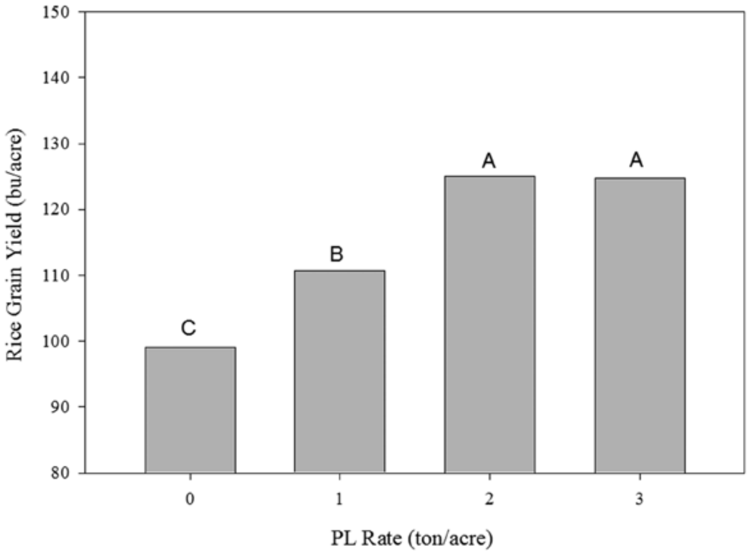


Fig. 1. Influence of poultry litter (PL) rate on rice grain yield. Means with the same letter are not significantly different at the $P < 0.05$ level.

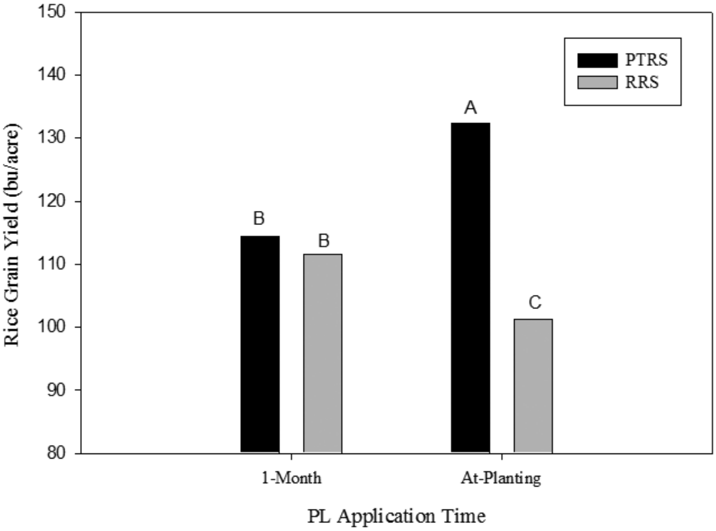


Fig. 2. Influence of poultry litter (PL) application time and location on rice grain yield. Means with the same letter are not significantly different at the $P < 0.05$ level. Locations are Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

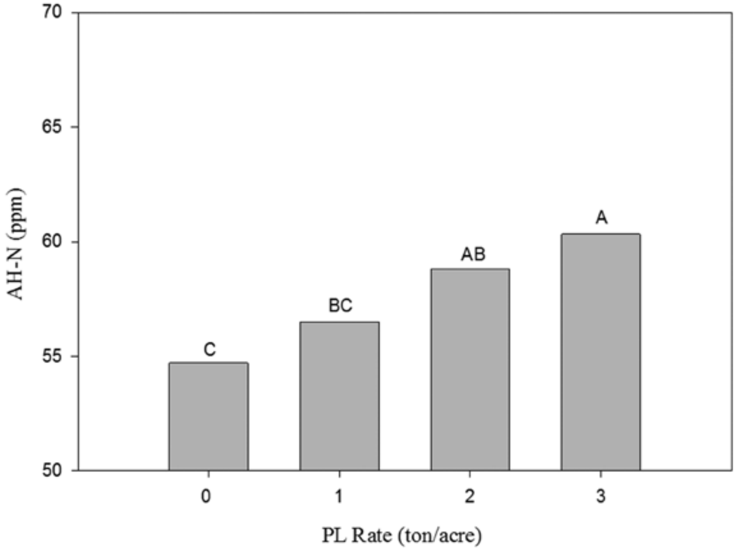


Fig. 3. Influence of poultry litter (PL) rate on alkaline hydrolyzable-N (AH-N). Means with the same letter are not significantly different at the *P* < 0.05 level.

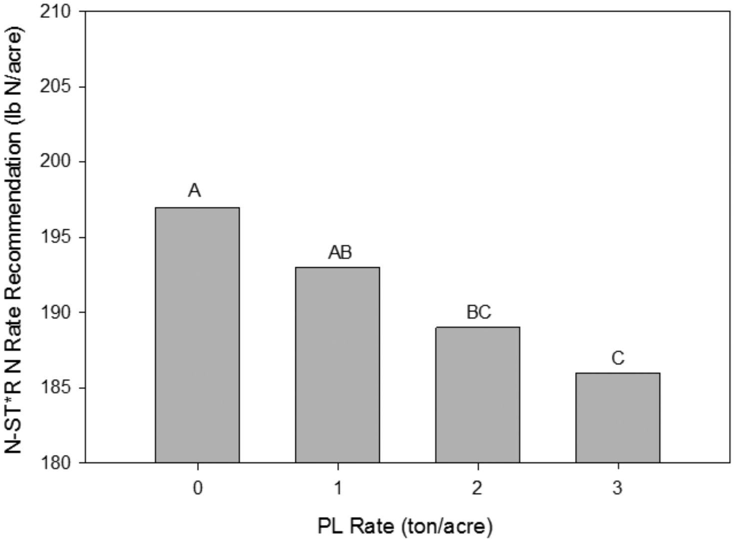


Fig. 4. Influence of poultry litter (PL) rate on N-ST*R (Nitrogen-Soil Test for Rice) nitrogen (N) rate recommendation. Means with the same letter are not significantly different at the *P* < 0.05 level.

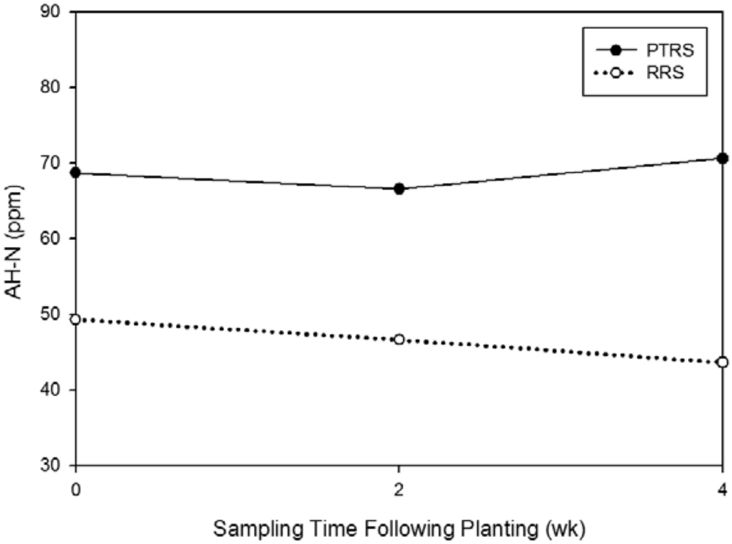


Fig. 5. Influence of soil sample time and location on alkaline hydrolyzable-N (AH-N). Locations are Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). Least significant difference (LSD) 0.05 to compare within a treatment across time was 7.35 ppm and the LSD 0.05 to compare across treatments within a sample time is 5.99 ppm.

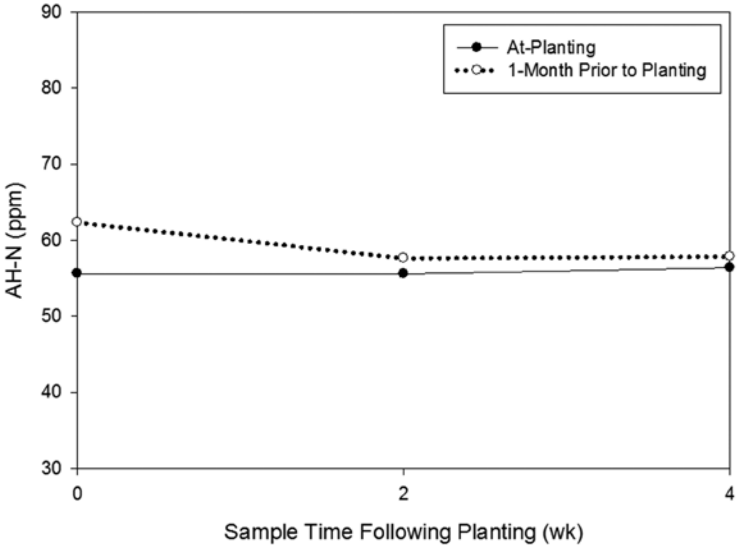


Fig. 6. Influence of soil sample time and poultry litter application time on alkaline hydrolyzable-N (AH-N). Least significant difference (LSD) 0.05 to compare within a treatment across time was 7.35 ppm and the LSD 0.05 to compare across treatments within a sample time is 5.99 ppm.

RICE CULTURE

Arkansas Rice Performance Trials

J.T. Hardke, D.L. Frizzell, C.E. Wilson Jr., K.A.K. Moldenhauer,
Y. Wamishe, R. Cartwright, R.J. Norman, J.D. Branson,
M.M. Blocker, J.A. Bulloch, E. Castaneda-Gonzalez, L.A. Schmidt, and R. Mazzanti

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. New cultivars in the 2012 ARPTs included: Antonio, Colorado, Della-2, Jazzman-2, Mermentau, and the hybrid RiceTec XL753. The ARPTs were conducted at five locations during 2012. Averaged across location, grain yield was highest for the hybrid RTXL753; while AREXP1, Bengal, Francis, Roy J, and Wells were the top five non-hybrid cultivars. Cultivars with the highest head rice yield during 2012 included: Caffey, Cheniere, CL142-AR, CL151, Francis, Jazzman-2, Rex, 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 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 Arkansas Rice Performance Trials (ARPTs) are conducted each year to compare promising new experimental lines and newly released cultivars from the breeding programs in Arkansas, Louisiana, Texas, and Mississippi 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 2012 ARPTs included the Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Newport Research Station (NRS) near Newport, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; and the Gary Shepard farm near Knobel, Ark., in Clay County. Twenty-five entries, which were either promising breeding lines or established cultivars, were grown in each of the three maturity groups (very early season, early season, and mid-season) for a total of 100 entries.

The studies were seeded at RREC, PTRS, NRS, NEREC, and the Shepard farm on 6 April, 23 April, 24 April, 2 April, and 4 April, respectively. The conventional varieties were drill-seeded at a rate of 40 seed/ft^2 in plots nine rows (7-inch spacing) wide and 17 ft in length. Hybrid entries were sown into the same plot configuration using the recommended reduced seeding rate for hybrids of 14 seed/ft^2. Cultural practices varied somewhat among the ARPT locations but were overall grown under conditions for high yield. Phosphorus and potassium fertilizers were applied before seeding at the RREC, PTRS, and NRS, and Clay County locations. Nitrogen was applied to ARPT studies located on experiment stations at the 4- to 5-lf growth stage in a single pre-flood application of 120 lb N/acre on silt loam soils and 150 lb N/acre on clay soils using urea as the N source. The permanent flood was applied within 2 days of pre-flood N application and maintained throughout the growing season. At maturity, the center five 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 and percent total white rice (%HR - %TR). Each location of the study was arranged in a randomized complete block design with three replications. Statistical analyses were conducted using PROC GLM (SAS v. 9.2; SAS Institute, Inc., Cary, N.C.) and mean separations were conducted based upon Fisher's protected least significant difference test ($\alpha = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The 3-year average of agronomic traits, grain yields, and milling yields of selected cultivars evaluated during 2010-2012 are listed in Table 1. The top yielding entries, averaged across the 3-year studyinclude: RiceTec XL723, Roy J, RiceTec CLXL729, RiceTec CLXL745, Taggart, and the Arkansas experimental line AREXP1. Two newer entries, the medium-grain cultivar Caffey and the hybrid cultivar RiceTec XL753, also did well with 2-year grain yield averages of 196 and 250 bu/acre, respectively. In regard to milling yield, both percent head rice and percent total white rice (%HR - %TR) were generally higher for each cultivar during the 2011 study year compared to both 2010 and 2012.

Selected agronomic traits, grain yield, and milling yields from the 2012 ARPT are shown in Table 2. Nine cultivars (RiceTec CLXP4534, RiceTec XL753, RiceTec XL723, RiceTec CLXP4523, AREXP1, Roy J, Bengal, Francis, and Mermentau) achieved an average grain yield of 210 bu/acre or greater over all locations. Milling yield, averaged across locations and cultivars, was 60-71 (%HR - %TR) during 2012. The long-grain cultivar Cheniere had the highest milling yield of all commercial entries, averaging 65-73 across all 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

The Arkansas Rice Performance Trials are supported through grower check-off funds administered by the Arkansas Rice Research and Promotion Board. We wish to thank the following people for their dedication to making the ARPT possible each year: Ron Baker, Randy Chlapecka, Shawn Clark, Mike Duren, Chuck Pipkins, and Joe Shaffer.

This page left blank intentionally to facilitate the following tables.

Table 1. Results of the Arkansas Rice Performance Trials

Maturity group and variety	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight	Milled kernel weight[d]	Chalky kernels[d]
		(rating)	(days)	(inches)	(lb/bu)	(mg)	(%)
Very Early Season							
CL111	L	3.7	82	41	42.0	21.14	0.843
CL151	L	4.0	83	40	41.3	19.71	1.187
CL162	L	3.5	81	42	40.0	21.34	1.129
CL261	M	2.7	82	40	41.8	20.01	1.126
Rex	L	1.3	84	42	42.1	21.80	0.968
RiceTec CL XL729	L	4.0	83	45	41.9	20.54	2.195
RiceTec CL XL745	L	4.7	79	45	41.5	21.27	1.132
RiceTec XL723	L	3.3	82	46	42.0	21.27	3.019
RiceTec XL753	L	2.5	81	44	42.0	22.27	2.033
AREXP1	L	4.0	82	44	42.2	21.97	0.913
Early Season							
Bengal	M	3.0	85	38	40.6	22.58	0.781
Caffey	M	2.0	85	38	42.7	.	.
Cheniere	L	1.7	86	38	42.0	18.60	0.907
CL142-AR	L	3.7	85	45	42.3	22.01	1.103
CL152	L	2.0	85	39	41.8	18.40	0.873
CL181-AR	L	1.0	86	36	42.3	19.99	0.750
Francis	L	2.7	85	42	42.0	19.08	1.025
Jazzman	L	2.3	86	41	41.5	21.02	0.373
Jazzman-2	L	1.5	84	38	41.9	18.59	0.295
Jupiter	M	2.0	85	37	42.0	20.23	1.062
Wells	L	2.3	86	43	42.2	21.68	0.801
Mid-Season							
ArizeQM1003	L	5.0	92	45	40.0	.	.
Roy J	L	1.0	90	43	41.5	20.61	0.733
Taggart	L	1.3	88	46	41.9	23.10	0.733
Templeton	L	2.7	88	44	41.7	18.87	0.526
Mean		2.7	85	42	41.7	20.63	1.022

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

[d] Data from 2010 and 2011 only.

[e] Data from Riceland Grain Quality Lab., Stuttgart, Ark.

averaged across the three-year period of 2010-2012.

Milling yield by year				Grain yield by year			
2010	2011[e]	2012	Mean	2010	2011	2012	Mean
------------------- (%HR-%TR) -----------------				-------------------- (bu/acre) --------------------			
58-65	67-73	62-71	63-70	167	158	179	168
55-64	67-72	63-71	62-69	182	142	204	176
.	61-69	59-70	56-69	.	166	187	176
56-67	68-73	59-69	61-70	170	163	180	171
55-64	67-72	63-69	62-68	167	175	196	179
55-65	62-72	59-70	59-69	223	180	203	202
55-67	64-73	57-72	59-70	212	184	205	201
55-66	67-72	61-71	61-70	231	191	222	215
.	66-74	57-71	61-73	.	254	246	250
56-66	62-70	61-72	60-69	194	190	210	198
52-67	67-73	61-70	60-70	176	153	216	182
.	69-74	63-71	63-71	.	189	203	196
51-65	68-74	65-73	61-71	160	177	192	176
54-66	59-73	63-71	55-70	166	174	193	178
.	65-70	57-72	59-68	.	178	192	185
55-65	66-72	61-70	61-69	151	181	195	176
56-66	63-70	63-72	61-69	184	195	213	197
53-64	62-71	60-70	58-69	146	170	153	156
.	67-72	63-70	65-71	.	159	170	164
58-66	67-73	61-68	62-69	158	196	204	186
53-66	63-75	54-71	57-71	170	182	205	186
.	.	56-67	56-69	.	83	148	115
54-65	62-72	64-72	60-70	179	196	234	203
52-66	62-73	56-71	57-70	180	215	199	198
51-64	62-72	61-71	58-69	166	166	186	173
54-65	64-72	60-71	60-70	178	173	195	182

Table 2. Results of the Arkansas Rice

Maturity group and variety	Grain length[a]	Straw strength[b]	50% heading[c]	Plant height	Test weight
		(rating)	(days)	(inches)	(lb/bu)
Very Early Season					
Antonio	L	4.0	83	38	42.5
CL111	L	4.0	82	39	42.3
CL151	L	2.0	84	39	42.1
CL162	L	4.0	82	42	41.4
CL261	M	3.0	83	39	43.0
Colorado	L	4.0	81	39	42.2
RiceTec CLXL729	L	5.0	84	43	40.8
RiceTec CLXL745	L	5.0	79	43	40.6
RiceTec CLXP4534	L	2.0	75	37	42.3
RiceTec XL723	L	4.0	82	45	41.2
RiceTec XL753	L	4.0	82	42	42.0
RiceTec XP4523	L	2.0	76	39	41.9
AREXP1	L	4.0	83	43	42.0
Early Season					
Bengal	M	3.0	86	36	42.4
Caffey	M	3.0	87	38	43.6
Cheniere	L	3.0	86	37	42.1
CL142-AR	L	5.0	85	44	43.1
CL152	L	3.0	85	38	42.0
CL181-AR	L	1.0	86	35	43.1
Della-2	L	2.0	87	42	42.1
Francis	L	5.0	86	41	43.1
Jazzman	L	3.0	86	42	41.9
Jazzman-2	L	2.0	85	37	41.5
Jupiter	M	3.0	88	37	43.5
Mermentau	L	2.0	84	38	41.5
Rex	L	2.0	83	42	42.1
Wells	L	5.0	85	40	42.8
Mid-Season					
ArizeQM1003	L	5.0	92	43	38.9
Roy J	L	1.0	89	41	42.3
Taggart	L	2.0	88	45	42.2
Templeton	L	4.0	89	43	42.0
Mean		3.4	85	41	42

[a] Grain length: L = long-grain; M = medium-grain.

[b] Relative straw strength based on field tests using the scale: 0 = very strong straw, 5 = very weak straw; based on percent lodging.

[c] Number of days from emergence until 50% of the panicles are visibly emerging from the boot.

Performance Trials at five locations during 2012.

Milling yield	Grain yield by location					
	Clay	NEREC	NRS	PTRS	RREC	Mean
(%HR-%TR)	-------------------------------------	(bu/acre)				---------------------------------------
64-71	211	214	173	202	192	198
62-71	221	180	161	165	170	179
63-71	224	234	207	188	169	204
59-70	177	201	.	178	190	187
59-69	170	209	192	156	172	180
61-70	183	195	169	152	172	174
59-70	253	191	196	183	193	203
57-72	252	164	.	198	206	205
50-70	261	226	205	262	274	246
61-71	273	179	193	209	256	222
57-71	248	239	219	263	260	246
54-70	236	209	207	242	232	225
61-72	227	215	210	207	193	210
61-70	226	209	240	.	189	216
60-69	217	252	148	216	184	203
65-73	198	218	167	179	199	192
51-70	244	216	117	211	179	193
63-71	227	194	159	207	171	192
61-70	213	212	139	211	200	195
61-70	176	175	142	199	218	182
63-72	219	227	192	215	.	213
60-70	174	194	141	106	150	153
63-70	183	187	155	175	151	170
61-68	209	236	200	187	186	204
65-71	212	220	.	218	213	216
63-69	180	228	184	180	206	196
54-71	221	204	155	228	215	205
56-69	112	203	129	179	117	148
64-72	222	212	217	260	257	234
56-71	202	202	185	232	176	199
61-71	177	224	.	197	147	186
60-71	211	209	178	200	195	199

Table 3. Rice cultivar reactions[a]

Cultivar	Sheath blight	Blast	Straight-head	Bacterial panicle blight	Narrow brown leaf spot
ANTONIO	S	MS		MS	
AREXP1	MS	S	MS	S	S
ARIZEQM1003	MS			MR/MS	
BENGAL	MS	S	VS	VS	S
CAFFEY	MS			S	R
CATAHOULA	VS	R	MS	S	MR
CHENIERE	S	VS	VS	VS	S
CL111	VS	MS	S	VS	VS
CL131	VS	MS	VS	VS	VS
CL142-AR	MS	S	MS	S	S
CL181-AR	VS	MS	MS	VS	S
CL151	S	VS	VS	VS	S
CL152	S	S	S	S	R
CL162	VS	S		VS	R
CL261	MS	VS	S	VS	S
COCODRIE	S	S	VS	S	S
COLORADO	S	VS		S	
DELLA-2				S	
FRANCIS	MS	VS	MR	VS	S
JAZZMAN	MS	S	S	MS	S
JAZZMAN-2	VS	MS		VS	MR
JES	S	R	VS	S	R
JUPITER	S	S	S	MR	MS
MERMENTAU	MS	MS	VS	MS	
NEPTUNE	MS	MS	VS	VS	MS
REX	S	S	S	S	MS
ROY J	MS	S	S	S	MR
RT CL XL729	MS	R	MS	MR	MS
RT CL XL745	MS	R	R	MR	MS
RT CL XP756	MS				
RT XL723	MS	R	S	MR	MS
RT XL 753	MS			MR	
RT XP 754	MS				
TAGGART	MS	MS	R	MS	MS
TEMPLETON	MS	R	S	MS	S
WELLS	S	S	S	S	S

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

to diseases (2012).

Stem rot	Kernel smut	False smut	Lodging	Black sheath rot	Sheath Spot
		MS	MS		
S	S	S	MS	MS	S
		S	VS		
VS	MS	MS	MR	MR	
		MS			
S	S	S	MR	S	
S	S	S	MR	MS	
VS	S	S	MS	S	
VS	S	S	MR	S	
S	S	S	S	S	
VS	S	S	MR	VS	
VS	S	S	MR	S	
	VS	S			
	S	S	S		
VS	MS	S	MS	MS	
VS	S	S	MR	S	
		S			
S	VS	S	MS	S	
S	MS	S	MS	MS	
		S			
VS	MS	MS	S	MR	
VS	MS	MS	MS	MR	
		MS	MS		
VS	MS	MS	MR	MR	
S	S	S	MR	S	
S	VS	S	MR	MS	
S	MS	S	S	S	
S	MS	S	S	S	S
		S		S	
S	MS	S	MS	S	
		S		S	
		S		S	S
S	S	S	MS	MS	
MS	S	S	MS	MS	
VS	S	S	MS	MS	

Response of Two Rice Varieties to Midseason Nitrogen Fertilizer Application Timing

R.J. Norman, J.T. Hardke, T.L. Roberts, N.A. Slaton,
D.L. Frizzell, J.M. Wiggins, M.W. Duren, and J.D. Branson

ABSTRACT

A study was conducted in 2012 to examine the influence of midseason nitrogen (N) application timing on the grain yield of conventional, pure-line rice (*Oryza sativa* L.) varieties from Louisiana and Arkansas. The conventional rice varieties chosen for the studies at the Northeast Research and Extension Center (NEREC), Keiser, Ark., and Rice Research and Extension Center (RREC), Stuttgart, Ark., were the Louisiana long-grain, semidwarf, Cheniere and the Arkansas long-grain, short stature, Taggart. The Louisiana long-grain, semidwarf, CL151 was grown at a third site located in a commercial field. Two preflood N rates of 45 and 90 lb N/acre were utilized along with four midseason N application timings. The midseason N rate was 45 lb N/acre and was applied at beginning internode elongation (BIE), BIE + 7 days, BIE + 14 days, and BIE + 21 days. Rice grain yield at the NEREC and RREC significantly increased for both varieties when the preflood N rate was increased from 45 to 90 lb N/acre, much more so for Cheniere than for Taggart. Taggart and Cheniere produced a similar grain yield when 45 lb N/acre was applied preflood, but Cheniere produced a significantly greater yield compared to Taggart when 90 lb N/acre was applied preflood. Application of midseason N at all four application times significantly increased rice grain at the NEREC and RREC. Rice grain yield of CL151, grown in a commercial field, significantly increased as preflood N rate increased, but midseason N applied at any of the four application times did not significantly increase the rice grain of CL151.

INTRODUCTION

Nitrogen fertilizer is applied to dry-seeded, delayed-flood rice in two-split applications for conventional, pure-line rice varieties (Wilson et al., 2001). The first N application is applied onto dry soil, preflood, at beginning tillering and the second N application is applied into the floodwater at midseason between BIE and 0.5-inch internode elongation. The preflood N application is the larger of the two and ranges from 75 to 105 lb N/acre, depending on the variety (Roberts and Wilson, 2012). The midseason N application is 45 lb N/acre for all conventional rice varieties.

It has been almost 15 years since the grain yield response to N application timing at midseason was last studied (Wilson et al., 1998). Consequently, a study was conducted in 2012 to reexamine the influence of midseason N application timing on the grain yield of two conventional, pure-line rice varieties from Louisiana and Arkansas.

PROCEDURES

The study was conducted in 2012 at the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam; at the Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey clay; and at the Winemiller Farm (WMF) near Swifton, Ark., on an Amagon/Forestdale silt loam. The two conventional rice varieties chosen for the study at the RREC and NEREC were the Louisiana long-grain, semidwarf, Cheniere and the Arkansas long-grain, short stature, Taggart. The variety at the WMF was the long-grain, semidwarf, CL151. Two preflood N rates of 45 and 90 lb N/acre where utilized along with four midseason N application timings. The midseason N rate was 45 lb N/acre and was applied at BIE, BIE + 7 days, BIE + 14 days, and BIE + 21 days. There was a check with no midseason N application. The preflood N was applied onto dry soil the day prior to flooding and the midseason N was applied directly into the floodwater.

The rice was drill-seeded, at a rate of 90 lb/acre on the silt loam at the RREC, 80 lb/acre on the silt loam soil at the WMF, and 120 lb/acre on the clay soil at the NEREC, in plots nine rows wide (row spacing of 7 inches), 15 ft in length. At the RREC, the rice was seeded on 25 April, emerged 2 May, the preflood N applied 31 May, and the BIE N application was applied on 21 June. At the NEREC, the rice was seeded on 2 April, emerged 30 April, the preflood N applied 30 May, and the BIE N application was applied on 20 June. At the WMF, the rice was seeded on 27 March, emerged 10 April, the preflood N applied 22 May, and the BIE N application was applied on 12 June. The permanent flood was established 1 to 2 days after the preflood N was applied at all locations when the rice was at the 4- to 5-lf stage and the flood maintained until the rice was mature. At maturity, the center five 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).

The treatments were arranged as a randomized complete block, 2 (variety) × 2 (preflood N rate) × 4 (midseason N application time), factorial design with four replications and a no midseason N application (control) with four replications at the RREC and NEREC. There was no significant influence of location on rice grain yields and therefore grain yields of the two locations, NEREC and RREC, were averaged. The treatments at the WMF, with just the single rice variety, were arranged as a randomized complete block, 2 (preflood N rate) × 4 (midseason N application time), factorial design with four replications and a no midseason N application (control) with four replications. Analysis of variance was performed on the grain yield data utilizing SAS v. 9.1 (SAS Institute, Inc., Cary, N.C.). Differences among means were compared using Fisher's protected least significance difference test at a $P = 0.10$ probability level.

RESULTS AND DISCUSSION

Analysis of variance *P* values for the studies at NEREC and RREC indicated the three-way interaction of variety × preflood N rate × midseason N application time for rice grain yield was not significant and there was no significant two-way interactions of preflood N rate × midseason N application time nor variety × midseason N application time for rice grain yield. However, there was a significant two-way interaction of variety × preflood N rate ($P = 0.0613$) for rice grain yield and a significant effect of midseason N application time ($P = 0.0205$) for rice grain yield. Rice grain yield significantly increased for both varieties when the preflood N rate was increased from 45 to 90 lb N/acre; much more so for Cheniere than for Taggart (Table 1). Taggart and Cheniere produced a similar grain yield when 45 lb N/acre was applied preflood, but Cheniere produced a significantly greater yield compared with Taggart when 90 lb N/acre was applied preflood. Application of midseason N at all four application times significantly increased rice grain at the NEREC and RREC (Table 2). These results have some similarities to results obtained by Wilson et al. (1998), who reported no difference between rice grain yields when the midseason N was applied at BIE compared with at 0.5-inch IE (~BIE + 7 days) and Norman et al. (2012) who reported no difference in the grain yield increase when the midseason N was applied at BIE, BIE + 7 days, and BIE + 14 days in 2011. However, the midseason N only significantly increased rice grain yields in 2011 when the preflood N rate was 45 lb N/acre not when 90 lb N/acre was applied at preflood. Somewhat contradictory, Norman et al. (2012) in 2010 found midseason N applied at 0.5-inch IE did not increase rice grain yields as much as when it was applied at 0.5-inch IE + 7 days and 0.5-inch IE + 14 days.

Analysis of variance *P* values for the study at the WMF indicated the two-way interaction of preflood N rate × midseason N application time for rice grain yield was not significant and there was no significant main effect of midseason N application time for rice grain yield. However, there was a significant main effect of preflood N rate ($P < 0.0001$) for rice grain yield. Rice grain yield at the WMF significantly increased as preflood N rate increased (Table 3), but there was no significant increase in rice grain when midseason N was applied at any of the four application times at the WMF (Table 4).

SIGNIFICANCE OF FINDINGS

These first year results indicate that the rice varieties currently being grown do not always respond to midseason N and that when they do the midseason N application window may be wider than previously thought. Midseason N applied at the WMF location had no significant effect on rice grain yield; whereas, at the NEREC and RREC, midseason N applied from BIE to BIE + 3 weeks significantly increased rice grain yield. This study needs to be repeated at other locations and with more of the currently grown rice varieties before a recommendation can be made on the need for midseason N and the best time to apply midseason N.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board.

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.

Roberts, T.L. and C.E. Wilson Jr. 2012. University of Arkansas Cooperative Extension Service. 2012 Recommended Nitrogen Rates and distribution for rice varieties in Arkansas. Available online at http://www.aragriculture.org/crops/rice/Publications/nratetable2012.pdf Accessed 14 Jan 2013.

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.

Wilson, C.E., Jr., N.A. Slaton, R.J. Norman, and D.M. Miller. 2001. Efficient use of fertilizer. *In:* N.A. Slaton (ed.). Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service MP192.

Table 1. Influence of cultivar, and preflood nitrogen (N) application rate, averaged across the Northeast Research and Extension Center, Keiser, Ark., and the Rice Research and Extension Center, Stuttgart, Ark., locations, on rice grain yield during 2012.

	Preflood N rate	
Cultivar	45 lb N/acre	90 lb N/acre
	----------------(bu/acre) --------------	
Cheniere	181	206
Taggart	180	193
LSD$_{(\alpha = 0.10)}$[a]	7.4	
C.V.	10.5	

[a] LSD = least significant difference, C.V. = coefficient of variation.

Table 2. Influence of mid-season nitrogen (N) application timing, averaged across the Northeast Research and Extension Center, Keiser, Ark., and the Rice Research and Extension Center, Stuttgart, Ark., locations, preflood N rates, and varieties, on rice grain yield during 2012.

Mid-season N timing	Grain yield
(45 lb N/acre)	(bu/acre)
No MS N	181
BIE[a]	194
BIE+7 days	190
BIE+14 days	193
BIE+21 days	194
LSD$_{(\alpha = 0.10)}$[b]	8.3
C.V.	10.5

[a] BIE - beginning internode elongation.

[b] LSD = least significant difference, C.V. = coefficient of variation.

Table 3. Influence of preflood nitrogen (N) rate on rice grain yield at Winemiller Farms, near Swifton, Ark., during 2012.

Preflood N rate	Grain yield
(lb N/acre)	(bu/acre)
0	112
45	136
90	148
LSD$_{(\alpha = 0.10)}$[a] 4.1	
C.V.	5.4

[a] LSD = least significant difference, C.V. = coefficient of variation.

Table 4. Influence of preflood nitrogen (N) rate and midseason nitrogen (N) application timing on rice grain yield at Winemiller Farms, near Swifton, Ark., during 2012.

	Mid-season N timing				
Preflood N rate	No mid-season N	BIE[a]	BIE+7 days	BIE+14 days	BIE+21 days
(lb N/acre)	(bu/acre)				
45	136	137	138	137	132
90	151	148	149	144	147
LSD$_{(\alpha = 0.10)}$[c]	NS[b]				
C.V.	5.4				

[a] BIE = beginning internode elongation.

[b] NS = not significant at the *P* < 0.1000 probability level.

[c] LSD = least significant difference, C.V. = coefficient of variation.

Grain Yield Response of Ten New Rice Cultivars to Nitrogen Fertilization

R.J. Norman, T.L Roberts, J.T. Hardke, N.A. Slaton,
K.A.K. Moldenhauer, D.L. Frizzell, M.W. Duren, and J.D. Branson

ABSTRACT

The Variety × Nitrogen (N) Fertilizer Rate Study determines the proper N fertilizer rates for the new rice varieties across the array of soil and climatic conditions which exist in the Arkansas rice-growing region. The ten rice varieties studied in 2012 were: Antonio, Caffey, Colorado, Della2, Jazzman2, Mermentau, Rex, Horizon Ag's CL152, Bayer CropScience's hybrid BCS01H10010, and Arkansas experimental line AREXP1. Grain yields at all locations were higher than the last 2 years even though we still had an atypically hot summer, but the warm, dry spring allowed us to plant all locations between 2 and 11 April. Antonio, Colorado, Della2, Mermentau, BCS01H10010, and AREXP1 were in the Variety × N Fertilizer Rate Study for the first time and thus there is not enough data to give a recommendation at this time. The remaining four varieties have been in the study for multiple years and a recommendation can be made. The most prudent N fertilizer recommendation for Caffey and Jazzman2 to maximize grain yield and minimize lodging when grown on most silt loam soils would be to apply 135 lb N/acre in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason; and when grown on clay soils the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre. Rex and CL152 should maximize yield on most silt loam soils when 150 lb N/acre is applied in a two-way split application of 105 lb N/acre at preflood followed by 45 lb N/acre at midseason. When grown on clay soils, the preflood N rate for Rex and CL152 should be increased by 30 lb N/acre to 135 lb N/acre.

INTRODUCTION

The Variety × N Fertilizer Rate Study measures the grain yield performance of the new rice varieties over a range of N fertilizer rates on representative clay and silt loam soils and determines the proper N fertilizer rates to maximize yield on these soils under the climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, Louisiana, Mississippi, and Texas as well as those from private industry are evaluated in this study. Ten new rice varieties were entered and studied in 2012 at three locations as follow: Antonio and Colorado were entered by Texas and they both are long-grain, semidwarf varieties; Louisiana entered the new semidwarf, long-grain Mermentau, the semidwarf, medium-grain variety Caffey, and the aromatic, long-grain rice varieties Della2 and Jazzman2; Mississippi entered the new standard stature, long-grain variety Rex; Bayer CropScience entered the new long-grain, hybrid BCS01H10010; Horizon AG entered the Clearfield semidwarf, long-grain variety CL152 in cooperation with Louisiana, and Arkansas entered the standard stature, long-grain experimental line AREXP1. Clearfield rice varieties are tolerant to the broad spectrum herbicide imazethapyr (Newpath).

PROCEDURES

Locations where the Variety × N Fertilizer Rate Study were conducted and corresponding soil series are as follows: Northeast Research and Extension Center (NEREC), Keiser, Ark, on a Sharkey clay (Vertic Haplaquepts); Pine Tree Research Station (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 all the rice varieties studied was a randomized complete block with four replications. A single preflood N fertilizer application was utilized for all varieties, except the Bayer hybrid BCS01H10010. The preflood N fertilizer was applied as urea onto a dry soil surface at 4- to 5-lf 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. The reasoning behind this is that rice usually requires about 30 lb N/acre more N fertilizer to maximize grain yield when grown on clay soils compared to the silt loams. The Bayer CropScience hybrid BCS01H10010 had the N fertilizer applied in a two-way split application scheme at preflood and late-boot (BT) in the following total N (preflood N + BT N) rate splits: 0 (0 + 0), 60 (30 + 30), 90 (60 + 30), 120 (90 + 30), 150 (120 + 30), 180 (150 + 30), and 210 (180 + 30) lb N/acre. All of the rice varieties, except Bayer hybrid BCS01H10010, were drill-seeded on the silt loams and clay soil at rates of 90 and 120 lb/acre, respectively, in plots nine-rows wide (row spacing of 7 inches), 15 ft. in length. The Bayer hybrid BCS01H10010 was drill-seeded on both the silt loam and clay soils at a rate of 30 lb/acre. Pertinent agronomic dates at each location in 2012 are shown in Table 1. The studies were flooded at each location when the rice was at the 4- to 5-lf stage and within 2 days of preflood N fertilization. The studies remained flooded until the rice was mature. At maturity, the center five 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 (SAS Institute, Inc., Cary, N.C.) and mean separations were based upon protected least significant difference test ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

A single preflood N application method was adopted in 2008 in all Variety × N Fertilizer Rate Studies due to the rising cost of N fertilizer and the preference of the short stature and semidwarf rice plant types currently being grown. The currently grown rice varieties reach a maximum yield with less N when the N is applied in a single preflood application compared to a two-way split. Typically, the rice varieties require 20 to 30 lb N/acre less when the N is applied in a single preflood application compared to two-split applications where the first split is applied preflood and the second split is applied between beginning internode elongation and 0.5 inch 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. With the rising costs of N fertilizer, growers should consider the single, optimum preflood N application method. 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-inch flood depth is maintained for at least 3 weeks following flood establishment.

In most years, the silt loam soil at the RREC has the largest amount of plant-available N, followed by the silt loam soil at the PTRS and then the clay soil at the NEREC. Thus, most rice varieties require a lower N fertilizer rate to maximize grain yield at the RREC compared to at the PTRS or NEREC, and usually a little less at the PTRS than at the NEREC. Pertinent agronomic information such as planting dates and flood dates are shown in Table 1. Hurricane Isaac came through Arkansas on 29 and 30 August causing some lodging of most of the rice varieties at the NEREC, but the PTRS and RREC were all harvested before the hurricane so any lodging at these locations was not from the hurricane. There was some stinkbug pressure at the RREC which necessitated two insecticide (Karate) applications. Although the summer was another hot one, rice yields were excellent for most rice varieties due to a warm, dry, spring which allowed planting at all locations between 2 and 11 April.

Antonio did not significantly increase in yield on the clay soil at the NEREC when more than 120 lb N/acre was applied preflood (Table 2). Antonio had a maximum grain yield of 212 bu/acre at the NEREC when 150 lb N/acre was applied preflood, but displayed some lodging at this N rate. When the N rate was increased to 180 or 210 lb N/acre at the NEREC, lodging increased and grain yield decreased. Antonio did not significantly increase in grain yield on the silt loam soils at the PTRS and RREC when more than 90 lb N/acre was applied preflood. The grain yields of Antonio reached a maximum of 208 bu/acre at the PTRS when 150 lb N/acre was applied preflood and 219 bu/acre at the RREC when 120 lb N/acre was applied. Antonio displayed good yield stability over a 60 lb N/acre wide range. This was the first year Antonio was in the Variety × N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

Caffey yielded over 200 bu/acre and did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood on the clay soil at the NEREC and the silt loam soil at the PTRS (Table 3). Caffey obtained maximum yields of 203 and 219 bu/acre at the NEREC and PTRS when 150 lb N/acre was applied preflood. Caffey obtained a grain yield of 220 bu/acre when only 60 lb N/acre was applied preflood on the silt loam soil at the RREC. Caffey reached a maximum grain yield of 234 bu/acre at the RREC when 120 lb N/acre was applied preflood. Caffey displayed good yield stability over a 90 lb N/acre wide N rate range at the PTRS and RREC with no lodging. The hurricane did cause Caffey to have some lodging and a decrease in grain yield at the NEREC when the N rate exceeded 90 lb N/acre. As shown in 2011 (Norman et al., 2012), Caffey is prone to some lodging when the N rate gets too high, like some other varieties. Results from 2011 and 2012 indicate Caffey should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils; and when grown on clay soils, the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

Colorado had extensive lodging at the NEREC in 2012, undoubtedly to some degree the result of the hurricane (Table 4). Lodging (58%) was evident at the NEREC when the lowest N rate of 90 lb N/acre was applied and increased to 100% when 150 lb N/acre or more was applied preflood. Colorado, due to the lodging, did not significantly increase in yield on the clay soil at NEREC when more than 90 lb N/acre was applied preflood and maximized yield at 200 bu/acre when 120 lb N/acre was applied preflood. Colorado obtained a maximum yield of 178 bu/acre on the silt loam soil at the PTRS when 120 lb N/acre was applied preflood and maintained this yield with no lodging when up to 180 N/acre was applied. Colorado obtained a peak yield of 206 bu/acre when only 60 lb N/acre was applied preflood at the RREC, but was only able to maintain this yield up to the 90 lb N/acre rate. Lodging of Colorado began and yields decreased at the RREC when 120 lb N/acre was applied preflood. The yield decrease of Colorado as N rate increased above 120 lb N/acre does not appear to be due to just lodging, but also perhaps mutual shading and/or possibly sterility. This was the first year Colorado was in the Variety × N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

Della2 did not significantly increase in grain yield when more than 150 lb N/acre (165 bu/acre) was applied preflood on the clay soil at the NEREC and did not significantly decrease in yield when up to 210 lb N/acre was applied preflood (Table 5). Della2 obtained a peak yield of 179 bu/acre when 120 lb N/acre was applied preflood on the silt loam soil at the PTRS and was able to maintain this yield when up to 180 lb N/acre was applied preflood. Della2 did not significantly increase in grain yield when more than 90 lb N/acre was applied preflood at the PTRS. Similarly, Della2 did not significantly increase in grain yield on the silt loam soil at the RREC when more than 90 lb N/acre was applied preflood and was able to maintain this yield when up to 180 bu/acre was applied. Della2 obtain its highest yield in 2012 at the RREC with a peak yield of 197 bu/acre and did not experience lodging at any of the locations. This was the first year Della2 was in the Variety × N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

Jazzman2 achieved a maximum grain yield of 203 bu/acre on the clay soil at the NEREC when 120 lb N/acre was applied preflood (Table 6). Jazzman2 was able to maintain a yield of about 200 bu/acre at the NEREC when up to 180 lb N/acre was applied preflood, but did display some lodging. Jazzman2 did not significantly increase in yield when more than 120 lb N/acre was applied preflood on the silt loam at the PTRS and obtained maximum grain yields of 182 and 183 bu/acre when 150 and 180 lb N/acre were applied preflood, respectively. JazzMan2 obtained maximum yields of 195 and 196 bu/acre when only 60 and 90 lb N/acre were applied preflood, respectively, on the silt loam soil at the RREC. Grain yields of Jazzman2 appeared to start to decrease at the RREC when the preflood N rate was increased to 120 lb N/acre; and then the yields significantly decreased and lodging was observed when the N rate was increased further. Results from 2011 (Norman et al., 2012) and 2012 indicate Jazzman2 should require an N rate of 135 lb N/acre applied in a two-way split application of 90 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils; and when grown on clay soils, the preflood N rate should be increased by 30 lb N/acre to 120 lb N/acre.

Mermentau displayed high and stable grain yields of 208 to 224 bu/acre at the NEREC when 120 to 210 lb N/acre were applied preflood (Table 7). Mermentau obtained a maximum grain yield of 210 bu/acre when 120 lb N/acre was applied preflood on the silt loam soil at the PTRS and did not significantly increase or decrease in grain yield when more N fertilizer was applied. Mermentau achieved a maximum grain yield of 226 bu/acre on the silt loam soil at the RREC when 90 lb N/acre was applied preflood. Mermentau had a very stable grain yield at the RREC when 60 to 180 lb N/acre was applied preflood with no lodging. Mermentau appears to have very stable grain yield over a wide N fertilizer range at all three locations at which it was studied in 2012. This was the first year Mermentau was in the Variety × N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

Rex achieved grain yields over 200 bu/acre at the NEREC when 120 to 180 lb N/acre were applied preflood and did not display any lodging until 210 lb N/acre was applied to this clay soil (Table 8). Rex had a maximum grain yield of 200 bu/acre on the silt loam soil at the PTRS when 120 lb N/acre was applied preflood and did not significantly increase or decrease in grain yield when more N fertilizer was applied or display any lodging. Rex achieved grain yields of 194 to 205 bu/acre on the silt loam at the RREC with no lodging when 90 to 180 lb N/acre were applied preflood, respectively. Grain yields of Rex did not significantly increase at the PTRS and RREC when more than120 and 90 lb N/acre were applied preflood, respectively. The results from 2010 (Norman et al., 2011), 2011 (Norman et al., 2012), and 2012 indicate Rex should require an N rate of 150 lb N/acre applied in a two-way split application of 105 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils. The total N rate should be increased to 180 lb N/acre applied in a two-way split application of 135 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most clay soils.

Clearfield 152 obtained a maximum grain yield of 200 bu/acre on the clay soil at NEREC when 150 lb N/acre was applied preflood (Table 9). Clearfield 152 was able to maintain a stable grain yield at the NEREC when 120 to 180 lb N/acre were applied preflood. There was some lodging of CL152 at the NEREC, at least partially due to the hurricane; and it steadily increased from 5% when 120 lb N/acre was applied to around 70% when 180 to 210 lb N/acre was applied preflood. A peak grain yield of 217 bu/acre was achieved by CL152 on the silt loam soil at PTRS when 150 lb N/acre was applied preflood, although CL152 did not significantly increase in yield when more than 120 lb N/acre was applied preflood. Clearfield 152 displayed a stable grain yield of over 200 bu/acre when 90 to 180 lb N/acre was applied preflood at this location with no evidence of lodging. The silt loam soil at the RREC has a higher native soil N concentration than at the PTRS and thus CL152 reached a maximum yield of 217 bu/acre at a lower N rate of 90 lb N/acre. CL152 had a stable and statistically similar grain yield when 60 to 120 lb N/acre was applied preflood at the RREC without any lodging. However, when the N rate was increased to 150 and 180 lb N/acre, lodging increased and grain yield significantly decreased. After 2 years of study, it appears CL152 will require 150 lb N/acre applied in a two-way split application of 105 lb N/acre at preflood and 45 lb N/acre at midseason when grown on most silt loam soils and 180 lb N/acre applied in a two-way split of 135 lb N/acre preflood and 45 lb N/acre at midseason when grown on a clay soils.

The hybrid BCS01H10010 reached a maximum grain yield of 172 bu/acre on the clay soil at NEREC when only 60 lb N/acre was applied preflood (Table 10). Considerable lodging (75%) of BCS01H10010 was observed when only 60 lb N/acre was applied and this was at least partially due to the hurricane. When the N rate was increased to 90 lb N/acre preflood, the yield did not decrease but the lodging did increase to 100%. Lodging of BCS01H10010 stayed at 100% as the preflood N rate was increased from 120 to 180 lb N/acre and resulted in a substantial decrease in grain yield. Bayer CropScience 01H10010 achieved maximum yields of 200 and 190 bu/acre when grown on the silt loam soils at PTRS and RREC, respectively. Lodging was not a problem for BCS01H10010 at the PTRS and yields steadily increased as the preflood N rate increased up to 90 lb N/acre; however, yields did not significantly increase when more than 60 lb N/acre was applied preflood. An increase in the preflood N rate from 90 to 120 lb N/acre and then from 120 to 150 lb N/acre at the PTRS resulted in a significant decrease in yield to 183 and 164 bu/acre, respectively, without any lodging to explain the yield decrease. Thus, mutual shading and/or sterility may have been the cause(s) of the yield decrease. Lodging of BCS01H10010 was observed on the silt loam soil with the higher native N at the RREC. The yield of BCS01H10010 maximized when only 30 lb N/acre was applied preflood and minimal lodging of 25% was observed. Yields of BCS01H10010 steadily decreased and lodging generally increased at the RREC as the preflood N rate was increased from 30 to 150 lb N/acre. This was the first year of testing of the BCS01H10010 hybrid and thus no firm conclusions can be drawn on the proper N rate to maximize yields and minimize lodging.

The Arkansas experimental rice line AREXP1 reached maximum grain yields of 210 and 226 bu/acre when 120 lb N/acre were applied preflood at the NEREC and PTRS (Table 11). The grain yield of AREXP1 did not significantly increase when more than 120 lb N/acre was applied preflood at either location, but yields were steady as the N rate was increased to 180 lb N/acre at PTRS, but not at the NEREC. Arkansas Experimental 1 displayed a steady decrease in yield at the NEREC as the N rate was increased from 120 to 210 lb N/acre due to lodging from the hurricane. The yield of AREXP1 reached 236 bu/acre when 90 lb N/acre was applied preflood at the RREC and did not significantly increase when the N rate was increased. Arkansas Experimental 1 obtained a grain yield of >200 bu/acre at the RREC over a preflood N rate range of 90 to 150 lb N/acre. However, lodging began when 150 lb N/acre was applied preflood and a significant yield decrease from 238 to 209 bu/acre was measured. Lodging increased further when the preflood N rate was increased to 180 lb N/acre. This was the first year AREXP1 was in the Variety × N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

The Wells rice variety was included in the study as a control and to give a frame of reference for comparing the grain yield performance and lodging percentage of the new varieties over the N fertilizer rates applied at the three locations (Table 12).

SIGNIFICANCE OF FINDINGS

The Variety × N Fertilizer Rate Study examines the grain yield performance of a new rice variety across a range of N fertilizer rates on representative soils and under climatic conditions that exist in the Arkansas rice-growing region. Thus, this study is able to determine the proper N fertilizer rate for a variety to achieve maximum grain yield when grown commercially on most soils in the Arkansas rice-growing region. The ten rice varieties studied in 2012 were: Antonio, Caffey, Colorado, Della2, Jazzman2; Mermentau, Rex; Horizon Ag's CL152; Bayer CropScience's hybrid BCS01H10010; and Arkansas experimental line AREXP1. The data generated from multiple years of testing of each variety will be used to determine the proper N fertilizer rate for a variety to achieve maximum yield when grown commercially on most silt loam and clay soils in Arkansas.

ACKNOWLEDGMENTS

This research was supported primarily by the Arkansas Rice Research and Promotion Board, and supported in part by Horizon AG and Bayer CropScience.

LITERATURE CITED

Norman, R.J., T.L. Roberts, C.E. Wilson Jr., N.A. Slaton, D.L. Frizzell, J.D. Branson, M.W. Duren, K.A.K. Moldenhauer, and J.W. Gibbons. 2011. Grain yield response of nine new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and K.A.K.

Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:208-218. Fayetteville.

Norman, R.J., T.L. Roberts, C.E. Wilson Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Frizzell, J.D. Branson, and M.W. Duren. 2012. Grain yield response of twelve new rice cultivars to nitrogen fertilization. *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 600:220-234. Fayetteville.

Table 1. Pertinent agronomic information for the 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 2012.

Practices	NEREC	PTRS	RREC
Preplant fertilizers	100 lb/acre DAP/acre	400 lb/acre 0-23-30 30 lb/acre $ZnSO_4$	200 lb/acre 0-20-30 +
Planting dates	2 April	11 April	5 April
Emergence dates	30 April	18 April	15 April
Herbicide spray dates and procedures	3 April 1.4 pt/acre Command + 0.6 lb/acre Facet 0.3 lb/acre Facet	19 April 3 qt/acre Stam + 2 pt/acre Prowl H_20 +	11 April 0.5 pt/acre Command + + 0.5 lb/acre Facet
Herbicide spray dates and procedures	28 May 4qt/acre Propanil	3 May 0.75 oz/acre Permit	10 May 20 oz/acre RiceStar HT
Herbicide spray dates and procedures		16 May 3 qt/acre Stam + 1 qt/acre Bolero	14 May 1 oz/acre Permit
Preflood N dates	30 May	22 May	16 May
Flood dates	1 June	23 May	17 May
Insecticide spray dates and procedures			11 August 3 oz/acre Karate
Insecticide spray dates and procedures			25 August 3 oz/acre Karate
Harvest dates	11 September	28 August	22 August

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Antonio rice at three locations during 2012.

N fertilizer rate	Grain yield		
	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	90	80	127
60	----	165	199
90	184	198	200
120	204	197	219
150	212 ^{18b}	208	212
180	200 ^{70}	197	212
210	179 ^{45}	----	-----
$LSD_{(\alpha = 0.05)}$[c]	11.9	10.2	21.1
C.V. (%)	4.4	3.9	7.1

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Caffey rice at three locations during 2012.

N fertilizer rate	Grain yield		
	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	108	95	160
60	----	183	220
90	202	205	227
120	206 ^{65b}	219	234
150	198 ^{90}	216	232
180	129 ^{100}	214	227
210	111 ^{98}	----	-----
$LSD_{(\alpha = 0.05)}$[c]	21.5	16.2	23.9
C.V. (%)	9.0	5.7	7.3

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of Colorado rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)		(bu/acre)	
0	86	78	136
60	----	151	206
90	183 ^{58}[b]	165	202
120	200 ^{93}	178	157 ^{48}
150	175 ^{100}	177	134 ^{45}
180	164 ^{100}	176	116 ^{23}
210	155 ^{100}	----	----
LSD$_{(\alpha = 0.05)}$[c]	37.5	12.5	25.2
C.V. (%)	15.5	5.4	10.6

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Della2 rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)		(bu/acre)	
0	77	86	124
60	----	153	185
90	137	169	193
120	157	179	195
150	165	179	197
180	171	177	191
210	168	----	----
LSD$_{(\alpha = 0.05)}$[b]	11.1	18.3	11.3
C.V. (%)	5.1	7.7	4.1

[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.V. = coefficient of variation.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of JazzMan2 rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	91	71	150
60	----	144	195
90	186	163	196
120	203	175	182
150	202	182	152
180	197 ^{15b}	183	124 ^{40}
210	188 ^{3}	----	----
LSD$_{(\alpha = 0.05)}$[c]	11.9	15.8	18.9
C.V. (%)	4.2	6.9	7.5

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of Mermentau rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	(bu/acre)		
0	88	88	137
60	----	173	214
90	183	198	226
120	208	210	223
150	212	205	219
180	214	197	206
210	224	----	----
LSD$_{(\alpha = 0.05)}$[b]	24.4	5.7	10.8
C.V. (%)	8.6	2.1	3.5

[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.V. = coefficient of variation.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of Rex rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	---------------	(bu/acre)	---------------
0	125 ^{20}[b]	90	132
60	----	155	183
90	175	171	194
120	202	200	197
150	216	196	205
180	224	200	201
210	191 ^{35}	----	----
LSD$_{(\alpha = 0.05)}$[c]	56.0	13.6	31.7
C.V. (%)	19.7	5.4	11.4

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield CL152 rice at three locations during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	---------------	(bu/acre)	---------------
0	74	102	134
60	----	180	207
90	170	201	217
120	192^{5}[b]	209	214
150	200^{35}	217	176^{23}
180	195^{70}	210	160^{38}
210	184^{68}	----	----
LSD$_{(\alpha = 0.05)}$[c]	12.7	9.1	18.9
C.V. (%)	5.0	3.2	6.8

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of experimental line BCS01H10010 rice at three locations in Arkansas during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------	(bu/acre)	----------------
0	111	94	161
30 + 30	----	151	190 ^{25}[b]
60 + 30	172 ^{75}	188	178 ^{38}
90 + 30	169 ^{100}	200	143 ^{73}
120 + 30	118 ^{100}	182	124 ^{95}
150 + 30	98 ^{100}	164	118 ^{85}
180 + 30	86 ^{100}	----	----
LSD$_{(\alpha = 0.05)}$[c]	53.2	13.2	54.0 (NS)
LSD$_{(\alpha = 0.10)}$	43.7	10.8	44.4
C.V. (%)	28.1	5.3	23.3

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 11. Influence of nitrogen (N) fertilizer rate on the grain yield of experimental line AREXP1 rice at three locations in Arkansas during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------	(bu/acre)	----------------
0	84	108	148
60	----	187	214
90	171 ^{25}[b]	207	236
120	210 ^{100}	226	238
150	188 ^{100}	222	209 ^{10}
180	160 ^{100}	221	165 ^{60}
210	170 ^{100}	----	----
LSD$_{(\alpha = 0.05)}$[c]	28.3	15.2	22.7
C.V. (%)	11.5	5.2	7.5

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Table 12. Influence of nitrogen (N) fertilizer rate on the grain yield of Wells rice at three locations in Arkansas during 2012.

	Grain yield		
N fertilizer rate	NEREC[a]	PTRS	RREC
(lb N/acre)	----------------------------	(bu/acre)	----------------------------
0	81	79	151
60	----	149	223
90	161	175	226
120	192	187	231
150	205 ^{3b}	187	219
180	215	185	206
210	210 ^{25}	----	----
$\mathrm{LSD}_{(\alpha = 0.05)}$[c]	14.9	12.7	16.8
C.V. (%)	5.6	5.2	5.3

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

[c] LSD = least significant difference, C.V. = coefficient of variation.

Main Crop and Ratoon Crop Grain Yield Response of the Rice Cultivars CL111, RTCLXL745, RTXP4523, and RTCLXP4534

T.L. Roberts, R.J. Norman, N.A. Slaton, J. Shafer, C.E. Greub,
A.M. Fulford, S.M. Williamson, D.L. Frizzell, and S. Clark

ABSTRACT

Warm autumns and new rice cultivars with shorter relative maturities have increased interest in the potential of ratooning rice crops in Arkansas. This study was designed to identify how main crop nitrogen (N) rates and ratoon crop N rates influenced the ratoon crop yield of the rice cultivars CL111, RTCLXL745, RTXP4523, and RTCLXP4534. Main crop N rate treatments included a standard preflood N rate of 120 lb N/acre and a treatment based on the Nitrogen-Soil Test for Rice (N-ST*R), optimum N rate recommendation which was 150 lb N/acre. Rice stubble height was kept as tall as possible to try and reduce the amount of time required for ratoon crop maturity and ranged from 15.4 to 21.5 inches. The ratoon crop rice yields of CLXL745 and XP4523 were significantly influenced by ratoon crop N rate and resulted in ratoon crop yields as high as 36 bu/acre. Ratoon rice yields of CLXP4534 were significantly influenced by main crop N rate and were significantly higher when the N-ST*R nitrogen rate was used to fertilize the main crop. Clearfield 111 ratoon crop yield was not significantly influenced by any of the factors considered in this trial and averaged 7 bu/acre regardless of main crop or ratoon crop N rate. These results indicate that hybrid rice cultivars are suitable for ratoon rice production in Arkansas and that 0 to 45 lb N/acre is optimal to maximize yield and increase the potential for ratoon crop maturity prior to the first frost.

INTRODUCTION

For the past 3 years, the Arkansas Delta region has experienced unusually warm falls that extend well into November, and many rice producers south of Interstate 40 have been successfully ratooning rice crops that were planted prior to 15 April. Little research has been done in Arkansas to address the potential of ratooning our current rice cultivars and the N rates required to maximize the yield potential of both the main and ratoon crops. Interest in potential ratoon rice crops in Arkansas have been fueled by RiceTec Corporation's recent hybrid cultivar developments with significantly shorter relative maturity dates. The purpose of this study was to identify the influence of preflood N and ratoon N rates on the main crop and ratoon crop rice grain yields of the rice cultivars CL111, RTCLXL745, RTXP4523, and RTCLXP4534.

PROCEDURES

The location chosen for this study was the Pine Tree Research Station (PTRS) near Colt, Ark. The soil series at this location was a Calhoun silt loam and has been identified as a site low in native N site using the Nitrogen-Soil Test for Rice (N-ST*R). The experimental design was a randomized complete block with four replications. The N fertilizer was applied as prilled-urea (45% N) in a single application at preflood (i.e., at the 4- to 5-lf growth stage). The N fertilizer rates for preflood N applications were the standard N recommendation for silt loams soils, which is 120 lb N/acre, and another based on the N-ST*R optimum N rate, which was 150 lb N/acre and determined by the procedure outlined by Roberts et al. (2011).

The rice was drill-seeded at a rate of 80 lb seed/acre for pure-line rice cultivars and 25 lb seed/acre for hybrids in plots 9 rows wide (row spacing of 7 inches) and 15 ft in length. Plots were established 3 April 2012 and emerged 12 April 2012. Plots were flooded when the rice was at the 4- to 5-lf stage (9 May 2012) and remained flooded until the rice was mature. The preflood N application was applied onto dry soil within 2 days before permanent flooding. At maturity, the center 7 rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bushel (bu)/acre at 12% moisture (a bu weighs 45 lb). Following main crop harvest (14 August 2012), border rows were also cut so that plots had a uniform stubble height. Combine header height during main crop harvest varied based on variety, but was left as high as possible to allow adequate ratoon crop regrowth. Immediately following main crop harvest, plots were fertilized with either 0, 45, or 90 lb N/acre and a shallow flood was established. Ratoon crop was harvested 1 November, 2012. Statistical analyses were conducted with SAS (SAS Institute, Inc., Cary, N.C.) and mean separations were based upon Fisher's protected least significant difference tests ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The purpose of this study was to determine the optimum ratoon N rates for newly developed and recently released rice cultivars commonly grown in Arkansas. Traditionally rice is not ratooned in Arkansas because the risk far outweighs the reward due to the relatively short amount of time from main crop harvest to the first hard freeze of the fall. The addition of N to the ratoon crop can delay the maturity of the ratooned rice, which typically requires 90 days of frost-free weather; and the later the main crop is harvested following 15 August, the less N should be applied (Saichuk et al., 2012; Way and McCauley, 2012). Another important aspect is stubble management. Research from Texas has shown that reducing stubble height will generally result in higher ratoon rice yields, but it also requires a longer growing period in order to produce a ratoon crop (Way and McCauley, 2012). Therefore typical recommendations for Arkansas suggest that the main crop is harvested with the tallest possible stubble height to promote regrowth of the ratoon crop and shorter amount of time to ratoon crop maturity. It should be noted that the varieties Wells and CL151 were also included in this study, but never produced a panicle during the ratoon portion of the study and were not harvested. Therefore these varieties were excluded from this report since there was not a ratoon crop to harvest.

Stubble height was quantified following main crop harvest and there was no significant influence of main crop N rate on stubble height, with cultivar being the only significant factor influencing main crop stubble height. The cultivar CLXL745 had significantly taller stubble height than all other cultivars, with a mean of 21.5 inches. Clearfield 111 stubble height was significantly lower than CLXL745, but was significantly greater than both XP4523 and CLXP4534, with a mean of 17.1 inches. The two experimental cultivars XP4523 and CLXP4534 had the lowest stubble height and were statistically shorter than both CLXL745 and CL111, but were not different than one another. While the header height was kept just below the panicle for all varieties to maximize harvest efficiency and stubble height, XP4523 and CLXP4534 were visibly shorter throughout the growing season and had a mean stubble height of 15.4 inches following main crop harvest.

Analysis of variance for ratoon crop rice yield was completed with the main plot factors represented by main crop N rate (MCN) and ratoon crop N rate (RCN) and their interaction (Table 1). For the rice cultivars CLXL745 and XP4523, RCN rate was the factor that significantly influenced ratoon crop yield. Clearfield XL745 had the highest overall ratoon crop rice yield and ranged from 17.4 to 35.4 bu/acre, with the RCN of 45 lb N/acre rate resulting in the highest ratoon crop yield (Table 2). The yield trend for CLXL745 showed an increase in rice yield when the RCN was increased from 0 to 45 lb N/acre, but a decrease in rice yield when the RCN was increased from 45 to 90 lb N /acre. These results suggest that 45 lb N/acre is the optimum N rate required to maximize ratoon crop rice yield for the cultivar CLXL745. Although the rice yield of XP4523 was significantly influenced by RCN, the trend in the data was much different.

The ratoon crop rice yield for XP4523 continued to increase with increased RCN, resulting in the highest ratoon crop rice yield when 90 lb N/acrewas applied (Table 2). RiceTec XP4523 achieved the highest yield of 30 bu/acre when 90 lb N/acre was applied, but was not significantly different than the yield when 45 lb N/acre was applied suggesting that a RCN of 45 lb N/acre should be considered since it is not statistically different and is a significantly lower N rate.

The yield of the ratoon crop for the cultivar CLXP4534 was not significantly influenced by RCN, but was significantly influenced by MCN (Table 1) with the N-ST*R main crop N rates resulting in significantly higher ratoon crop yields than where the standard N rate recommendation was used (Table 3). When the N-ST*R nitrogen rate was used for CLXP4534, the main crop yield and the ratoon crop yield were significantly higher than when the standard N rate of 150 lb N/acre was used.

For the rice cultivar CL111, there was no significant influence of any main plot factors or their interactions on ratoon crop rice yield (Table 1). The average ratoon rice yield for CL111 was 7 bu/acre with a range of 6 to 8 bu/acre (Table 2). Although the main crop yield of CL111 was not as high as the other varieties, it still performed well (>178 bu/acre) and there were no visible complications or reasons for poor ratoon rice yields. This variety is routinely planted with the intention of producing a ratoon crop in areas such as Louisiana, but did not perform well in this particular study.

SIGNIFICANCE OF FINDINGS

In the past 4 years "unusual weather patterns" have become the new norm, with record floods followed by record droughts. Warm autumns and the introduction of new rice cultivars with significantly shorter relative maturities have prompted rice producers to gain more interest in the possibility of producing ratoon rice crops. These results indicate that the hybrid rice cultivars are a viable option for producers who are interested in ratooning rice in Arkansas, even north of I-40. All three of the hybrid rice cultivars performed well in this trial, but the ratoon crop rice yield was significantly influenced by different factors indicating that more data is required to draw conclusions on developing new guidelines for producing ratoon crops in Arkansas. The ratoon rice yield of the hybrid cultivars ranged from 14 bu/acre when no N was applied to a maximum of 36 bu/acre. Based on the limited results of this study at a single location, it appears that the highest total rice yields were achieved when N-ST*R was used to determine the MCN and the RCN was 45 lb N/acre. Additional research is also warranted as the performance of CL111 in this trial was not indicative of performance it has achieved in other trials. Clearfield 111 is recommended for fields that are intended for ratoon rice crop production in other states and should be suitable for Arkansas producers as well.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board, Horizon Ag, and RiceTec Inc. Appreciation is also expressed to Horizon Ag and RiceTec Inc. for supplying the seed to conduct this study as well as the Experiment station and hourly personnel that help manage and conduct this research.

LITERATURE CITED

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.

Saichuk, J., D. Harrell, K. Fontenot, D. Groth, C. Hollier, N Hummel, S. Linscombe, X. Sha, M. Stout. E. Webster, and L. White. 2012. Rice Varieties and Management Tips. Pub. 2270. LSU AgCenter, Baton Rouge, La.

Way, M.O. and G.N. McCauley. 2012. Texas Rice Production Guidelines. Texas A&M University System. Beaumont, Texas.

Table 1. Analysis of variance for ratoon yield as influenced by main crop nitrogen (N) rate and ratoon crop N rate at the Pine Tree Research Station, near Colt, Ark., during 2012.

Source of variation	CLXL745	XP4523	CLXP4534	CL111
Main crop N rate (MCN)	0.0872	0.4131	0.0042	0.4719
Ratoon crop N rate (RCN)	<0.0001	0.0007	0.1793	0.3857
MCN × RCN	0.5523	0.0555	0.5172	0.9561

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of RiceTec CLXL745 at the Pine Tree Research Station, near Colt, Ark., during 2012.

Ratoon N Fertilizer rate	Ratoon grain yield			
	CLXL745	XP4523	CLXP4534	CL111
(lb N/acre)	-------------------------------- (bu/acre)	--------------------------------		
0	17.4	16.8	15.9	6.4
45	35.4	24.7	19.3	6.6
90	31.3	30.0	20.5	7.5
LSD $_{0.05}$[a]	4.4	6.5	NS[b]	NS
CV (%)	12.2	9.3	13.5	6.7

[a] LSD = least significant difference, C.V. = coefficient of variation.

[b] NS = not significant at $P < 0.05$.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of RiceTec CLXP4534 at the Pine Tree Research Station, near Colt, Ark., during 2012.

N fertilizer rate	Grain yield of CLXP4534		
	Main crop	Ratoon crop[a]	Total yield
(lb N/acre)	--------------------------------	(bu/acre)	--------------------------------
N-ST*R + 0	219	19.3	238.3
N-ST*R + 45	-		-
N-ST*R + 90	-		-
STD Rec + 0	206	15.3	221.3
STD Rec + 45	-	-	-
STD Rec + 90	-	-	-

[a] Least significant difference (LSD) $_{0.05}$ to compare ratoon crop rice yield is 2.8.

Screening Rice Cultivars for Salinity Tolerance Using a Simple Laboratory Incubation

T.L. Roberts, S.M. Williamson, C.L. Scott, R.J. Norman,
N.A. Slaton, J. Shafer, C.E. Greub, A.M. Fulford, and D.L. Frizzell

ABSTRACT

The research presented here highlights the use of a simple incubation procedure to evaluate the relative salt tolerance of currently available rice cultivars over a wide range of salt concentrations. Rice seeds were subjected to a series of salt solutions from 0 to 20 micromhos/cm, and the ability of each cultivar to germinate and develop to the S3 growth stage was evaluated. Germination values were normalized based on the germination of an individual cultivar at 0 micromho/cm salt concentration so that the influence of salt concentration on rice germination could be assessed independent of other factors that might influence germination. Seven cultivars included in the screening never dropped below the threshold of 80% germination set for this study, even at the highest salt concentrations. These cultivars included CL111, CL151, CL261, CLXL745, XP4523, CLXP4534, and Taggart. A wide range in relative germination was reported in this study indicating that within the cultivars currently available to rice producers there is the potential for some cultivars to perform better in salt affected soils than others. This study only evaluated rice seed germination through the S3 growth stage and further work should be completed to evaluate the performance of these cultivars during the vegetative growth stage.

INTRODUCTION

Soil salinity and its effects on rice production have been well documented. Rice is one of the more salt sensitive crop species during emergence and early vegetative growth, but becomes more salt tolerant after the mid-tillering growth stage (Kaddah et al., 1975). High salt accumulation in the root zone has caused many problems in Arkansas rice fields during rice seedling emergence and stand establishment, therefore flushing is the current recommendation to prevent seedling injury due to high salinity levels (Gilmour et al., 1985; Slaton, 2001). Well water is the primary irrigation source for ~80% of the rice grown in Arkansas and contains varying levels of soluble salts; but considering the amount of water added during the growing season, this can result in a large mass of salt over a short period of time (Wilson et al., 2010).

Screening rice germplasm on a wide scale was last conducted in 1992 and contained over 15,000 accessions from the USDA/ARS rice collection (Wells et al., 1992). The purpose of this screening procedure was to identify salt tolerant lines that might be developed into breeding programs to help combat the growing problem of salinity in Arkansas rice production. This study used a wide range of salt solutions and assessed the germination of rice seedlings at the end of a 3 wk period. Wells and others (1992) concluded that there was no appreciable difference in salt tolerance among the cultivars grown in the southern U.S. at that time.

The declining quality and quantity of groundwater in much of the Arkansas Delta combined with the long-term effects of using these water sources has sparked interest in the salt tolerance of currently grown rice cultivars. Within the past 10 years, hybrid rice has made its mark on Arkansas rice production, but there is currently no information evaluating the relative salt tolerance of these cultivars and many pure-lines to aid in cultivar selection. The purpose of this study was to evaluate the salt tolerance of several currently released hybrid and pure-line cultivars using a short-term laboratory incubation.

PROCEDURES

The salinity screening study was conducted using a simple procedure developed to assess the ability of rice seeds to imbibe water and develop to the S3 growth stage as outlined by Counce et al. (2000). Rice cultivars were obtained from entries in the Arkansas Rice Performance Trials as well as from Horizon Ag and RiceTec Incorporated. The rice cultivars included in the study and information regarding grain length, herbicide tolerance, line origin, breeding program and days to 50% heading are listed in Table 1. Petri dishes were lined with VWR 410 filter paper and 10 rice seeds of each cultivar were placed onto the filter paper. A series of salt solutions, which included 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, and 20 micromhos/cm, were developed using NaCl and represent a wide range of salt concentrations for screening these cultivars. The cultivar × salt solution treatments were replicated four times. Each perti dish was treated with 5 ml of solution and covered with the lid to prevent evaporation but still allow some exchange with the ambient air. Petri dishes were placed into a incubator set at 80 °F for a period of 7 days. Following the 7 day incubation, petri dishes were removed, and rice seedlings which reached the S3 growth stage were counted and recorded. For each cultivar, the maximum seedling germination occurred at the lowest salt solutions, and this number was used as the baseline to assess the germination percentage of the rice cultivars under "ideal" germination conditions. Rice seedling germination for the salt treatments was normalized using the baseline germination percentage allowing researchers to evaluate the influence of salt level independently. By normalizing the germination percentage of each individual cultivar, we can assess the influence of increasing salt levels on rice seedling germination and eliminate the effects of variable germination based on differences in rice cultivars. To provide an easy assessment of these cultivars and their relative salt tolerance, the salinity level required to reduce normalized germination percentage to 80% was selected and used for comparison. Within each cultivar, the 80% normalized germination level was selected as the highest salt treatment that resulted in statistically significant differences in germination at or above 80% assessed at the $P = 0.05$ level.

RESULTS AND DISCUSSION

Soil salinization is an issue that has impacted the Southern Rice Belt for years and will continue to be an issue as the quality of both surface and groundwater sources declines. Reclamation of salt-effected soils is not an easy process, especially in areas cropped to rice that have relatively low infiltration rates making them ideal for rice production. One of the primary ways to combat these issues of increasing salt content is to select cultivars that have increased salt tolerance. Many of the modern rice cultivars available to producers have not been formally screened for salt tolerance, and there has not been any published data on the salt tolerance of hybrid rice.

Relative salt tolerances of the cultivars screened in this study are presented in Table 2 and highlight a large difference in relative salt tolerance across rice cultivars. The salinity level required to reduce normalized germination to 80% was selected as that is the minimum germination required for seed certification by the Arkansas State Plant Board. Major differences exist in the relative salt tolerance of the cultivars screened with some cultivars having normalized germination percentages well above 80%, even at the highest salinity levels, while others experienced severe reduction in normalized germination at relatively low salt concentrations. Salinity levels required to reduce normalized germination to 80% ranged from 7.5 micromhos/cm for Della 2 to at least 7 cultivars having >80% germination even at the highest salinity level of 20 micromhos/cm.

General trends in the results appear to highlight some interesting findings in regard to potential breeding lines and their increased salt tolerance (Table 2). All of the pure-line Clearfield cultivars had high levels of salt tolerance with CL111, CL151, and CL261 all resulting in normalized germinations >80% even at the highest salt concentrations. This trend suggests that these cultivars are generally more tolerant to high levels of salt and that there is potentially some commonality in the Clearfield breeding line that carries increased salt tolerance. The cultivar CL111 has the highest normalized germination of all the Clearfield pureline cultivars at 89%, and it is interesting to note that this cultivar is often planted in many salt affected areas of southern Louisiana and performs very well. Clearfield 261 is the only Clearfield medium-grain cultivar (lowest normalized germination of 85%) and outperformed the other medium-grains in this trial including

Caffey and Jupiter, which required only 15 and 17.5 micromhos/cm to reduce to 80% germination, respectively.

There were six hybrids included in this current salinity screening, and results suggest that they have a significant level of salt tolerance (Table 2). Four of the hybrid cultivars including CLXP4534, CLXL745, XP4523, and XL723 had normalized germinations of 80% or greater at the highest salinity level, with CLXL745 and XP4523 having the highest overall germinations of 92% at 20 micromhos/cm. Clearfield XL729 had a reduced salt tolerance compared to the other hybrids, with 15 micomhos/cm lowering the germination to 80%. RiceTec XP753 was the least salt tolerant hybrid requiring only 12.5 micromhos/cm to reduce germination to 80%. These results suggest that at least some of the hybrid rice cultivars have very high relative salt tolerance and have the potential to overcome high salt concentrations. The hybrid vigor and high salt tolerance of the cultivars CLXP4534, CLXL745, and XP4523 make them ideal candidates for 'problem fields' or areas suspected of high salt concentrations.

All of the cultivars released by the University of Arkansas System Division of Agriculture Breeding program performed well in this salinity screening with Taggart rising to the top having a minimum normalized germination of 88% at the highest salinity level. Francis' normalized germination was reduced to 80% at 17.5 micromhos/cm and was the lowest performing of all the Arkansas cultivars. The high yield potential, milling quality, and relative salt tolerance of the Arkansas cultivars Roy J, Wells, and Taggart make them ideal candidates for producers looking for quality pure-line cultivars with relatively strong salt tolerance.

The results presented here indicate the ability of some currently marketed rice cultivars to germinate and grow to the S3 growth stage, which is a good indication of relative salt tolerance. Further research is needed to help classify these cultivars into more distinct categories and evaluate them at growth stages past S3 where rice cultivars in the early vegetative growth stages may actually be more prone to increased salinity levels than during the seedling stages. This study allows comparison of the rice cultivar's ability to imbibe water, germinate and produce both a radicle and coleoptile, which is important information in terms of salt tolerance and stand establishment. The methods outlined here provide a quick and simple determination of relative salt tolerance and could be incorporated into breeding programs to help identify potential lines with exceptional salt tolerance.

SIGNIFICANCE OF FINDINGS

This salt screening is simple in nature and can be used as a guide to identify rice cultivars that have increased salt tolerance. The results of this study indicate that there is a wide range of relative salt tolerance in the rice cultivars currently available to producers and that certain cultivars should be avoided when a history or potential for high salt concentrations are possible. In general, the hybrids and Clearfield cultivars consistently performed well even under relatively high salt concentrations. Additional work to identify differences in salt tolerance during the vegetative growth stages is warranted to complete the full screening and will help producers to make informed decisions concerning cultivar selection, especially in areas of high salt concentrations. Although this study only focuses on the influence of salt concentration on rice germination, producers must be aware that there are many other factors that can impact rice stand establishment and the harvest of a successful rice crop.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board, Horizon Ag, and RiceTec Inc. Appreciation is also expressed to Horizon Ag and RiceTec Inc. for supplying the seed to conduct this study as well as the Arkansas Agricultural Experiment Station and hourly personnel that help manage and conduct this research.

LITERATURE CITED

Counce, P.A, T.C. Keisling, and A.J. Mitchell. 2000. A uniform, objective and adaptive system for expressing rice development. Crop Sci. 40:436-443.

Gilmour, J.T., J.A Ferguson, H.D Scott, and R.E. Baser. 1985. The behavior of soluble salt in Sharkey clay-II. Publ 123. Arkansas Water Resources Research Center, Fayetteville.

Kaddah, M.T., W.F. Lehman, B.D. Meek, and F.E. Robinson. 1975. Salinity effects on rice after the boot stage. Agron. J. 75:1-12.

Slaton, N.A. (ed.). 2001. Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service MP192.

Wells, B.R., R.E Baser, and R.H. Dilday. 1992. Evaluation of the USDA/ARS rice germplasm collection for tolerance to saline and alkaline soils. *In:* B.R. Wells (ed.) Arkansas Rice Research Studies 1992. University of Arkansas Agricultural Experiment Station Research Series 431:41-45. Fayetteville.

Wilson, C.E. Jr., S.K. Runsick, and R. Mazzanti. 2010. Trends in Arkansas rice production. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Series 2009. University of Arkansas Agricultural Experiment Station Research Series 581:11-21. Fayetteville.

Table 1. Common characteristics of the cultivars used in the salinity screening including grain length, herbicide tolerance, line origin, breeding program, and days to 50% heading.

Cultivar	Grain length	Herbicide resistance	Line origin	Breeding program[a]	Days to 50% heading
Bowman	Long	Conventional	Pure-line	MSU	96
Caffey	Medium	Conventional	Pure-line	LSU	79
Cheniere	Long	Conventional	Pure-line	LSU	87
CL111	Long	Clearfield	Pure-line	LSU	83
CL142 AR	Long	Clearfield	Pure-line	UA	85
CL151	Long	Clearfield	Pure-line	LSU	83
CL152	Long	Clearfield	Pure-line	LSU	79
CL162	Long	Clearfield	Pure-line	MSU	92
CL261	Medium	Clearfield	Pure-line	LSU	79
CLXL729	Long	Clearfield	Hybrid	RT	82
CLXP4534	Long	Clearfield	Hybrid	RT	74
Colorado	Long	Conventional	Pure-line	TAMU	91
Cypress	Long	Conventional	Pure-line	LSU	87
Della 2	Long	Conventional	Pure-line	LSU	87
Francis	Long	Conventional	Pure-line	UA	85
Jazzman 2	Long	Conventional	Pure-line	LSU	77
Jupiter	Medium	Conventional	Pure-line	LSU	84
Mermentau	Long	Conventional	Pure-line	LSU	87
Presidio	Long	Conventional	Pure-line	TAMU	91
Rex	Long	Conventional	Pure-line	MSU	81
Roy J	Long	Conventional	Pure-line	UA	91
RTCLXL745	Long	Clearfield	Hybrid	RT	80
RTXP4523	Long	Conventional	Hybrid	RT	79
Taggart	Long	Conventional	Pure-line	UA	89
Wells	Long	Conventional	Pure-line	UA	87
XL723	Long	Conventional	Hybrid	RT	86
XP753	Long	Conventional	Hybrid	RT	86

[a] LSU= Louisiana State University; MSU = Mississippi State University; RT = RiceTec Inc.; TAMU = Texas A&M University; and UA = University of Arkansas.

Table 2. Salinity level required to reduce normalized germination to 80% and the lowest germination recorded only for rice cultivars that did not have a significant reduction to 80% normalized germination.

Cultivar	Salinity level required to reduce germination to 80%	Lowest germination recorded
	(micromhos/cm)	(%)
Bowman	17.5	
Caffey	15.0	
Cheniere	17.5	
CL111	-	89.0
CL142AR	20.0	
CL151	-	82.5
CL152	20.0	
CL162	20.0	
CL261	-	85.0
CLXL729	15.0	
CLXP4534	-	85.0
Colorado	15.0	
Cypress	20.0	
Della 2	7.5	
Francis	17.5	
Jazzman 2	12.5	
Jupiter	17.5	
Mermentau	15.0	
Presidio	20.0	
Rex	20.0	
Roy J	20.0	
RTCLXL745	-	92.0
RTXP4523	-	92.0
Taggart	-	88.0
Wells	20.0	
XL723	20.0	
XP753	12.5	

Field Evaluation of Urease Inhibitors in Direct-Seeded, Delayed-Flood Rice on a Silt-Loam Soil

C.W. Rogers, R.J. Norman, K.R. Brye, A.D. Smartt,
T.L. Roberts, N.A. Slaton, A.M. Fulford, and D.L. Frizzell

ABSTRACT

Urea is the most widely used nitrogen (N) fertilizer in direct-seeded, delayed-flood rice production. Urea fertilizer is susceptible to loss as ammonia gas to the atmosphere if not flooded in a timely manner. A urease inhibitor [i.e. N-(n-butyl) thiophosphoric-triamide; NBPT] is recommended when a timely flood cannot be established. Recent research has indicated that when relative humidity (RH) is less than the critical relative humidity (CRH) of urea then ammonia volatilization can be limited. Also, recent field research in rice at the Rice Research and Extension Center (RREC), Stuttgart, Ark., using NBPT in comparison to untreated urea, has not produced significant yield differences. The objectives of this study were to (i) investigate the effectiveness of NBPT at inhibiting ammonia volatilization, (ii) investigate the effectiveness of NBPT at increasing grain yield, and (iii) determine the effect of RH in relation to CRH when comparing volatilization data to yield data. The study was comprised of two parts: i) an early-season ammonia volatilization study and ii) a grain yield study. Untreated urea, Agrotain-treated urea, and Arborite-treated urea were investigated. The volatilization study was conducted using semi-open static chambers with an acid trapping solution over a 20-d period. Dataloggers were included both in the chamber and in ambient conditions to measure temperature, RH, and for CRH determination. The yield study investigated the 3 fertilizer sources, 3 application timings (10, 5, and 1 day prior to flooding), and 2 N application rates (90 and 45 lb N/acre). Cumulative N-losses at the end of the measurement period were 15.8%, 4.3%, and 3.8% from urea, Agrotain-treated urea, and Arborite-treated urea, respectively. Agrotain-treated urea and Arborite-treated urea did not differ during the 20-d study but both had statistically less ammonia-N loss than untreated urea. However, there was no difference in rice grain measured between N

sources or N application timings. The variation between the studies appears to be related to the measured ambient RH < CRH for urea and the chamber RH > CRH. Thus, NBPT is effective at reducing ammonia volatilization under conducive conditions. The research indicated unfavorable conditions for ammonia loss (i.e. RH < CRH), which resulted in no grain yield differences between NBPT-treated urea compared to untreated urea.

INTRODUCTION

Nitrogen is the nutrient applied in the largest quantity and over the largest acreage in direct-seeded, delayed-flood rice (*Oryza sativa* L.) production. Currently, urea fertilizer is most commonly used due to its relatively high N analysis (46%), low-cost, and ease of handling. Urea undergoes hydrolysis and reacts with the urease enzyme in soil. This reaction results in an increase in pH adjacent to the fertilizer, which can accentuate loss of applied fertilizer N as ammonia gas. Thus, recommended practices have been developed to reduce these losses in direct-seeded, delayed-flood rice production. Current recommendations are to apply fertilizer to a dry soil surface near the 5-lf stage and incorporate the fertilizer by establishing the permanent-flood within 2 d on silt-loam soils. Under proper urea-N fertilizer management, it has been reported that rice can recover 60% to 75% of applied N (Norman et al., 2003). Thus, following recommended management practices results in high yields with minimal environmental losses.

Prior research in direct-seeded, delayed-flood rice has reported losses from ammonia volatilization ranging from 20% to 30% (Griggs et al., 2007). Vaio et al. (2008) indicated that differences in environmental conditions [i.e. relative humidity (RH) related to the critical relative humidity (CRH) of urea] may impact the loss of urea-N fertilizer via ammonia volatilization. Thus, if microclimate conditions in the chamber exist that are significantly different than the field, then differences could exist in ammonia volatilization between the two environments. Prior field research at the Rice Research and Extension Center (RREC), Stuttgart, Ark., in direct-seeded, delayed-flood rice utilizing the urease inhibitor N-(n-butyl) thiophosphorictriamide (NBPT) and untreated urea have reported no yield differences based on N source even though they were expected (Rogers et al., 2012a, b). The objectives of the current research were to determine the effectiveness of urea coated with the NBPT-containing products, Weyerhaeuser-Arborite (Weyerhaeuser Company, Vanceboro, N.C.) and Agrotain-Ultra (Agrotain International; St. Louis, Mo.) at inhibiting ammonia volatilization; determine if the products would increase rice grain yield by effectively limiting ammonia volatilization compared to untreated urea when applied several days in advance of the permanent flood; and finally to investigate the CRH of urea as a possible environmental factor affecting ammonia volatilization.

METHODS AND MATERIALS

Site Description

Research was conducted during the 2012 growing season at the RREC near Stuttgart, Ark., on a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) in a field managed in a rice-soybean (*Glycine max* L.) rotation. Soil nutrient data for the study area are presented in Table 1. The study was comprised of two components: i) early-season ammonia volatilization quantification, and ii) grain yield measurement.

Ammonia Volatilization Study

Early-season ammonia volatilization was determined for untreated urea, Agrotain-treated urea (Agrotain International; St. Louis, Mo.), and Arborite-treated urea (Weyerhaeuser Company, Vanceboro, N.C.). In-field ammonia volatilization was evaluated using static diffusion chambers similar to those described by Beyrouty et al. (1988), Griggs et al. (2007), and Massey et al. (2011). Transparent plexiglass chambers with dimensions of 24-inches (61 cm) high by 5.5-inches (14 cm) diameter were driven into the ground to a depth of 6 inches (15 cm). Polyurethane foam sorbers with 20 mL of 0.75 M H_3PO_4 - 33% glycerol (v/v) were placed 6 inches (15 cm) below the top of the chamber to capture volatilized ammonia from the soil, and a second sorber was placed at the chamber top to capture and eliminate atmospheric ammonia. Foam sorbers were stored in plastic storage bags, extracted with 100 mL of 2 *M* KCL overnight, and subsequently analyzed by colorimetry [Sans Skalar Wet Chemistry Auto-Analyser (Skalar, Netherlands); Mulvaney, 1996]. At the initiation of the study, four outdoor temperature/humidity dataloggers (HOBO Pro v2-Part No. U23-001, Onset Computer Corp. Inc., Poccasett, Mass.) were suspended within a static-open chamber in each block and four dataloggers in the ambient air adjacent to the chambers near the soil surface. These dataloggers recorded temperature and humidity data hourly. To avoid inaccurate measurement of temperature and humidity, and limit any debris entering the chamber, a bucket was suspended over individual chambers and a canopy was constructed over the research area. Temperature data (°C) was used to calculate the critical relative humidity (CRH) of urea, the RH at which urea dissolves, as described by Vaio et al. (2008):

$$\text{CRH (\%)} = 84.669 - 0.1457\text{T} - 0.0055T^2 \qquad \text{[Eq. 1]}$$

where T is temperature (°C).

Fertilizer sources were added to the chambers at a rate of 90 lb/acre. Samples were collected on days 2, 5, 7, and 10 prior to flooding. After day 10 sampling, the flood was established and water carefully added to individual chambers by hand. Post-flood sampling occurred on days 15 and 20.

Yield Study

Plots with dimensions of 6.5-ft wide by 16-ft long were flagged to establish boundaries. Phosphorus (36 lb P_2O_5/acre as triple superphosphate) and potassium (72 lb K_2O/acre as muriate of potash) fertilizers were broadcast to all plots, along with zinc (10 lb Zn/acre as $ZnSO_4$). The long-grain rice cultivar Wells was drill-seeded into conventionally tilled seedbeds at 80 lb seed/acre. Plots were comprised of 9 rows of rice spaced 7.5 inches apart. Fertilizer N was added as untreated urea, Agrotain-treated urea, and Arborite-treated urea at rates of 45 and 90 lb N/acre, along with an unfertilized control. The N sources were applied at timings of 10, 5, and 1 d before flooding (DBF) onto a dry soil surface. After the 1 day N application, a 2- to 4-inch deep permanent flood was established and maintained until harvest. Rice management closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, pest management, and irrigation management (Slaton and Cartwright, 2001).

STATISTICAL ANALYSIS

The ammonia volatilization study was analyzed as a split-plot design with product as the whole-plot factor and time as the split-plot factor. The yield study was analyzed as a 3 factor randomized complete block where the factors were 3 N-sources, 2 N-rates, and 3 application timings. Statistical analysis was performed in SAS v. 9.2 (SAS Institute Inc., Cary, N.C.) using an analysis of variance (ANOVA) and mean separations were conducted were appropriate using Fisher's protected least significant difference (LSD) test at $P < 0.05$.

RESULTS

Ammonia Volatilization

Ammonia volatilization was measured using the static-chamber method during the 20-d experiment (Table 2). Untreated urea lost statistically more N via ammonia volatilization than either Agrotain-treated urea or Arborite-treated urea at all sampling dates with 5.1%, 13.3%, 15.2%, 15.7%, 15.7%, and 15.8 % cumulative loss of applied N on days 2, 5, 7, 10, 15, and 20, respectively. The cumulative loss of 15.8% from untreated urea was greater than urea treated with the NBPT containing products Agrotain and Arborite, which lost statistically less N than untreated urea but did not differ statistically from one another with cumulative losses of 4.3% and 3.8%, respectively.

These losses are similar to prior studies where NBPT has been reported to minimize ammonia volatilization of urea for a week after fertilizer application (Bremner and Chai, 1989). Our cumulative losses were slightly lower (15.8 %) than the >20% losses reported by Norman et al. (2009) and Griggs et al. (2007) on a Calloway silt loam (a fine-silty, mixed, active, thermic Aquic Fraglossudalf) and a DeWitt silt loam, respectively. However, our results further confirm the results of Norman et al. (2009) and Griggs et al. (2007) concerning the ability of NBPT to reduce ammonia volatilization from urea fertilizer in direct-seeded, delayed-flood rice under conducive environmental conditions.

Rice Yield

Based on measured in-field ammonia volatilization losses, it was expected that yield differences would be apparent based upon product and application timing. However, the only significant factor was N-rate (Table 3). As expected, yield was the greatest at 196 bu/acre from the 90 lb N/acre rate as compared to 171 bu/acre from the 45 lb N/

acre rate or the 0 lb N/acre rate (check plot) of 129 bu/acre (Table 4). Averaged across N fertilization rate, it appears that some N loss did occur as the rice that received N fertilizers 10 d before flooding (DBF) had the lowest yield of 177 bu/acre; however, this was not significant, and yields from the different N fertilizer sources were within <10 bu/acre of one another (Table 5). The comparable yield across all N-fertilizer sources and application timings indicates that in-field ammonia volatilization loss was not sufficient to result in statistically significant differences.

Critical Relative Humidity

In-chamber and ambient humidity data are presented in Fig. 1. The data presents a potential explanation as to why ammonia volatilization was measured in-chamber but yield differences were not measured in-field. During the 10 DBF, the ambient-RH approached but did not reach the CRH for urea. Relative humidity increased throughout the evening and into the early morning and decreased during the day as temperature increased; however, CRH is inversely related to temperature and at lower temperatures CRH is higher. The chamber-RH reached 100% RH within the first day after the sorbers were installed and remained well above the CRH throughout the study. Vaio et al. (2008) reported that ammonia losses from urea can be decreased when RH < CRH due to the slowing of dissolution and hydrolysis. Thus, our results would indicate that while-Agrotain-treated urea and Arborite-treated urea effectively limited ammonia volatilization in the chamber environment where RH > CRH of urea, the in-field conditions of RH < CRH of urea during the entirety of the study limited ammonia volatilization and thus, the benefit of a urease inhibitor in relation to rice grain yield.

SIGNIFICANCE OF FINDINGS

This study further indicates the appropriateness of urease inhibitors containing NBPT for reducing ammonia volatilization of preflood N-applications in direct-seeded, delayed-flood rice production when environmental conditions are conducive. This study is also the first in direct-seeded, delayed-flood rice to identify possible environmental conditions creating a situation that are not conducive to ammonia volatilization (i.e. RH < CRH). Furthermore, NBPT did not impact yields as ammonia volatilization was likely not occurring to a large enough degree in-field to create significant N loss in respect to rice yield. The fact that producers are unable to accurately predict the temperature, CRH, and RH following N application limits the ability of this study to predict (at the time of application) whether NBPT will be necessary to limit ammonia volatilization loss. Thus, NBPT is recommended for silt-loam soils when the flood cannot be established quickly (i.e. 2 d) following urea fertilizer application.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board. We would like to thank Jamie Branson and Chuck Pipkins for field maintenance during this study.

LITERATURE CITED

Beyrouty, C.A., L.E. Sommers, and D.W. Nelson. 1988. Ammonia volatilization from surface-applied urea as affected by several phosphoroamide compounds. Soil Sci. Soc. Am. J. 52:1173-1178.

Bremner, J.M. and H.S. Chai. 1989. Effectos of phosphoramides on ammonia volatilization and nitrite accumulation in soils treated with urea. Biol. Fertil. Soils 8:227-230.

Griggs, B.R., R.J. Norman, C.E. Wilson Jr., and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake for conventional and conservation tilled dry-seeded, delayed-flood rice. Soil Sci. Soc. Am. J. 71:745-751.

Massey, C.G., N.A. Slaton, R.J. Norman, E.E. Gbur, R.E. DeLong, and B.R. Golden. 2011. Bermudagrass forage yield and ammonia volatilization as affected by nitrogen fertilization. Soil Sci. Soc. Am. J. 75:638-648.

Mulvaney, R.L. 1996. Nitrogen-Inorganic Forms. pp. 1123-1185. *In:* D.L. Sparks (ed.). Methods of Soil Analysis Part 3: Chemical Methods. 3rd ed. SSSA. Madison, Wis.

Norman, R.J., C.E. Wilson Jr., and N.A. Slaton. 2003. Soil fertilization and rice nutrition in United States mechanized rice culture. pp. 331-411. *In:* C.W. Smith and R.H. Dilday (eds.). Rice: Origin, History, Technology, and Production. Wiley Sciences. Hoboken, N.J.

Norman, R.J., C.E. Wilson Jr., N.A. Slaton, B.R. Griggs, J.T. Bushong, and E.E. Gbur. 2009. Nitrogen fertilizer sources and timing before flooding dry-seeded, delayed-flood rice. 73:2184-2190.

Rogers, C.W., R.J. Norman, T.L. Roberts, N.A. Slaton, C.E. Wilson, A.M. Fulford, D.L. Frizzel, and J.D. Branson. 2012a. Rice grain yield as influenced by nitrogen source, nitrogen rate, and nitrogen 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 600:253-264. Fayetteville.

Rogers, C.W., R.J. Norman, T.L. Roberts, N.A. Slaton, C.E. Wilson, A.M. Fulford, D.L. Frizzel, and J.D. Branson. 2012b. Evaluation of inhibitors to reduce ammonia volatilization for usage in direct-seeded, delayed-flood rice production. *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. 600:248-252. Fayetteville.

Slaton, N.A. and R. Cartwright. 2001. Rice stand establishment. pp. 21-28. *In:* N.A. Slaton (ed.). Rice Production Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service MP 192.

Vaio, N., M.L. Cabrera, D.E. Kissel, J.A. Rema, J.F. Newsome, and V.H. Calvert. 2008. Ammonia volatilization from urea-based fertilizers applied to tall fescue pastures in Georgia, USA. Soil Sci. Soc. Am. J. 72:1665-1671.

Table 1. Selected soil chemical property means (n = 4) of research established at the Rice Research Extension Center (RREC), Stuttgart, Ark., on a Dewitt silt loam in 2012.

Site	Soil pH	Mehlich-3 extractable nutrients							
		P	K	Ca	Mg	Na	S	Cu	Zn
	(1:2)	------------------------------------ (mg/kg) ------------------------------------							
North Bay	6.5	30	90	1146	172	63	12.7	1.0	7.6
South Bay	6.8	32	84	1165	189	69	11.4	1.0	4.9

Table 2. Cumulative ammonia volatilization losses of nitrogen (N) from untreated urea, urea treated with Agrotain-Ultra, and urea treated with Arborite applied to a silt-loam soil.

Product[†]	Time after application (days)					
	2	5	7	10	15	20
	-------------------------------(% of applied N lost) ----------------------------					
Untreated urea	5.1	13.3	15.2	15.7	15.7	15.8
Agrotain-urea	0.2	1.7	3.3	4.3	4.3	4.3
Arborite-urea	0.1	1.1	2.3	3.7	3.8	3.8

[†] Least signficant difference (*P* = 0.05) to compare means between days within the same product = 1.4% and to compare means from different products = 4.3%.

Table 3. Analysis of variance *P* values for rice grain yield as affected by nitrogen (N) source, N rate, N timing,and their interactions for the study at the Rice Research and Extension Center, Stuttgart, Ark., in 2012.

Parameter	*P*-value
N source	0.15
N rate	< 0.01
N timing	0.64
N source × N rate	0.44
N source × N timing	0.98
N rate × N timing	0.56
N source × N rate × N timing	0.95

Table 4. Effect of nitrogen (N) fertilizer rate on rice grain yield during the 2012 season at the Rice Research and Extension Center, Stuttgart, Ark.

N fertilizer rate	Grain yield
(lb N/acre)	(bu/acre)
90	196 a[†]
45	171 b
0	129

[†] Means followed by the same letter are not significantly different at *P* < 0.05.

Table 5. Effect of nitrogen (N) fertilizer source and application timing on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2012.

N fertilizer source	Grain yield 1 DBF[†]	 5 DBF	 10 DBF
	------(bu/acre) ------		
Arborite-urea	186	186	184
Agrotain-urea	186	185	184
Untreated urea	183	180	177
None		129	
p-value		0.98	

[†] DBF = number of days before permanent flood establishment.

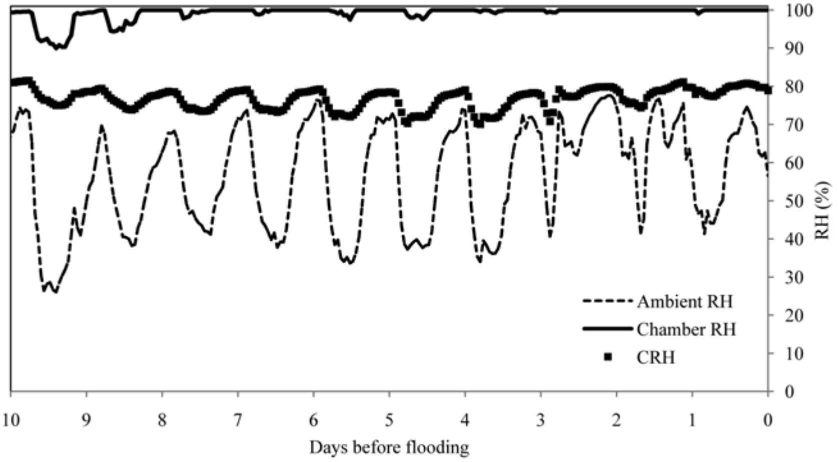


Fig. 1. Ambient relative humidity (RH), semi-open static chamber RH, and the critical relative humidity (CRH) of urea for the 10 days before flooding from a DeWitt silt-loam soil following urea application at the Rice Research and Extension Center, near Stuttgart, Ark.

Seasonal Pattern of Methane Fluxes from a Silt-Loam Soil as Affected by Previous Crop and Cultivar

C.W. Rogers, K.R. Brye, R.J. Norman,
A.D. Smartt, E.E. Gbur, A.M. Fulford, and D. Frizzell

ABSTRACT

Arkansas is the largest rice (*Oryza sativa* L.) producer in the United States. Research assessing factors known to affect methane production is limited in the drill-seeded, delayed-flood system common in the southern U.S. rice-growing region. The objective of this research was to investigate the influence of previous crop [soybean (*Glycine max* L.) or rice] and cultivar (standard stature, semi-dwarf, and hybrid) on methane fluxes. Research was conducted in 2012 on a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs). The chamber method was used to collect gas samples at 0, 20, 40, and 60 min after the chamber was sealed. Samples were collected weekly from flooding until flood release and then every other day for 1 week following flood release with one additional sample taken prior to harvest. Methane fluxes were low at the beginning of the season, increased until approximately 50% heading, and steadily decreased until flood release. Methane fluxes from flooding until flood release differed significantly among previous crop, cultivar, and sampling date ($P = 0.01$). From flooding until the sampling prior to 50% heading, rice following soybean typically had lower fluxes across all cultivars compared to rice following rice. After flood release, all treatments exhibited a numerical methane flux increase and ranged from 4.3 to 13.7 mg CH_4-C/m^2/h. The study indicates that rice following soybean had lower fluxes throughout a large portion of the growing season regardless of cultivar. Hybrid rice following soybean had the lowest measured peak flux, and hybrid rice following rice decreased most rapidly following the peak flux. Therefore, further research concerning common cultural practices (i.e., previous crop and cultivar selection) in Arkansas will improve the accuracy of methane emission estimates, which largely determine the carbon footprint associated with Arkansas rice production.

INTRODUCTION

Methane, a greenhouse gas with a global warming potential approximately 25 times greater than carbon dioxide, is produced under highly anaerobic environments. Key sources of methane include natural wetlands, ruminant production, landfills, fossil fuel production/consumption, and rice (*Oryza sativa* L.) agriculture (EPA, 2011). Of these sources, rice production is the only agricultural cropping system cited as a predominant source of methane. This relationship is related to the fact that rice is the only crop where the majority of the growing season the plant is under flooded soil conditions. Upon flooding, soils quickly become anaerobic, which is a necessary precursor to methane production. In contrast, cereal crops, such as wheat (*Triticum aestivum* L.) or maize (*Zea mays* L.), cannot survive a prolonged flood. The fact that rice is a semi-aquatic plant and is produced under flooded conditions has resulted in an estimated global warming potential larger than either wheat or maize (Linquist et al., 2011). The larger global warming potential for rice cultivation than other cropping systems is a result of increased methane emissions due to the common practice of producing rice under flooded soil conditions.

The United States Environmental Protection Agency (EPA, 2011) currently uses an emissions factor of 160 kg CH_4-C/ha/season for a primary rice crop. However, the emissions factor for a primary crop of rice is based on a relatively small number of studies (Sass et al., 1991a,b; Cicerone et al., 1992; Bossio et al., 1999) that do not represent current practices common to Arkansas. In particular, the fact that the majority of rice in Arkansas follows a low-residue-producing soybean (*Glycine max* L.) crop may result in lower emissions than rice following rice, as research has shown that residue incorporation can increase emissions (Bossio et al., 1999; Sass et al., 1991a,b). Furthermore, cultivar selection has been shown to significantly impact methane emissions (Lindau et al., 1995) and hybrid rice, which constitutes a substantial portion of the rice acreage in Arkansas, reportedly oxidizes more methane in the rhizosphere than conventional cultivars resulting in a decrease in methane emissions (Ma et al., 2010). The current study addresses a lack of data in the drill-seeded, delayed-flood rice production system in Arkansas on a silt-loam soil concerning both previous crop in rotation and cultivar selection as they affect methane fluxes. Thus, the objective of this study was to evaluate previous crop in rotation and cultivar selection in relation to methane fluxes from a silt-loam soil over the 2012 growing season.

PROCEDURES

Research was conducted in 2012 at the University of Arkansas Rice Research and Extension Center near Stuttgart, Ark., on a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) with the previous crop either rice or soybean. Three cultivars were selected representing a conventional stand stature (Taggart), a conventional semi-dwarf (Cheniere), and a hybrid [Clearfield XL745 (CLXL745)]. Field plots for the study were 6.5-ft wide by 16-ft long arranged in a split-plot design with four blocks, where the whole-plot factor was previous crop and the spilt-plot factor was cultivar. Taggart and Cheniere were seeded at a rate of 100 lb/acre with 7.5.-inch row spacing. Based on recommended practices from RiceTec Inc., CLXL745 was seeded at a rate of 27 lb/acre with 7.5-inch row spacing.

For the conventional cultivars, nitrogen (N) fertilizer was applied at a rate of 150 lb N/acre in a split application of 105 lb N/acre at preflood followed by a 45 lb N/acre at midseason. Nitrogen fertilizer was applied at 150 lb N/acre to the hybrid rice in a split application of 120 lb N/acre at preflood followed by a 30 lb N/acre application at late boot. A permanent flood was established at the 4- to 5-lf growth stage to a depth of 2-4 inches and was maintained until maturity at which time the flood was removed for harvest.

A composite soil sample was collected from the top 4 inches from individual plots prior to flooding. Soil was oven-dried at 158 ºF (70 ºC) then crushed and sieved through a 2-mm mesh screen for soil chemical analyses. Mehlich-3 extractable nutrients were determined on a Spectro Arcos inductively coupled argon plasma spectrometer (Spectro Analytical Instruments, Kleve, Germany). Inorganic-N (NO_3-N and NH_4-N) was determined after extraction with potassium chloride (KCl) colorimetrically on a Sans Skalar Wet Chemistry Auto-Analyser (Skalar, Netherlands). Total carbon (TC) and total N (TN) were determined by high temperature combustion on a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). Soil pH and electrical conductivity (EC) were determined on a 1:2 soil-to-water ratio. Prior to flooding, soil samples were also collected from the top 4 inches of each plot using a core chamber and slide hammer for bulk density determination. Subsequently, samples were oven-dried at 158 ºF (70 ºC), crushed, and sieved through a 2-mm mesh screen for particle-size analysis (Gee and Or, 2002).

Methane-flux measurements were conducted using enclosure-based chambers (Livingston and Hutchinson, 1995) constructed of polyvinyl chloride with a diameter of 12 inches (30.5-cm) and heights of 15.7 inches (40 cm), 23.6 inches (60 cm), and 39.4 inches (100 cm) to accommodate increasing plant height during the season. Similar to Shang et al. (2011), all samples were collected mid-morning between 800 to 1000 hr to closely correspond to the daily mean soil temperature. Gas samples were collected at 0, 20, 40, and 60 min after sealing the chamber by syringe into pre-evacuated vials and subsequently analyzed by gas chromatography (Agilent 6890N, Agilent Technologies, Santa Clara, Calif.). Following flood release, samples were collected every other day for one week and one additional sampling was conducted prior to harvest 92 days after flooding (DAF).

Statistical analyses were performed on the preflood soil chemical and physical properties to assess whether differences existed based on the whole-plot factor of previous crop and the spilt-plot factor (pre-assigned location of cultivar) using an analysis of variance (ANOVA) with PROC Mixed in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). Methane fluxes were analyzed based upon the split-plot design, where the whole-plot factor was previous crop (rice and soybean), the spilt-plot factor was cultivar (Cheniere, CLXL745, and Taggart), and time (sampling date) was treated as a repeated measure. Measured methane fluxes were separated into two time periods, flooding to flood release and flood release to harvest, due to the known differences in controlling mechanisms between the two time frames. For both time periods, an ANOVA was performed in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) using PROC Mixed to evaluate the effect of previous crop, cultivar, and their interactions on methane fluxes. Where appropriate, means were separated using Fisher's protected least significant difference (LSD) test at the 0.05 level.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

Differences existed between select soil physical and chemical property means based on previous crop ($P < 0.05$), however, no differences existed among cultivars (Table 1). The relative proportion of sand, silt, and clay did not differ, but differences in bulk density existed between previous-crop treatments. Bulk density was slightly greater when the previous crop was soybean (1.25 g/cm^3) than when the previous crop was rice (1.18 g/cm^3). Soil EC, M3-P, M3-K, M3-Fe, M3-Na, and M3-S soil concentrations were slightly greater when rice was the previous crop as compared to soybean. In contrast, pH, M3-Ca, M3-Mg, M3-Mn, M3-Cu, and M3-Zn were slightly greater when soybean was the previous crop. However, no differences were observed in soil concentrations of inorganic-N, TN, TC, or SOM based on either previous crop or pre-assigned cultivar.

Flooding to Flood Release

Methane fluxes during the 2012 growing season were significantly affected by previous crop, cultivar, and sampling date ($P = 0.01$; Table 1). Fluxes at the initial sampling date (9 DAF) were all < 1.2 mg CH_4-C/m^2/hr and did not differ among treatments (Fig. 1). At 16 DAF, no differences existed among treatments, but fluxes had numerically increased from the initial sampling and ranged from a minimum of 1.1 mg CH_4-C/m^2/hr from CLXL745 following soybean to a maximum of 4.4 mg CH_4-C/m^2/hr from Taggart following rice. Following panicle differentiation, fluxes rapidly increased with the greatest increases observed from the cultivars following rice. These larger fluxes from rice following rice have previously been reported when rice straw is retained as opposed to removal or burning (Bossio et al., 1999; Sass et al., 1991a,b). The trend of greater fluxes when rice was the previous crop was generally followed until approximately 44 DAF prior to 50% heading (HDG).

Methane fluxes from all treatments peaked 51 DAF following 50% HDG with the exception of Cheniere following rice, which peaked just prior to 50% HDG (44 DAF; Fig. 1). Peak fluxes ranged from 8.3 mg CH_4-C/m^2/hr from CLXL745 following soybean to 18.7 mg CH_4-C/m^2/hr from CLXL745 following rice. However, fluxes from CLXL745 following rice did not differ from Taggart following rice, or Taggart following soybean 51 DAF. Following peak fluxes, methane fluxes declined until flood release (74 DAF). Particularly notable was the response of CLXL745 following rice, where the peak flux decreased from 18.7 (51 DAF) to 8.5 mg CH_4-C/m^2/hr in one week (58 DAF). Ma et al. (2010) observed a similar decline from hybrid rice and reported that this was due to an increase in methanotrophic bacteria in the rhizosphere and subsequent increase in the rate of methane oxidation. On the final sampling prior to flood release, fluxes ranged from 2.1 to 8.5 mg CH_4-C/m^2/hr from CLXL745 following soybean and Taggart following soybean, respectively.

Flood Release to Harvest

Following flood release, methane fluxes in all treatments numerically increased (Fig. 1), which has been noted previously by multiple studies (Denier van der Gon et al., 1996; Bossio et al., 1998; Rogers et al., 2012). Similar to Rogers et al. (2012) in a DeWitt silt loam under similar production practices, the post-flood methane pulse in the current study was variable among treatments, and ranged from 4.3 to 13.7 mg CH_4-C/m^2/hr from CLXL745 following soybean and Taggart following rice, respectively. However, the post-flood release was only significant based on cultivar and time (P = 0.03; Table 2). Averaged across previous crop, fluxes from CLXL745 were typically lower than from the other cultivars until the final sampling date prior to harvest (Fig. 1). On the final sampling date (92 DAF), fluxes did not differ and had returned to < 0.1 mg CH_4-C/m^2/h indicating that methane release had ceased.

SIGNIFICANCE OF FINDINGS

Data concerning the effects of common Arkansas cultural practices on methane fluxes are limited. Therefore, this study provides direct observations of methane fluxes from common cultural practices in the drill-seeded, delayed-flood production system in Arkansas. In particular, the fact that a majority of Arkansas rice is produced following soybean coupled with the trend of lower fluxes from rice grown following soybean, particularly early in the growing season, presents a key factor which can be used when determining the contribution of Arkansas to United States estimates of methane emissions from rice. In addition, the trend of lower fluxes from the hybrid CLXL745 following soybean during a large portion of the growing season and the rapid decrease in fluxes from CLXL745 following rice indicate a potential decrease in methane emissions when growing hybrid rice, which has constituted a substantial portion of planted rice acreage in the past decade. Continued research into the effects of cultural practices on methane release will lead to more accurate estimates of emissions from Arkansas rice production.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board. We would also like to thank Chester Greub, Taylor Adams, and Doug Wolf, for field and laboratory assistance and Jamie Branson and Chuck Pipkins for field maintenance during this study.

LITERATURE CITED

Bossio, D.A., W.R. Horwath, R.G. Mutters, and C. van Kessel. 1999. Methane pool and flux dynamics in a rice field following straw incorporation. Soil Biol. Biochem. 31:1313-1322.

Cicerone, R.J., C.C. Delwiche, S.C. Tyler, and P.R. Zimmerman. 1992. Methane emissions from California rice paddies with varied treatments. Global Biogeochem. Cycles 6:233-248.

Denier van der Gon, H.A.C. and H. Neue. 1995. Influence of organic matter incorporation on the methane emission from a wetland rice field. Global Biogeochem. Cycles 9:11-22.

Denier van der Gon, H.A.C., N. van Breemen, H.U. Neue, R.S. Lantin, J. Aduna, M. Alberto, and R. Wassmann. 1996. Release of entrapped methane from wetland rice fields upon soil drying. Global Biogeochem. Cycles 10:1–7.

EPA, Environmental Protection Agency. 2011. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2009 [on-line]. Available at http://www.epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Complete_Report.pdf (Accessed 4 Jan, 2013).

Gee, G.W. and D. Or. 2002. Particle size analysis. pp. 255-293. *In:* J.H. Dane and G.C. Topp (eds.). Methods of soil analysis: Physical Analysis. Soil Sci. Soc. Am., Madison, Wis.

Lindau, C.W., P.K. Bollich, and R.D. DeLaune. 1995. Effect of rice variety on methane emission from Louisiana rice. Agric. Ecosys. Environ. 54:109-114.

Linquist, B.A., K.J. van Groenigen, M.A. Adviento-Borbe, C. Pittelkow, and C. van Kessel. 2011. An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biol. 18:194-209.

Livingston, G. and G. Hutchinson. 1995. Enclosure-based measurement of trace gas exchange: applications and sources of error. pp. 14-51. *In:* P.A. Matson and R.C. Harris (eds.). Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell Sciences Ltd., Osney Mead, Oxford.

Ma, K., Q. Qiu, and Y. Lu. 2010. Microbial mechanism for rice variety control on methane emission from rice field soil. Global Change Biol. 16:3085-3095.

Rogers, C.W., K.R. Brye, R.J. Norman, and T. Gasnier. 2012. Methane emissions from a silt-loam soil under direct-seeded, delayed-flood rice management. *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 600:240-247. Fayetteville.

Sass, R.L., F.M Fisher, P.A. Harcombe, and F.T. Turner. 1991a. Mitigation of methane emissions from rice fields: Possible adverse effects of incorporated rice straw. Global Biogeochem. Cycles 5:275-287.

Sass, R.L., F.M. Fisher, F.T. Turner, and M.F. Jund. 1991b. Methane emissions from rice fields as influenced by solar radiation, temperature, and straw incorporation. Global Biogeochem. Cycles 5:335-350.

Shang, Q., X. Yang, C. Gao, P. Wu, J. Liu, Y. Xu, Q. Shen, J. Zou, and S. Guo. 2011. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments. Global Change Biol. 17:2196-2210.

Table 1. Mean soil properties (n = 24) in the top 4 inches associated with methane fluxes from a silt-loam soil during the 2012 growing season at the Rice Research and Extension Center, near Stuttgart, Ark.

	Previous crop	
Soil property	Rice	Soybean
pH	5.9 b[†]	6.2 a
EC	131 a	95 b
Sand (g/g)	0.12	0.11
Silt (g/g)	0.69	0.70
Clay (g/g)	0.19	0.19
Bulk Density (g/cm3)	1.18 b	1.25 a
Mehich-3 nutrients (mg/kg)		
P	29 a	19 b
K	173 a	129 b
Ca	804 b	922 a
Mg	131 b	157 a
Fe	471 a	321 b
Mn	270 b	335 a
Na	87 a	73 b
S	10.5 a	7.1 b
Cu	0.9 b	1.0 a
Zn	1.1 b	1.8 a
NO_3-N (mg/kg)	4.4	3.7
NH_4-N(mg/kg)	3.4	2.9
Organic Matter (g/kg)	17.3	17.8
Total N (g/kg)	0.7	0.7
Total C (g/kg)	8.0	7.0

[†] Values in the same row followed by different letters are significantly different ($P < 0.05$).

Table 2. Analysis of variance summary of the effects of previous crop, cultivar, time, and their interaction on methane fluxes from a silt-loam soil during the 2012 growing season at the Rice Research and Extension Center, near Stuttgart, Ark.

	Measurement period	
Source of variation	Flooding to flood release	Flood release to harvest
	---------------------------- (*P*)	----------------------------
Previous crop	0.02	0.54
Cultivar	< 0.01	< 0.01
Previous crop × Cultivar	0.19	0.02
Time	< 0.01	< 0.01
Rotation × Time	< 0.01	0.29
Cultivar × Time	< 0.01	0.03
Rotation × Cultivar × Time	0.01	0.66

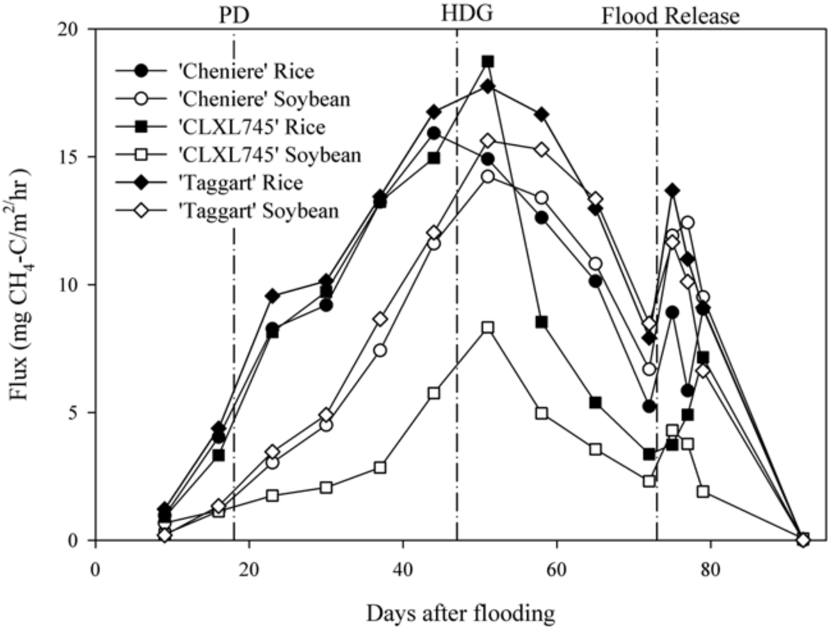


Fig. 1. Growing-season (2012) time-series profile of methane fluxes from Cheniere, CLXL745, and Taggart where the previous crop was rice or soybean and the soil was a silt-loam at the Rice Research and Extension Center, near Stuttgart, Ark. Panicle differentiation (PD) and 50% heading (HDG) occurred at approximately 18 and 47 days after flooding.

Evaluation of Phosphorus and Zinc Fertilization Strategies for Rice

N.A. Slaton, T.L. Roberts, R.J. Norman,
R.E. DeLong, C.G. Massey, J.B. Shafer, and S.D. Clark

ABSTRACT

Development and evaluation of new fertilizer sources and/or nutrient application methods that improve crop nutrient use efficiency and reduce production costs are important. The objectives of research reviewed in this report include the evaluation of rice growth and yield response to: 1) phosphorus (P) fertilizer sources, 2) tillage and P and zinc (Zn) fertilization, and 3) P and Zn application strategies. Grain yields of rice were not affected by P source or rate, tillage method, or Zn or P fertilizer source and application strategy. Despite the lack of significant grain yield differences, information regarding plant nutrient uptake was obtained. For example, for the second year, the tillage trial suggests that early-season Zn uptake in no-till systems is limited compared to conventionally tilled seedbeds and that too much P can contribute to lodging of a weak-strawed variety.

INTRODUCTION

Phosphorus and Zn fertilizers are often applied to rice grown on soils having low P and Zn availability index values. In Arkansas, triple superphosphate (TSP) and diammonium phosphate (DAP) are the most common P fertilizers, which are usually broadcast-applied from before seeding to before flooding at the 5-lf stage. Although monoammonium phosphate (MAP) is an excellent P fertilizer, is it not commonly available in eastern Arkansas. MicroEssentials (MESZ, 12-40-0-10S-1Zn) is a relatively new P fertilizer that also contains some other nutrients being marketed in Arkansas.

Zinc is supplied to rice using one or more methods that may include treating seed with low rates of Zn, broadcasting granular Zn preplant, or spraying Zn solutions to rice foliage before flooding. Fertilization with P and Zn are considered key components for early-season seedling vigor and producing high yields, especially on alkaline silt loam soils.

Research has shown that significant rice yield increases to P fertilization are relatively uncommon in Arkansas and difficult to accurately predict with soil testing. However, when P and/or Zn are deficient, rice management is difficult, production costs increase, and rice yield potential decreases. Furthermore, the likelihood of P and Zn deficiency increases when rice is planted early due to cool air and soil temperatures. Thus, fertilization strategies that prevent P and Zn deficiencies and maintain adequate soil P and Zn availability have been adopted. Development and evaluation of new fertilizer sources and/or nutrient application methods that improve crop nutrient use efficiency and reduce production costs are important. The objectives of research covered in this report include the evaluation of rice growth and yield response to: 1) different P fertilizer sources, 2) tillage and P and Zn fertilization, and 3) fertilizer application strategy (band vs broadcast).

PROCEDURES

Phosphorus Source Trial

Two experiments evaluating different P fertilizers and rates were established at the Pine Tree Research Station (PTRS), near Colt, Ark., on soils mapped as a Calhoun (PSource-1) and a Calloway (PSource-2) silt loam. The PSource-1 trial followed grain sorghum and PSource-2 followed soybean in rotation. In each trial, composite soil samples were collected from the 0- to 4-inch depth from plots that had received no P or K 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 16-ft long. Triple superphosphate (46% P_2O_5), MAP (11% N and 52% P_2O_5), and MESZ (12% N, 40% P_2O_5, 10% S, and 1% Zn) were broadcast at 0, 40, 80, and 120 lb P_2O_5/acre. Treatments were applied to a tilled soil surface immediately before drill-seeding CL152 rice (100 lb/acre) at PSource-1 on 4 April or CL151 at PSource-2 on 23 April. The different amounts of N supplied among P fertilizers and rates were not equalized in these trials. Muriate of potash was applied to supply 80 lb K_2O/acre. At the 5-lf stage, 130 lb urea-N/acre was applied and a 4-inch deep flood was established within 2 days after N application. Standard disease, weed, and insect control practices were used as needed based on regular scouting to ensure that pests were not yield limiting.

At the midtillering growth stage, whole, aboveground rice plants receiving 0 or 80 lb P_2O_5/acre were cut 1 inch above the soil surface, bagged, oven-dried at 130 °F to a constant weight, weighed, ground to pass a 1-mm sieve, and a subsample was digested for nutrient analysis. Harvest at both sites was performed with a small-plot combine, harvested grain weight and moisture were determined, and yield was calculated based on a uniform 12% moisture content.

Dry matter and tissue concentration data were analyzed as a randomized complete block (4 blocks) design comparing P sources applied at 80 lb P_2O_5/acre to the no

P control. Grain yield data were analyzed using a 3 (P rate) by 3 (P source) factorial treatment structure compared to a no P control (No P or 0 lb P_2O_5/acre). Analysis of variance was performed using the PROC GLM procedure in SAS (v. 9.2, SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

Tillage Trial

A tillage trial (Zn-Tillage) was established on a Calloway silt loam at the PTRS in a field that was cropped to soybean in 2011. Six, 14-ft wide by 60-ft long strips were flagged in an untilled field. One-half of each strip was designated (randomly) for tillage or no-tillage. Soil samples were collected before tillage as described previously (Table 1). One-half of each strip was worked to a depth of about 3 inches with a rototiller in late-April. On 10 May, CL152 rice was planted (100 lb seed/acre) into each strip. Before planting, three different fertilizer treatments were hand applied to the soil surface with like treatments in adjacent plots with different tillage. The fertilizer treatments were no P or Zn, 10 lb Zn/acre as Zink-Gro granular $ZnSO_4$ (35.5% Zn), and 10 lb Zn plus 60 lb P_2O_5/acre as TSP. Each plot was 7-ft wide and 20-ft long and contained 9 rows of rice with 7.5-inch wide row spacing. Plant sampling and harvest were performed as described previously. The experiment was a randomized complete block with a strip-plot structure and four blocks. Analysis of variance was conducted using the PROC MIXED procedure in SAS. When appropriate, mean separations were performed using Fishers protected least significant difference method at a significance level of 0.10.

Band versus Broadcast Trials

Experiments were established on a Calhoun silt loam at the PTRS to examine rice growth, P and Zn uptake, and yield response to P (P-Method) and Zn (Zn-Method) source and application strategy (i.e., rate and method). The area was cropped to grain sorghum in 2011. Two adjacent research areas were flagged to define plot boundaries and a composite soil sample (0- to 4-inches) was collected from plots designated to receive no P or Zn in each replicate to characterize soil chemical properties (Table 1). Each plot was 16-ft long and 6.5-ft wide allowing for nine, 7.5-inch wide rows in each plot with the outside rows of each plot separated by a 1.75-ft wide alley that contained no rice. Muriate of potash (60 lb K_2O/acre) was applied to each trial and 60 lb P_2O_5/acre as TSP was applied to the Zn trial.

The P trial treatments included MAP and TSP with each source band applied at 15, 30, 45, and 60 lb P_2O_5/acre and compared to a broadcast application of 60 lb P_2O_5/acre, and no P. The Zn trial treatments included the granular Zn fertilizers sold as EZ20 (2% N, 14% S, and 20% Zn, Agrium Advanced Technologies Inc., Loveland, Colo.) and Zn 10% LS (LS-Zn, 7% S, and 10% Zn as Zn Lignosulfonate, Winfield Solutions LLC, St Paul, Minn.) with each source band applied at 1, 2, 4, and 10 lb Zn/acre and compared to 10 lb Zn/acre broadcast to the soil surface and a no Zn control. The band-applied treatments occurred on 4 April about 0.75 inch deep into a conventionally tilled seedbed using a 9-row Hege drill (7-inch row spacing). Clearfield 152 rice (100 lb seed/acre) was seeded into the same plots using a 9-row Great Plains no-till drill (7.5 inch row spacing). The broadcast applications were made by hand to the soil surface immediately after planting. Rice emerged on 14 April. At the 5-lf stage (16 May), 130 lb urea-N/acre was applied and the plots were flooded within 2 days. Plant sampling and harvest were performed as described previously.

Each trial was a randomized complete block with a 2 (fertilizer) by 6 (method and rate) factorial treatment structure containing four blocks. For each trial, analysis of variance (ANOVA) was conducted using the PROC GLM procedure in SAS. When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Phosphorus Source by Rate Trial

Phosphorus source had no influence on rice growth at PSource-1 (Table 2), but significantly affected dry matter at PSource-2 (Table 3). At PSource-2, dry matter was greatest for rice fertilized with 80 lb P_2O_5/acre as MAP. Rice that received no P or 80 lb P_2O_5/acre as TSP, or MESZ produced similar dry matter. Tissue P concentration was not affected by P source at either site (Tables 2 and 3). The mean tissue P concentrations of all rice was considered sufficient for normal growth (>0.20% P). Rice Zn concentrations were not affected by P fertilization at PSource-2, but application of 80 lb P_2O_5/acre as TSP, MAP, or MESZ decreased tissue Zn concentration at PSource-1.

Rice grain yields were not affected by P source, P rate, or their interaction at either site (Tables 2 and 3). Harvest of PSource-2 was performed following Hurricane Isaac which caused significant lodging in many Arkansas rice fields. Lodging of the CL151 variety was affected by the interaction between P fertilizer and rate ($P = 0.0117$, data not shown). The lodging data was highly variable, but, in general, showed that lodging tended to be worst for rice fertilized with MAP and MESZ, N-containing P fertilizers, and increased as rate increased from 40 to 120 lb P_2O_5/acre. Rice that received no P had 1% lodging, compared to 15%, 9%, and 30% lodging for rice fertilized with 40, 80, and 120 lb P_2O_5/acre, respectively, when averaged across P sources.

Tillage Trial

Dry matter at midtillering, rice P concentration, and grain yield were not significantly affected by fertilizer treatment, tillage, or their interaction (Table 4). Rice whole-plant Zn concentration was the only measurement that was significantly affected. Mean Zn concentration values for the main effect shows tissue Zn was greater for the conventional tillage, but the interaction was significant (not shown). The interaction showed that rice fertilized with Zn in the conventionally tilled soil had greater Zn concentrations (32.6 ppm Zn) than all other treatments which had similar Zn concentrations that ranged from 22.6 to 26.6 ppm Zn. There were some non-significant trends that have been observed in both years of this trial (Slaton et al., 2012). Rice planted in a no-till seedbed tends to produce slightly lower yields and have slightly lower tissue Zn concentrations than rice grown in stale or conventionally tilled seedbeds. Although not conclusive, these trends suggest that rice grown with no-tillage may absorb less soil and/or fertilizer Zn and be more prone to Zn deficiency.

Band versus Broadcast Trials

The two-way interaction between Zn application method and Zn source was significant for rice dry matter and tissue Zn concentration at the midtillering stage (Table 5). Although significant, rice receiving no Zn had similar dry matter as treatments that produced the minimum (Band 2 lb Zn-LS/acre) and maximum (Band 4 lb Zn-LS/acre) dry matter suggesting that there was no single Zn treatment that was superior to another. In general, tissue Zn concentration showed that tissue Zn increased as Zn application rate increased and that rice fertilized with Zn-LS tended to have higher tissue Zn than when EZ20 was the Zn source. The interaction for tissue Zn concentration showed that rice fertilized with Zn-LS had numerically higher tissue Zn than rice fertilized with EZ20-Zn at all application methods and rates, except 4 lb Zn/acre applied in a band. Rice Zn concentrations were considered sufficient (>20 ppm) in all treatments suggesting that there would be no yield benefit to Zn fertilization. Grain yield was not affected by Zn source ($P = 0.5578$), application method ($P = 0.3285$), or their interaction ($P = 0.4179$) and the overall yield average was 166 bu/acre.

The 2-way interaction also affected midtillering dry matter accumulation in the P fertilization strategy trial (Table 6). In general, rice fertilized with MAP produced higher dry matter than when TSP was the P source and dry matter tended to increase with P rate. The no P control produced less dry matter than rice that received banded 30 lb P_2O_5/acre as TSP, broadcast 60 lb P_2O_5/acre as MAP, banded 45 lb P_2O_5/acre as MAP, and banded 60 lb P_2O_5/acre as MAP suggesting that the observed dry matter increase may have been from the N in the MAP. Tissue P concentration and grain yield were not affected ($P > 0.10$) by fertilization. Tissue P concentrations were more than sufficient for normal rice growth with an overall mean value of 0.313% P and the overall average grain yield was 182 bu/acre. Although not significant, rice receiving no P contained the lowest P concentration (0.306% P) and produced the lowest numerical mean yield (177 bu/acre).

SIGNIFICANCE OF FINDINGS

Rice fertilization experiments conducted in 2012 did not show significant grain yield increases or decreases from P or Zn fertilization. However, lodging of a lodging-prone variety, CL151, increased as P-fertilizer rate increased, especially for the N-containing P fertilizers. Similar results were reported from a trial with this same variety in 2011 (Slaton et al., 2012). There does not appear to be any consistent differences among the evaluated P fertilizers suggesting that growers should purchase the one that best fits their short- and long-term fertilization goals. For the second year, rice grown in a no-till system tended to produce lower grain yields and take up lower amounts of Zn than rice grown in a tilled seedbed providing evidence that Zn deficiency may be of greater concern in no-till systems.

ACKNOWLEDGMENTS

Research was funded by the Arkansas Rice Check-off Program from funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

LITERATURE CITED

Slaton, N.A., T.L. Roberts, R.J. Norman, R.E. DeLong, C.G. Massey, J. Shafer, J.D. Branson, and S.D. Clark. 2012. Evaluation of phosphorus, potassium, and zinc fertilization strategies for rice. *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 600:271-280. Fayetteville.

Table 1. Selected soil chemical property means (0- to 4-inch depth, n = 4-6) of sites used to evaluate crop response to different fertilization strategies at the Pine Tree Research Station, Colt, Ark., in 2012.

	Soil[†]		Mehlich-3 extractable soil nutrients					
Trial	OM	pH	P	K	Ca	Mg	S	Zn
	(%)		----------------------------	--------	(ppm)	--------	--------	--------
PSource-1	2.5	7.3	19 (1.4)[‡]	68	1483	257	9	1.4
PSource-2	2.7	7.4	18 (1.7)	67	1842	244	14	1.7
P-Method	2.3	7.4	25 (2.8)	68	1478	260	9	1.5
Zn-Method	2.2	7.2	37	70	1435	266	9	1.7
Zn-Tillage	2.2	6.9	26	66	1451	249	8	1.4

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

[‡] Values in parentheses are the standard deviation of the mean soil-test P (given only for P fertilization trials).

Table 2. Rice dry matter, tissue P and Zn at the midtillering stage, and grain yield means of rice grown on a Calhoun silt loam (PSource-1) as affected by P fertilizer source, averaged across P rate for yield, in 2012.

Fertilizer[†]	Dry matter	Tissue P	Tissue Zn	Grain yield
	(lb/acre)	(%)	(ppm)	(bu/acre)
No P	1687 a[‡]	0.320 a	30.4 a	193 a
MAP	1766 a	0.298 a	27.7 b	193 a
MESZ	1984 a	0.308 a	26.1 b	194 a
TSP	1955 a	0.303 a	27.0 b	187 a
	---------------------------------- (*P*-values)	--------------------------------		
P source	0.2701	0.4769	0.0029	0.1675
P rate	--[§]	--	--	0.5756
Interaction	--	--	--	0.5683

[†] MAP, monoammonium phosphate; MESZ, MicroEssentials; and TSP, triple superphosphate.

[‡] Within each column, means followed by different lowercase letters are statistically different at the 0.10 level.

[§] Dry matter and tissue nutrient concentration means are for rice receiving 80 lb P_2O_5/acre and grain yield is an average across three P_2O_5 rates (40, 80, and 120 lb P_2O_5).

Table 3. Rice dry matter, tissue P, and Zn at the midtillering stage, and grain yield means of rice grown on a Calloway silt loam (PSource-2) as affected by P fertilizer source, averaged across P rate for yield, in 2012.

ertilizer[†]	Dry matter	Tissue P	Tissue Zn	Grain yield
	(lb/acre)	(%)	(ppm)	(bu/acre)
No P	2744 b[‡]	0.333 a	26.4 a	194 a
MAP	3402 a	0.340 a	24.1 a	175 a
MESZ	2955 b	0.348 a	25.6 a	180 a
TSP	2859 b	0.338 a	25.7 a	190 a
	---------------------------------- (*P*-values)	--------------------------------		
P source	0.0651	0.9289	0.2595	0.2958
P rate	--[§]	--	--	0.6463
Interaction	--	--	--	0.2972

[†] MAP, monoammonium phosphate; MESZ, MicroEssentials; and TSP, triple superphosphate.

[‡] Within each column, means followed by different lowercase letters are statistically different at the 0.10 level.

[§] Dry matter and tissue nutrient concentration means are for rice receiving 80 lb P_2O_5/acre and grain yield is an average across three P_2O_5 rates (40, 80, and 120 lb P_2O_5).

Table 4. Rice dry matter and tissue P and Zn at the midtillering stage and grain yield means of rice as affected by tillage, averaged across fertilizer treatments, and fertilizer treatment, averaged across tillage treatments in 2012.

Tillage	Dry matter	Tissue P	Tissue Zn	Grain yield
	(lb/acre)	(%)	(ppm)	(bu/acre)
No-till	1953 a[†]	0.284 a	25.2 b	183 a
Conventional	2040 a	0.300 a	27.5 a	190 a
P-value	0.4446	0.1701	0.0852	0.1097
Fertilizer[‡]				
No P and Zn	1944 a	0.284 a	23.6 b	184 a
Zn only	2086 a	0.288 a	29.3 a	186 a
Zn + P	1959 a	0.300 a	26.1 ab	188 a
P-value	0.4810	0.2769	0.0539	0.4250
Interaction *P*-value[§]	0.4247	0.6797	0.0573	0.6762

[†] Within each column, means followed by different lowercase letters are statistically different at the 0.10 level.

[‡] Zn only, 10 lb/Zn acre; Zn + P, 10 lb Zn/acre + 60 lb P_2O_5/acre.

[§] *P*-value of the 2-way interaction between main effects.

Table 5. Rice dry matter and tissue Zn concentration at the midtillering growth stage as affected by the Zn source by fertilization strategy interaction in 2012.

Strategy		Dry matter		Tissue Zn	
Method	Zn rate	EZ20[†]	LS10[†]	EZ20	LS10
	(lb Zn/acre)	-------- (lb/acre)--------		-------- (ppm)---------	
None	0	---------- 1724 ----------		--------- 20.7 ----------	
Band	1	1693	1651	21.6	21.5
Band	2	1717	1639	22.6	23.3
Band	4	1715	1952	25.6	24.0
Band	10	1693	1687	26.0	32.4
BDST[‡]	10	1522	1927	23.6	26.9
$LSD_{0.10}$		----------- 229 -----------		---------- 3.4 -----------	
P-value		--------- 0.0712 ---------		--------0.0653 --------	

[†] Zn fertilizer sources include: EZ20 (20% Zn, Agrium Advanced Technologies, Inc., Loveland, Colo.) and LS10 (10% Zn lignosulfonate, WinField Solutions, Shoreview, Minn.).

[‡] BDST = broadcast.

Table 6. Rice dry matter at the midtillering growth stage as affected by the P source by fertilization strategy interaction in 2012.

P fertilization strategy		Dry matter	
Method	P rate	MAP[†]	TSP[†]
	(lb P_2O_5/acre)	----------- (lb/acre) -----------	
None	0	1657	
Band	15	1822	1579
Band	30	1756	2078
Band	45	2037	1623
Band	60	2150	1832
BDST[‡]	60	1963	1693
$LSD_{0.10}$		296	
P-value		0.0483	

[†] MAP = monoammonium phosphate and TSP = triple superphosphate.

[‡] BDST = broadcast.

Rice Response to the Interaction Between Nitrogen and Potassium Fertilizer Rate

N.A. Slaton, T.L. Roberts, R.J. Norman,
C.G. Massey, R.E. DeLong, J.B. Shafer, and S.D. Clark

ABSTRACT

Our research objectives were to evaluate rice growth and yield responses to multiple nitrogen (N) and potassium (K) rates on silt-loam soils with a range of soil K availability index values. Two trials were conducted using multiple N and K rate combinations. Rice growth and yield parameters were measured. In the short-term trial, K fertilization had no benefit on rice grain yield, but yields increased as N rate increased from 80 to 160 lb N/acre indicating that N was the only growth- and yield-limiting nutrient. In the long-term trial, soil K availability was insufficient for rice that had received 0, 40, or 80 lb K_2O/acre/year since 2001 and response to N fertilization was limited. Compared to the no K control, N fertilizer recovery efficiency was increased 9% to 21% by 40 to 160 lb K_2O/acre/year, dry matter was increased by 9% to 23%, and grain yield was increased by 11% to 18%. These results highlight the need for routine soil analysis and periodic assessment of farm- or field-specific nutrient balances to determine whether nutrients are being added to the soil at higher or lower rates than the rate of nutrient removal by the harvested portion of the crops.

INTRODUCTION

Uptake of N and K by rice with medium to high yield potential often exceeds 200 lb/acre and plant uptake of both nutrients follows a similar pattern during the growing season. However, N is recognized as the more yield-limiting of the two nutrients. A large proportion (70%) of the N taken up by rice is translocated to rice grains and removed from the field during harvest (Norman et al., 2003). In contrast to N, only a small portion (20%) of the K taken up by the rice plant is removed in the harvested grain. Despite their different physiological plant functions and different removal rates, both nutrients are often recommended for rice grown on silt-loam soils.

Rice growth and yield responses to each nutrient are well documented in Arkansas, but the interaction of N and K fertilizer rate has not been researched. Interest in the N by K interaction has been stimulated by, among other things, low yields despite seemingly adequate N fertilization and symptoms resembling K deficiency that appear during the boot stage (e.g., chlorosis and necrosis of leaf tips) on rice that has usually been fertilized with relatively high N rates, has adequate plant K concentrations, and produces high yields. Our research objectives were to evaluate rice growth and yield responses to multiple N and K rates on silt-loam soils with a range of soil K availability index values.

PROCEDURES

Two field trials were established at the Pine Tree Research Station (PTRS), near Colt, Ark., in 2012. The trials will be discussed as either the short (ST) or long-term (LT) trial. The soil at each site was mapped as a Calhoun silt loam. The PTRS-ST trial was located in a field that had been managed and cropped uniformly in previous years and followed grain sorghum in the rotation. The long-term K fertilization trial (PTRS-LT) was located in an area that was first established in 2001 and has plots that have since received different rates of K fertilizer (Slaton et al., 2011a), followed soybean in the rotation, and was used for the first year of the N × K interaction trial (Slaton et al., 2011b). Before fertilizer treatments were applied to the PTRS-ST, a composite soil sample (0- to 4-inch depth) was collected from each plot designated to receive no K to determine soil chemical properties. For the PTRS-LT site, a composite soil sample was collected from every plot in February 2012. Soil samples were dried at 130 °F (55 °C) in a forced-draft oven, crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture by electrode, and subsamples of soil were extracted using the Mehlich-3 method. Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma spectroscopy (ICPS). Selected soil chemical properties for each experiment are listed in Table 1. Triple superphosphate was broadcast before planting to provide 50 lb P_2O_5/acre.

Clearfield 152 rice was drill-seeded into a conventionally tilled seedbed at the PTRS-ST (4 April) and an untilled seedbed at PTRS-LT (2 May). Management of rice with respect to stand establishment, pest control, irrigation, and other practices closely followed University of Arkansas System Division of Agriculture Cooperative Extension Service guidelines for direct-seeded, delayed-flood rice production. Each plot was 6.5-ft wide (9 rows of rice per plot) and 16-ft long with a 1- to 2.5-ft wide alley surrounding each plot. Muriate of potash was applied before planting on 4 April to the soil surface (no incorporation) at PTRS-ST, and after planting on 15 May at PTRS-LT. For the PTRS-LT, the K rates were the same as the annual rates applied in previous years (0, 40, 80, 120, and 160 lb K_2O/acre). For the PTRS-ST, the K rates were 0, 50, 100, and 150 lb K_2O/acre.

The aforementioned K rates were applied in combination with four urea-N rates which were applied preflood. The applied N rates ranged from insufficient to excessive preflood N rates. Preflood urea treatments were broadcast to the soil surface by hand on 16 May for PTRS-ST and 30 May for PTRS-LT and the plots were flooded within 2 days. The preflood N rates were 80, 120, 160, and 200 lb urea-N/acre for PTRS-LT and -ST.

At the late boot to early heading stage, whole, aboveground plant samples were collected from a 3-ft section of an inside row in each plot at the PTRS-ST site and from four of the eight blocks of PTRS-LT. Samples were dried at 130 °F to a constant moisture, weighed for dry matter, ground to pass a 1-mm sieve, and digested in concentrated HNO_3 and 30% H_2O_2 for determination of tissue K concentration and uptake. At maturity, plots were trimmed, length was measured, and the middle rows were harvested with a small-plot combine. Grain weights and moistures were determined by hand and used to adjust grain yields to 12% moisture by weight for statistical analysis.

Each experiment was a randomized complete block (RCB) design. Soil-test K in the PTRS-LT trials was analyzed as a RCB. At PTRS-LT, the treatment structure for dry matter and yield data was a split-plot where K rate was the main plot and N rate was the subplot. The trial was arranged in this structure since the annual K rates at PTRS-LT were fixed and allowed for four N rates. Each treatment was replicated eight times but plant samples at the late boot stage were collected from only four replicates. For the PTRS-ST trial, the whole-plot was N rate and the subplot was K rate with each site having four blocks. Analysis of variance was performed with the MIXED procedure in SAS v9.2 (SAS Institute, Inc., Cary, N.C.) with significant differences interpreted when $P < 0.05$ for plant growth and yield parameters or 0.10 for soil test information. Mean separations were performed by Fisher's protected least significant difference method.

RESULTS AND DISCUSSION

At the PTRS-LT site, soil-test K was different among the annual K fertilizer rates and has influenced crop yields in recent years providing an ideal area to investigate how N and K fertilizer rates interact (Slaton et al., 2011a, b). Soil-test K ranged from 'Very Low' (<61 ppm) to 'Low' (61 - 90 ppm) at PTRS-LT (Table 2) and was considered Low at PTRS-ST (Table 1). These soil-test levels suggest that grain yields would be different among K rates at both sites. The mean soil-test K values of soil samples collected in 2012 were numerically similar to the values from samples collected in 2011.

The N by K fertilizer rate interaction was not significant for any of the rice growth measurements collected at PTRS-ST (Table 3). Rice dry matter at early heading and grain yield were not affected by K-fertilizer rate, but did influence aboveground tissue K concentration and K uptake, averaged across N rates. Both increased numerically and usually significantly with each increment of K rate increase. Linear regression of aboveground K uptake means against K application rate suggests that rice recovered 37% of the applied K (not shown). Despite the low soil-test K value (Table 1), the tissue K concentration of rice receiving no K was sufficient (>1.3%) at early heading (Table 3). This result suggests that the tissue analysis was more accurate than the preplant soil-test K was in predicting whether K fertilizer was needed to optimize yield.

The main effect of N rate, averaged across K rates, significantly affected dry matter and K concentration at early heading and grain yield (Table 3). The two highest

N rates produced similar dry matter which was greater than the two lowest N rates. The greater dry matter of rice receiving the greatest N rates diluted the aboveground K concentration resulting in lower K concentrations, but not total K uptake values. Grain yield increased with each increment of added N until a yield plateau was reached with 160 and 200 lb N/acre.

At PTRS-LT, the interaction between N and K rates was not significant for any of the measurements, but rice growth and yield were affected by the main effects (Table 4). All growth measurements except tissue N concentration were significantly affected by annual K rate. Each growth parameter that was significantly affected increased numerically and often significantly, especially when annual K rate was <120 lb K_2O/acre, as annual K rate increased. Compared to the no K control, N fertilizer recovery efficiency was increased 9% to 21% by annual applications of 40 to 160 lb K_2O/acre (i.e., N uptake mean divided by the mean N rate of 140 lb N/acre), dry matter was increased by 9% to 23%, and grain yield was increased by 11% to 18%. Application of 80 lb K_2O/acre/year increased whole plant K concentration above the critical level of 1.3% K, but did not maximize grain yield. Grain yields were maximal when 120 and 160 lb K_2O/acre/year were applied. Potassium fertilizer recovery, calculated as described previously, was 61%, but unlike the short-term trial, K uptake in PTRS-LT represents K fertilizer that has been applied for a number of years.

Dry matter, tissue N concentration, N uptake, and grain yield were affected by N rate with all measurements tending to increase numerically and sometimes significantly as N rate increased (Table 4). Averaged across K-fertilizer rates, 55% of the applied urea-N was recovered by the rice at early heading and the preflood application of 120 lb urea-N/acre produced near maximal grain yields.

SIGNIFICANCE OF FINDINGS

Nitrogen by K rate interaction trials during the last 3 years have shown that when one nutrient is limiting, plant use of other fertilizer nutrients becomes less efficient and sometimes can interact to reduce crop growth and yield potential. These results highlight the need for accurate soil-test based recommendations, frequent soil sample collection for routine soil analysis, and periodic assessment of farm- or field-specific nutrient balances to determine whether nutrients are being added to the soil at higher or lower rates than the rate of nutrient removal by the harvested crop portion(s). One of the more important findings is that K deficiency resulted in poor rice use of the applied N fertilizer. Further analysis of these data will show that both whole plant K concentration and N:K concentration ratio are good measures of K sufficiency at early heading and can be used jointly for diagnosing K deficiency.

ACKNOWLEDGMENTS

Research was funded by the Arkansas Rice Check-off Program from funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

LITERATURE CITED

Norman, R.J., C.E. Wilson Jr., and N.A. Slaton. 2003. Soil fertilization and mineral nutrition in U.S. mechanized rice Culture. pp. 331-412. *In:* C.W. Smith and R.H. Dilday (eds.). Rice: Origin, History, Technology, and Production. John Wiley and Sons, Inc. Hoboken, N.J.

Slaton, N.A., R.E. DeLong, C.G. Massey, J. Shafer, S. Clark, and J. Branson. 2011a. Soybean yield response to phosphorus and potassium fertilization. *In:* N.A. Slaton (ed.). Wayne E. Sabbe Arkansas Soil Fertility Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 588:53-57. Fayetteville.

Slaton, N.A., R.J. Norman, T.L. Roberts, R.E. DeLong, C.G. Massey, and S. Clark. 2011b. Rice response to nitrogen and potassium fertilization rate. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:253-258. Fayetteville.

Table 1. Selected soil chemical property means (0- to 4-inch depth, n = 8) of sites used to evaluate crop response to N and K fertilization rate in short- (ST) and long-term (LT) trials at the Pine Tree Research Station (PTRS), Colt, Ark., in 2012.

Site	Soil pH[†]	Mehlich-3 extractable soil nutrients					
		P	K	Ca	Mg	S	Zn
		-------------------- [ppm (standard deviation)] --------------------					
PTRS-LT	7.8	30	68[‡]	2196	400	14	10.9
PTRS-ST	7.1	27	76 (10)	1375	252	9	1.5

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

[‡] Mean soil-test K values for each annual K rate in the long-term trial are listed in Table 2.

Table 2. Soil-test K as affected by annual K rate for the last 4 years in the long-term trial at the Pine Tree Research Station, Colt, Ark. (PTRS-LT).

Annual K rate	2009	2010	2011	2012
(lb K_2O/acre/yr)	--------------------------------(ppm K)--------------------------------			
0	66	60	49	49
40	79	64	57	58
80	86	69	66	63
120	107	73	78	79
160	116	82	94	89
$LSD_{0.10}$	10	6	6	6
P-value	<0.0001	<0.0001	<0.0001	<0.0001
C.V. %	14.4	11.3	11.6	9.6

Table 3. Rice dry matter and aboveground K concentration and content at the early heading growth stage and grain yield as affected by K rate, averaged across N rates, and N rate, averaged across K rates, in the short-term trial at the Pine Tree Research Station, Colt, Ark., (PTRS-ST) in 2012.

K or N rate	Dry matter	Concentration K	Total uptake K	Grain yield
(lb K_2O/acre)	(lb/acre)	(% K)	(lb K/acre)	(bu/acre)
0	9600 a[‡]	1.32 d	126 c	183
50	9790 a	1.47 c	144 b	185
100	9815 a	1.60 b	157 b	186
150	10062 a	1.76 a	177 a	185
P-value	0.5253	<0.0001	<0.0001	0.8613
lb N/acre				
80	9006 b	1.63 a	147 a	169 c
120	10084 a	1.61 a	162 a	185 b
160	10139 a	1.44 b	146 a	191 a
200	10039 a	1.47 b	149 a	194 a
P-value	0.0128	0.0480	0.2064	<0.0001
P-value[†]	0.5729	0.1303	0.2254	0.3006

[†] *P*-value for the N × K interaction.

[‡] Within each column, means followed by different lowercase letters are statistically different at the 0.05 level.

Table 4. Rice dry matter and aboveground K and N concentration and content at the early heading growth stage and grain yield as affected by annual K rate, averaged across N rates, and N rate, averaged across K rates, in the long-term trial at the Pine Tree Research Station, Colt, Ark., (PTRS-LT) in 2012.

		Concentration		Total uptake		Grain
K or N rate	Dry matter	N	K	N	K	yield
(lb K_2O/acre)	(lb/acre)	(% N)	(% K)	(lb N/acre)	(lb K/acre)	(bu/acre)
0	7354 c[‡]	1.64 a	0.94 e	122 c	69 e	160 c
40	7933 b	1.67 a	1.08 d	134 b	85 d	177 b
80	8342 b	1.66 a	1.35 c	139 b	112 c	180 b
120	8925 a	1.65 a	1.57 b	142 ab	143 b	188 a
160	9078 a	1.58 a	1.81 a	151 a	162 a	189 a
P-value	0.0004	0.4437	<0.0001	0.0081	<0.0001	<0.0001
(lb N/acre)						
80	7706 c	1.39 d	1.37 a	107 d	108 a	169 c
120	8107 bc	1.55 c	1.35 a	125 c	112 a	180 b
160	8413 b	1.70 b	1.36 a	143 b	117 a	182 ab
200	9001 a	1.94 a	1.33 a	174 a	121 a	184 a
P-value	<0.0001	<0.0001	0.7881	<0.0001	0.1200	<0.0001
P-value[†]	0.9011	0.9744	0.9882	0.7347	0.9691	0.1680

[†] *P*-value for the N × K interaction.

[‡] Within each column, means followed by different lowercase letters are statistically different at the 0.05 level.

Rice and Soybean Response to Selected Humic Acid or Soil Amendments

N.A. Slaton, R.J. Norman, T.L. Roberts,
R.E. DeLong, C.G. Massey, J.B. Shafer, J. Branson, and S.D. Clark

ABSTRACT

Unbiased information is lacking regarding the benefits of various organic soil amendments and biological stimulants that are being marketed for use in row-crop agriculture. Our research objectives were to evaluate rice and soybean growth and/or yield as affected by the application of Hydra-Hume DG (HH), Carbon Boost-S (CB), and Titan-Accomplish (TA). Hydra Hume was applied at 0, 1, 5, and 10× the manufacturer-recommended rate of 40 lb HH/acre. Carbon-Boost-S and TA were evaluated at different rates and application times. Each experiment also included different preplant and/or preflood fertilizer rates. Fertilizer rate had a greater and more consistent influence on rice growth and yield than treatment components involving HH, CB, or TA, which had little or no significant effect on rice yield. The lack of yield benefits from these products at recommended and/or higher rates suggests that they have limited utility for improving soil and fertilizer nutrient use efficiency or enhancing yields of rice and irrigated soybean grown on undisturbed soils.

INTRODUCTION

Organic amendments and biological stimulants are increasingly being marketed for use in row-crop agriculture. Manufacturers often claim that their products increase soil microbial activity, crop uptake of soil and/or fertilizer nutrients, decomposition rate of crop residues, soil nutrient holding capacity, and/or crop vigor and yield while reducing the rate of fertilizer needed to maximize yields. Although a large number of these products exist, there is a lack of unbiased replicated field research available to support or refute their claims.

University scientists and agronomists spend years researching various aspects (pest management, fertilization, irrigation, etc.) of crop production to develop best management practices that help growers increase crop yields and net profitability. Crop management specialists are often frustrated by the lack of information available to answer grower questions regarding the utility of organic amendments, growth regulators, and biological stimulants and are discouraged when growers abandon research-based production guidelines in favor of unproven amendments. Thus, the overall goal of this project is to evaluate crop growth and yield responses to selected products that are being marketed in Arkansas. Our specific objective was to evaluate rice dry matter, nutrient uptake, and/or grain yield as affected by Hydra-Hume DG (HH, Helena Chemical Company, Collierville, Tenn.), Carbon Boost-S (CB, FBSciences, Collierville, Tenn.) and Titan-Accomplish (TA, Loveland Products, Greeley, Colo.) rate applied in combination with different fertilizer treatments. A secondary objective was to evaluate soybean yield response to HH rate.

PROCEDURES

Field trials were established with rice at the Pine Tree Research Station (PTRS), near Colt, Ark., to examine crop growth and yield responses to products that claim to enhance nutrient uptake, yield, or both. For each trial, the research area was flagged to define plot boundaries and a composite soil sample (0- to 4-inches) was collected from each replicate to characterize soil chemical properties. Soil samples were dried, crushed, sieved, and analyzed for soil pH, organic matter content, and Mehlich-3 extractable soil nutrients (Table 1).

Hydra-Hume DG is a granular formulation of humic acid derived from leonardite, a soft coal-like substance (oxidized form of lignite) that is a byproduct of near-surface mining. In 2012, trials utilizing the same treatments were established on Calhoun (HH-1, Field 19) and Calloway (HH-2, Field L2) silt loams. At HH-1, CL152 rice was drill-seeded following grain sorghum on 4 April; and at HH-2, CL151 rice was drilled following soybean on 23 April. At both sites, rice was seeded into a conventionally tilled seedbed and each plot was 16-ft long and 6.5-ft wide allowing for nine 7.5-inch wide rows. The outside rows of each plot were separated by a 1.75-ft wide alley that contained no rice. Treatments included four HH rates designated as 0, 1, 5, and 10× the recommended rate and corresponded to 0, 40, 200, and 400 lb HH/acre. The HH label suggests an application rate of 40 lb/acre, which can be considered the standard 1× rate. Each HH rate was broadcast to a tilled soil surface, but not incorporated, in combination with two rates (0 and 150 lb) of MESZ fertilizer (12-40-0-10 S-1 Zn, The Mosaic Company, Plymouth, Minn.) before seeding and two rates of urea-N, 0 and 100 lb N/acre, were applied preflood on 16 May (HH-1) or 22 May (HH-2). A permanent flood was established 1 or 2 days after preflood N was applied at the 5-lf stage. The 150 lb/acre rate of MESZ fertilizer provided 18 lb N and S, 60 lb P_2O_5, and 1.5 lb Zn/acre. The preplant MESZ and preflood urea-N rates will be referred to as NP fertilizer rates. The preflood N rates were selected to test whether the HH provided significant N to rice supplied with suboptimal N rates. Each research area received 60 lb K_2O/

acre before planting. Standard disease, weed, and insect control practices were used as needed based on regular scouting to ensure that pests were not yield limiting.

Whole, aboveground plant samples, at the midtillering stage, were collected from a 3-ft section of an inside row of each plot on 5 (HH-1) and 12 (HH-2) June. Plant samples were placed in paper bags, oven-dried (130 °F) until a consistent weight was attained, weighed for dry matter, ground to pass a 1-mm sieve, and digested with 30% H_2O_2 and concentrated HNO_3 for determination of tissue nutrient concentrations on an inductively coupled plasma atomic emission spectrophotometer. Plant samples were collected a second time on 11 July (both sites) at the early heading stage to evaluate total dry matter accumulation and nutrient uptake using the same collection and processing procedures described for the midtillering samples, but only for rice receiving 0 lb MESZ/acre preplant. Eight rows of each plot were harvested with a small-plot combine, harvested grain weight and moisture were determined, and yield was calculated based on a uniform 12% moisture content.

The trial was a randomized complete block (RCB) that contained four blocks with a split-plot treatment structure where the combination of preplant MESZ and preflood N rate was the whole plot and HH rate was the subplot. The trial contained four blocks. Analysis of variance was conducted using the PROC MIXED in SAS (v. 9.2, SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

The CB and TA experiments were seeded on a Calhoun silt loam with CL152 rice on 4 April and were established, maintained, and harvested using the same procedures and equipment described for the HH-1 rice trial. Treatments for the CB trial included 2 preflood N rates (70 and 120 lb urea-N/acre) and 6 CB treatments. The CB treatments included 1) no CB, 2) 12 oz CB/acre applied preplant, 3) 12 oz CB/acre preplant followed by (fb) 8 oz CB/acre preflood, 4) 8 oz CB/acre preflood fb 8 oz CB/acre midseason, 5) 12 oz CB/acre preplant fb 8 oz CB/acre midseason, and 6) 12 oz CB/acre preplant fb 8 oz CB/acre preflood fb 8 oz CB/acre midseason. The CB was applied directly to triple superphosphate fertilizer for the preplant treatment and urea fertilizer for the preflood and midseason (46 lb urea-N/acre) treatments. All plots received 60 lb P_2O_5/acre (CB- treated or untreated) as triple superphosphate preplant, 60 lb K_2O/acre as muriate of potash preplant, the designated preflood urea-N rate treatment (CB-treated or untreated), and midseason N applied at 46 lb urea-N/acre (CB-treated or untreated). The preplant, preflood, and midseason fertilizer applications were made on 4 April, 16 May, and 13 June, respectively. The permanent flood was established on 18 May. Plant samples were collected from the first four CB treatments (from list above), weighed for dry matter accumulation, and processed to determine nutrient concentration during the tillering stage (4 June). The ingredients of CB are not well-defined, but according to the label, contains 0.5% Zn derived from ethylenediaminetetraacetic acid (EDTA). The experiment was a RCB design and contained four blocks with a split-plot treatment structure where preflood urea-N was the whole plot and CB tr eatment was the subplot. Data were analyzed by site as described for the HH-1 trial. Because plant samples were collected before the midseason N-treatments were applied, the statistical analysis of dry matter and tissue nutrient concentrations excludes the two treatments that received CB-amended urea at midseason. When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

The TA material is a mixture of UAN (3% N) and bacteria (*Bacillus* species). The TA trial treatments included 2 preflood N rates (80 and 140 lb N/acre) and 5 TA treatments. The five TA treatments included 1) no preplant P and K and no TA; 2) no preplant P and K with TA sprayed to soil surface preplant; 3) 60 lb P_2O_5 and 80 lb K_2O/acre applied preplant (no TA); 4) 60 lb P_2O_5 and 80 lb K_2O/acre applied preplant with TA amended to the triple superphosphate; and 5) 60 lb P_2O_5 and 80 lb K_2O/acre applied preplant with TA amended to the triple superphosphate preplant and the muriate of potash applied preflood. When TA was sprayed directly onto the soil surface, 246 (preplant) or 251 (preflood) mL TA/acre was applied using a calibrated, CO_2-pressurized backpack sprayer (10 gal/acre) on 10 April between planting and rice emergence. When fertilizer was the carrier, the TA was sprayed onto triple superphosphate fertilizer for preplant application at a rate of 60 lb P_2O_5/acre (130 lb fertilizer/acre) and muriate of potash fertilizer for preflood application at a rate of 80 lb K_2O/acre (133 lb fertilizer/acre) with TA applied at 4 qt/ton fertilizer. The preplant application of TA-amended fertilizer was made before planting on 4 April and the preflood application was before establishing the permanent flood on 16 May. Plant samples were collected at the tillering stage (4 June) and processed as described for the other experiments. The TA experiment was a RCB design that contained three blocks with a split-plot treatment structure where preflood urea-N was the whole plot and TA treatment was the subplot. When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

The effect of HH on soybean was also evaluated at the PTRS on a Calhoun silt loam. The soybean trial examined the same four HH rates described for the rice trials. Soybean (Armor 53-R15) was planted in 15-inch wide rows on 24 April in plots that were 7-ft wide and 20-ft long allowing for 5 rows per plot. The HH was broadcast to the surface of a freshly tilled soil on 24 April. Triple superphosphate (60 lb P_2O_5/acre) and muriate of potash (90 lb K_2O/acre) were broadcast to the entire research area preplant. Soybean was irrigated as needed and pests were controlled using conventional practices. Seed yield was the only parameter measured in the soybean trials. The three inside rows of each soybean plot were harvested with a small plot combine. Soybean yields were calculated by adjusting grain weights to a uniform moisture content of 13%. The soybean experiment was a randomized complete block design with six blocks. Analysis of variance was conducted using the PROC MIXED in SAS. When appropriate, mean separations were performed using Fisher's protected least significant difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

All the sites used in the described experiments had soils that can be characterized as having alkaline pH, Low soil-test P (16-25 ppm), and Low or Very Low soil-test

K (<90 ppm, Table 1). All the soils used for rice experiments also had below optimal soil-test Zn. Based on soil-test information these soils would be expected to respond positively to P, K, and Zn fertilization.

Hydra-Hume DG Trials

The two-way interaction between NP fertilizer and HH rates was significant ($P < 0.10$) only for aboveground dry matter production ($P = 0.0563$) at the late boot stage at HH-1 (data not shown). Consequently, only the significant main effects will be discussed. At both sites, the NP fertilizer rate, averaged across HH rates, had a significant effect on dry matter, tissue P concentration, and tissue Zn concentration at midtillering; dry matter at late boot; and grain yield (Table 2). In general, tissue P and Zn concentration, dry matter, and grain yield was numerically and oftentimes statistically greatest for rice receiving 150 lb MESZ preplant plus 100 lb urea-N preflood and was followed in decreasing order by 100 lb urea-N preflood/acre, 150 lb MESZ/acre plus 0 lb urea-N preflood/acre, and no MESZ or urea-N. These results suggest that, regardless of the preflood urea-N rate, rice tended to benefit from one or more of the nutrients (N, P, S, or Zn) applied preplant as MESZ.

Hydra-Hume DG rate, averaged across NP fertilizer rates, had no significant effect on any of these parameters, except dry matter at the late boot stage for HH-1 (Table 3). Late boot stage dry matter, averaged across preplant and preflood fertilizer rates, was greatest for rice that received no HH compared with rice that received 40 to 400 lb HH/acre, which produced similar dry matters.

Soybean yield was significantly affected by HH rate ($P = 0.0090$, C.V., 5.8%). Soybean receiving 0 and 200 lb HH/acre produced 60 bu/acre, which was greater than the yields of soybean receiving 40 (52 bu/acre) and 400 lb (50 bu/acre) HH/acre (LSD 0.10 = 3 bu/acre). The results suggest that HH had no consistent benefit or detriment to soybean yield in 2012.

Overall, the 2012 results highlight the potential benefits of MESZ applied as preplant fertilizer to supply the recommended rate of P or as a starter (small amount of N to increase seedling vigor). Identifying which nutrient provided the majority of this growth benefit is of interest for additional research.

Carbon Boost-S

Neither the main effect of CB treatment nor the preflood N rate by CB treatment interaction significantly affected rice grain yield or dry matter and tissue P and Zn concentration at late tillering (Table 4). Preflood N rate did influence grain yield and tissue P and Zn concentrations, but had no significant influence on rice dry matter accumulation ~3 weeks after flooding (Table 5). The lack of a significant difference of preflood N rate on dry matter accumulation is likely due to the short interval between N application and plant sampling time as rice was actively taking up N from both treatments at the time plant samples were collected. Tissue P and Zn concentrations and grain yield of rice fertilized with 120 lb preflood urea-N/acre was 0.037%, 2 ppm, and 16% greater, respectively, than that of rice receiving 70 lb urea-N/acre.

Titan-Accomplish

The two-way interaction between preflood N rate and TA treatment had no significant influence on rice dry matter accumulation, P and K concentration, or rice grain yield. Application of the higher preflood N rate (140 lb urea-N/acre) increased rice plant P concentration by 0.045% and grain yield by 32% (Table 6). Titan-Accomplish treatments, averaged across preflood N rates, influenced only midtillering tissue K concentration (Table 7), which was a result of the method of TA application. When TA was sprayed onto the soil, no P and K fertilizers were applied to the rice. Rice receiving P and K fertilizer, regardless of the addition of TA, had higher whole plant K concentrations. When the same preplant P and K fertilizer additions were compared, tissue K concentration, and to a lesser extent P concentration, was numerically, but not statistically higher in treatments that received 8.3 oz TA/preplant. This trend was not observed in 2011 research (Slaton et al., 2012)

SIGNIFICANCE OF FINDINGS

Trials conducted during 2011 and 2012 showed consistent results and suggested that Hydra-Hume DG, Carbon Boost-S, and Titan-Accomplish had no significant and consistent benefit on rice growth, nutrient uptake, and yield. The results suggest that fertilization with proper amounts of N, P, K, and Zn do influence rice growth and yield and cannot be replaced in a crop management plan by these products. The trials conducted in 2012 with Hydra-Hume DG represent the third year of research on undisturbed soils and no benefit has been observed during the course of these experiments (Slaton et al., 2011, 2012).

Research in 2012 represents the second year with Titan-Accomplish and Carbon Boost. Application of these products to rice grown with suboptimal and optimal N rates showed no positive results suggesting these products have little or no effect on soil and fertilizer nutrient availability. The scope of research during the past 3 years is not sufficient to conclude that these products, or other products that may make similar claims, have no beneficial effect on rice and soybean growth. However, the results provide credible preliminary evidence indicating the manufacturers recommended product rates may not be research based or that claims of yield increases from product application may be due to very specific isolated reasons, due to experimental error, and/or creative (or lack of) statistical analysis. Recommendations for use of these products can only be made after a large number of unbiased replicated research trials have been conducted and results can be statistically analyzed to determine the probability and magnitude of all possible yield responses (e.g., positive, negative, and no effect).

Farmers should be wary of products that make claims of substantially increasing soil and fertilizer nutrient availability and crop yield. Money spent on products that claim to increase soil productivity would likely be better invested in additional fertilizer inputs or other on-farm improvements (e.g., irrigation and land leveling). We recommend that farmers avoid products that have not been adequately researched by unbiased entities and prefer that research have been conducted and published by the University of Arkansas or other peer institutions.

ACKNOWLEDGMENTS

Research was funded by the Arkansas Rice Check-off Program from funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture.

LITERATURE CITED

Slaton, N.A., R.J. Norman, T.L. Roberts, R.E. DeLong, C.G. Massey, and S. Clark. 2011. Rice and soybean response to selected humic acid and biological enhancing soil amendments. *In:* R.J. Norman and K.A.K. Moldenhauer (eds). B.R. Wells Rice Research Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 591:259-265. Fayetteville.

Slaton, N.A., T.L. Roberts, R.J. Norman, R.E. DeLong, C.G. Massey, J. Shafer, J.D. Branson, and S.D. Clark. 2012. Rice and soybean response to selected humic acid or biological enhancing soil amendments. *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 600:281-291. Fayetteville.

Table 1. Selected soil chemical property means (0-to 4-inch depth, n = 2-6) of sites used to evaluate crop response to Hydra-Hume DG (HH), Carbon Boost-S (CB), and Titan Accomplish (TA) on silt-loam soils at the Pine Tree Research Station, Colt, Ark., in 2012.

Crop and site	Soil[†]		Mehlich-3 extractable soil nutrients					
	OM	pH	P	K	Ca	Mg	S	Zn
	(%)	(1:2)	---------------------------- (ppm) ------------------------------					
Rice								
HH-1	2.3	7.7	22	72	1990	247	10	1.6
HH-2	2.2	7.5	16	52	1771	226	14	1.3
CB	2.4	7.8	19	69	1831	254	10	1.3
TA	2.4	7.8	21	71	1892	247	9	1.4
Soybean								
HH-Soy	2.6	7.4	18	85	1751	278	11	3.1

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

Table 2. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering and early heading stages and grain yield as affected by the main effect of N and P rates, averaged across Hydra-Hume DG rates, from two experiments (HH-1 & HH-2) at the Pine Tree Research Station, Colt, Ark., in 2012.

Site	Preplant N-P_2O_5[†] rates	Preflood N rate	Midtillering dry matter	Midtillering tissue concentration P	Midtillering tissue concentration Zn	Heading dry matter	Grain yield
	---------------- (lb/acre)		----------------	(%)	(ppm)	(lb/acre)	(bu/acre)
HH-1	0-0	0	576 d[‡]	0.165 b	23.8 b	3609 b	77 c
	18-60	0	762 c	0.180 b	22.8 b	--	91 b
	0-0	100	1443 b	0.283 a	26.6 a	8773 a	166 a
	18-60	100	1752 a	0.300 a	26.0 a	--	172 a
		P-value	<0.0001	<0.0001	0.0307	<0.0001[§]	<0.0001
HH-2	0-0	0	1283 b	0.189 b	12.8 c	4906 b	113 d
	18-60	0	1562 b	0.206 b	12.8 c	--	125 c
	0-0	100	2878 a	0.295 a	21.8 a	9242 a	180 b
	18-60	100	3146 a	0.291 a	19.9 b	--	188 a
		P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[†] Preplant N and P_2O_5 applied as 150 lb MESZ/acre (MESZ 12-40-0-10S-1Zn).

[‡] Means within each column followed by different lowercase letters are statistically different at 0.10.

[§] The NP-Fertilizer × Hydra-Hume DG rate interaction was significant *P* = 0.0565.

Table 3. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering and early heading stages and grain yield as affected by the main effect of Hydra-Hume DG (HH) rates, averaged across preplant P and preflood N rates, from two experiments (HH-1 & HH-2) established at at the Pine Tree Research Station, Colt, Ark., in 2012.

Site	HH rate[†]	Midtillering dry matter	Midtillering concentration P	Midtillering concentration Zn	Heading dry matter	Grain yield
	--------- (lb/acre)	---------	(%)	(ppm)	(lb/acre)	(bu/acre)
HH-1	0	1112 a[‡]	0.242 a	25.3 a	6653 a	125 a
	40	1174 a	0.229 a	24.5 a	5935 b	126 a
	200	1088 a	0.231 a	25.5 a	6133 b	127 a
	400	1148 a	0.225 a	24.0 a	6042 b	127 a
	P-value	0.6008	0.4991	0.5516	0.0346[§]	0.8336
HH-2	0	2261 a	0.246 a	17.1 a	6736 a	149 a
	40	2230 a	0.248 a	16.6 a	6923 a	152 a
	200	2144 a	0.242 a	16.6 a	7191 a	143 a
	400	2234 a	0.244 a	17.0 a	7447 a	153 a
	P-value	0.7095	0.8141	0.5959	0.2151	0.6409

[†] Hydra-Hume DG rates correspond to 0, 1, 5, and 10× the recommended rate of 40 lb HH/acre.

[‡] Means within each column followed by different lowercase letters are statistically different at 0.10.

[§] The NP-Fertilizer × Hydra-Hume DG rate interaction was significant at 0.0565.

Table 4. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering stage as affected by the main effect of Carbon Boost-S (CB) treatment, averaged across preflood N rates, at the Pine Tree Research Station, Colt, Ark., in 2012.

Carbon Boost-S application time[†]			Midtillering	Midtillering concentration		Grain
Preplant	Preflood	Midseason	dry matter	P	Zn	yield
------- (oz CB/acre/application) --------			(lb/acre)	(%)	(ppm)	(bu/acre)
0	0	0	1475 a[‡]	0.260 a	22.8 a	187 a
12	0	0	1350 a	0.262 a	23.1 a	181 a
12	8	0	1262 a	0.277a	22.4 a	184 a
0	8	8	1444 a	0.252 a	23.2 a	188 a
12	0	8	--[§]	--	--	186 a
12	8	8	--	--	--	186 a
		P-value	0.3456	0.5820	0.8562	0.7648

[†] Carbon Boost-S impregnated on triple superphosphate preplant or urea applied preflood or at midseason 8 oz/acre = 124 oz/ton fertilizer and 12 oz/acre = 185 oz/ton fertilizer.

[‡] Means within each column followed by the same lowercase letter are not statistically different at 0.10.

[§] -- indicates that there were no observations for these treatments.

Table 5. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering stage and grain yield as affected by preflood N rate, averaged across Carbon Boost-S treatments, at the Pine Tree Research Station, Colt, Ark., in 2012.

Preflood N rate	Midtillering dry matter	Midtillering tissue concentration P	Midtillering tissue concentration Zn	Grain yield
(lb urea-N/acre)	(lb/acre)	(%)	(ppm)	(bu/acre)
70	1372 a[†]	0.244 b	21.9 b	172 b
120	1393 a	0.281 a	23.9 a	199 a
P-value	0.6966	0.0249	0.0435	0.0123

[†] Means within each column followed by the same lowercase letter are not statistically different at 0.10.

Table 6. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering stage and grain yield as affected by preflood N rate, averaged across Titan-Accomplish treatments, at the Pine Tree Research Station, Colt, Ark., in 2012.

Preflood N rate	Midtillering dry matter	Midtillering tissue concentration P	Midtillering tissue concentration Zn	Grain yield
(lb urea-N/acre)	(lb/acre)	(%)	(ppm)	(bu/acre)
80	1378 a[†]	0.273 b	2.53 a	144 b
140	1225 a	0.318 a	2.78 a	190 a
P-value	0.4129	0.0078	0.1385	0.0003

[†] Means within each column followed by the same lowercase letter are not statistically different at 0.10.

Table 7. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering stage as affected by the main effect of Titan-Accomplish (TA) treatment, averaged across preflood N rates, at the Pine Tree Research Station, Colt, Ark., in 2012.

Titan-Accomplish application[†]				Midtillering concentration		
Apply method	Preplant TA Rate	Preflood TA Rate	Midtillering dry matter	P	K	Grain yield
	--------(oz TA/acre) ------		(lb/acre)	-------(%) -------		(bu/acre)
Spray	0	0	1180 a[‡]	0.283 a	2.35 b	161 a
Spray	8.3	0	1368 a	0.297 a	2.49 b	166 a
Fertilizer	0	0	1385 a	0.297 a	2.79 a	165 a
Fertilizer	8.3	0	1272 a	0.305 a	2.98 a	168 a
Fertilizer	8.3	8.5	--[§]	--	--	174 a
		P-value	0.6052	0.6749	0.0014	0.3004

[†] Apply method description: Spray, TA applied with backpack sprayer (no P or K fertilizer applied); and Fertilizer, Titan Accomplish impregnated on 60 lb P_2O_5/acre as triple superphoshate preplant or 80 lb K_2O/acre as muriate of potash applied preflood.

[‡] Means within each column followed by different lowercase letters are statistically different at 0.10.

[§] -- indicates that there were no observations for these treatments.

Growing-Season Methane Fluxes from Direct-Seeded, Delayed-Flood Rice Produced on a Clay Soil

A.D. Smartt, K.R. Brye, R.J. Norman, C.W. Rogers, and M. Duren

ABSTRACT

Rice (*Oryza sativa* L.) is the only major row crop that is grown under flooded soil conditions and is one of the main staple crops for much of the world. Rice production systems have a greater global warming potential (GWP) than upland row crops due to methane (CH_4) emissions resulting from anaerobic conditions of the flooded soils. The objectives of this study were to estimate methane emissions from rice and to begin an examination of factors and processes that affect methane emissions from rice production on clay soils in Arkansas. This study was conducted in 2012 at the Northeast Research and Extension Center in Keiser, Ark., on a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). The three experimental treatments evaluated were unfertilized bare-soil, optimally nitrogen (N)-fertilized rice, and non-N-fertilized rice. Gas samples were collected from enclosed-headspace gas sampling chambers at 0, 20, 40, and 60 min after chamber closure and methane fluxes were calculated from changes in headspace methane concentration over time. Fluxes were determined weekly during the flood retention period and every other day for one week following flood release. Methane fluxes increased during the vegetative growth period in both the fertilized and unfertilized rice treatments reaching maximum observed fluxes of 4.8 and 0.94 mg CH_4-C/m^2/hr, respectively, following 50% heading. Methane fluxes then decreased over time in both treatments containing rice and approached 0 mg CH_4-C/m^2/hr at flood release. Methane fluxes from the bare-soil treatment remained near zero throughout the flooded period. Methane fluxes after flood release remained low in all treatments until 5 days after flood release when substantial methane pulses of 0.77, 1.2, and 2.5 mg CH_4-C/m^2/hr were measured in the fertilized rice, unfertilized rice, and bare soil, respectively. Estimated methane emissions in this study were approximately 25%

of the Environmental Protection Agency (EPA) emissions factor, indicating that methane emissions from Arkansas rice production on a clay soil may be substantially less than the EPA estimate. More data are needed in order to accurately quantify methane emissions from Arkansas rice production.

INTRODUCTION

Rice (*Oryza sativa* L.) is the only major row crop that is grown under flooded-soil conditions and is one of the main staple crops for much of the world, with direct human consumption accounting for 85% of rice production compared to 72% and 19% for wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.), respectively (Maclean et al., 2002). However, the global warming potential (GWP) of rice systems is estimated to be 5.7 and 2.7 times greater than that of wheat and corn systems, respectively (Linquist et al., 2011). The greater GWP of rice systems is primarily due to methane (CH_4) emissions resulting from flooded-soil conditions, with methane contributing 92% to 93% of the GWP in rice systems (Linquist et al., 2012). Methane production occurs in flooded soils after oxygen is depleted and subsequent terminal electron acceptors are used before carbon dioxide is reduced to methane by anaerobic methanogenic bacteria at redox potentials less than -150 mV (Masscheleyn et al., 1993). Aerobic methanotrophic bacteria in oxygenated zones surrounding rice roots and at the soil-water interface potentially oxidize 58% to 90% of the produced methane (Holzapfel-Pschorn et al., 1985; Sass et al., 1990). The majority of methane emissions from a rice system occur through the rice plants via aerenchyma cells.

Methane is a greenhouse gas with a GWP 25 times greater than carbon dioxide (Forster et al., 2007). Globally, agriculture accounts for 47% of total anthropogenic methane emissions with 64% and 22% of agricultural emissions resulting from enteric fermentation and rice cultivation, respectively (EPA, 2006; Smith et al., 2007). In the United States, 30% of methane emissions result from agricultural activities with 70% of agricultural methane emissions from enteric fermentation and 4% from rice cultivation (EPA, 2012). A methane emissions factor of 160 kg CH_4-C/ha/season has been reported by the United States Environmental Protection Agency (EPA) for estimating methane emissions from a primary-rice crop in the U.S. (EPA, 2012). However, the-primary crop emissions factor is based on four U.S. studies conducted in California and Texas with emissions ranging from 16 to 359 kg CH_4-C/ha/season (Sass et al., 1991a,b; Cicerone et al., 1992; Bossio et al., 1999).

Methane emission studies in Arkansas under common cultural practices of the region have only recently been initiated (Rogers et al., 2012). It is important to accurately represent methane emissions under Arkansas cultural practices, as Arkansas is the leading rice producing state in the United States. Methane emissions from rice are also dependent upon factors such as soil texture, cultivar, residue management, and flood management (Sass et al., 1991a, 1992, 1994; Wassmann et al., 1993; Lindau et al., 1995). The objective of this study was to quantify methane fluxes from rice produced on a clay soil under common Arkansas production practices and examine factors and processes that affect methane emissions. This is the first study in Arkansas to address methane emissions from a clay soil, and it is important to be able to compare emissions to data being collected from silt-loam soils in Arkansas as well as data from other rice-producing regions of the United States. It is hypothesized that peak methane fluxes will be less from a clay soil than from a silt-loam soil under similar management and that fluxes will be greatest from N fertilized compared to unfertilized rice and bare soil, due to the resulting increase in biomass and root exudates from added N.

PROCEDURES

Research was conducted in 2012 at the Northeast Research and Extension Center in Keiser, Ark., on a Sharkey clay soil (very-fine, smectitic, thermic Chromic Epiaquerts). Residue management at the study site involved incorporation of crop residue in the fall using tillage and disking to a depth of 4 inches. Field plots were 6-ft wide by 16-ft long arranged in a randomized complete block design and were seeded in early April with the long-grain conventional cultivar Taggart at a rate of 100 lb/acre with 7.5-inch row spacing. The three treatments evaluated were unfertilized bare-soil that was kept weed free throughout the season, optimally N-fertilized rice, and non-fertilized rice. Nitrogen was applied to fertilized plots in the form of urea at a rate of 135 lb N/acre within 1 day prior to establishment of a permanent flood. An additional application of 45 lb N/acre as urea was made at panicle differentiation (PD) to fertilized plots. A flood depth of 2 to 4 inches was maintained on the plots until the flood was released at grain maturity in late August.

Soil samples were collected prior to flooding using a 1 inch push probe by combining 6 or 7 cores from the 0- to 4-inch depth in each plot. Samples were dried in a forced-draft oven at 160 °F (70 °C) for 48 h and sieved through a 2-mm mesh screen prior to being analyzed for Mehlich-3 extractable nutrients (P, K, Ca, Mg, Fe, Mn, Na, S, Cu, and Zn, Spectro Analytical Instruments, Spectro Arcos ICP, Kleve, Germany). Inorganic-N (NO_3-N and NH_4-N) was extracted with potassium chloride (KCl) and analyzed colorometrically on a Sans Skalar Wet Chemistry Auto-Analyser (Skalar, Netherlands). Total N and total C were determined by high-temperature combustion using a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). Soil pH was determined using a 1:2 soil to water ratio. Soil samples for bulk density determination were collected from the 0- to 4-inch depth using a 2 inch diameter core chamber. Soil bulk density samples were also ground and sieved through a 2-mm mesh screen and analyzed for particle-size distribution using a modified 12-h hydrometer method (Gee and Or, 2002).

Enclosed-headspace sampling chambers were used for collection of gas samples (Parkin and Venterea, 2010). Polyvinyl chloride chambers with an inner diameter of 11.75 inches and heights of 16, 24, and 40 inches were used to enclose rice plants and accommodate increasing plant heights over the growing season. Methane fluxes were determined weekly during flooded conditions by calculating rates of change in methane concentration over time from headspace gas collected from each chamber at 0, 20, 40, and 60 min after chamber closure. Methane fluxes were additionally determined every other day for one week immediately following flood release. Gas samples were analyzed using an Agilent 6890-N gas chromatograph (Agilent Technologies, Santa Clara, Calif.).

An analysis of variance was conducted to evaluate the effects of pre-assigned treatments on initial soil properties using SAS (v. 9.3, SAS Institute, Inc., Cary, N.C.). Means and standard errors are presented for initial soil properties and methane fluxes.

RESULTS AND DISCUSSION

Initial Soil Properties

Initial soil properties in the top 4 inches measured prior to flooding were unaffected by pre-assigned treatments (Table 1). Initial Mehlich-3 extractable soil P and K were within the optimal range for rice growth. Sufficient available nutrients are required for optimal plant growth and limiting nutrients such as N can strongly impact yield and biomass production in a crop. The impacts of fertility on plant growth as well as the abundance of electron acceptors such as Fe, Mn, NO_3, and SO_4 can all impact methane emissions. Soil physical properties such as particle size distribution and bulk density also affect methane emissions by influencing the rate of diffusion of gases through the soil. Diffusion of gases is slower through fine-textured soils due to increased tortuosity and smaller pore sizes.

Flooding to Flood Release

Methane release from rice cropping begins within days or weeks after flood establishment and methane flux peaks may be observed early in the growing season due to degradation of previous-crop residues, in the middle of the growing season as root exudates reach a maximum, and late in the season as plants and roots senesce and begin to decompose. Methane fluxes were negligible at 11 days after flooding (DAF) with fluxes ranging from <0.01 to 0.03 mg CH_4-C/m^2/hr (Fig. 1). Methane fluxes increased over time during the vegetative growth period in both the fertilized and unfertilized rice reaching maximum observed fluxes of 4.8 and 0.94 mg CH_4-C/m^2/hr, respectively, occurring just after 50% heading (HDG) in both treatments. Methane fluxes then decreased over time in both rice treatments and approached 0 mg CH_4-C/m^2/hr at flood release. Similar seasonal patterns have been observed in other studies, which suggest that root exudates increase during vegetative growth providing substrate for methanogenesis and decrease again during grain fill as resources are translocated to the grains (Sass et al., 1990, 1991a, 1991b, 1992). Methane fluxes from bare soil remained near zero throughout the flooded period, with a maximum flux of 0.06 mg CH_4-C/m^2/hr at 18 DAF. The early season maximum flux observed from the bare soil was likely the result of organic residue degradation, a process that has been linked to early season flux peaks in studies where organic residues were added prior to flooding (Schutz et al., 1990; Yagi and Minami, 1990).

Similar studies conducted on clay and silty-clay soils have reported maximum fluxes from fertilized rice ranging from 2.1 to 25 mg CH_4-C/m^2/hr, with all of the greater fluxes observed in direct-seeded, delayed-flood rice along the gulf coast in Texas (Sass et al., 1991a,b; Cicerone et al., 1992; Bossio et al., 1999). Cicerone et al. (1992) conducted a similar study on a Capay silty-clay soil (fine, smectitic, thermic Typic Haploxererts) in California and observed maximum methane fluxes of 0.9, 1.3, and 4.3 mg CH_4-C/m^2/hr from unfertilized bare soil, unfertilized rice, and fertilized rice, respectively. On a silt-loam soil under Arkansas production practices, Rogers et al. (2012) observed maxima of 11.6, 13.9, and 22.6 mg CH_4-C/m^2/hr for unfertilized bare soil, unfertilized rice, and fertilized rice, respectively. The two studies previously mentioned, as well as others, have given strong evidence that methane fluxes are less in fine-textured clay soils than in more coarse-textured soils such as silt loams (Sass et al., 1994; Sass and Fisher, 1997). The effect of N fertilizer on methane fluxes observed in this study is likely a result of the influence of N on plant growth due to the fact that added N increases biomass and root exudate production providing carbon for methane production and a larger pathway for release through the aerenchyma cells of rice plants. Without added N, rice yield and biomass are greatly reduced, generally more so for rice grown on clay soils than silt-loam soils in Arkansas. In this study, aboveground biomass accumulated over the growing season amounted to 1.0 and 2.8 kg/m^2 from the unfertilized and N fertilized rice, respectively. Sass et al. (1991a) report a strong positive relationship between methane emissions and biomass accumulation, supporting the observation of greater fluxes from N fertilized rice.

Flood Release to Harvest

Soil methane fluxes in all three treatments were approaching zero prior to flood release (74 DAF) and remained low until 5 days after flood release (DAFR) when substantial methane fluxes were observed from all three treatments (Fig. 1). Methane fluxes measured at 7 DAFR indicated negligible methane release from the soil. A similar trend was observed by Cicerone et al. (1992) where methane fluxes had neared zero immediately prior to flood release, peaked at 4 DAFR, then became negligible a few days later. Studies have indicated that post-flood-release pulses of methane can account for up to 10% of total methane released during the growing season (Denier van der Gon et al., 1995; Bossio et al., 1999; Rogers et al., 2012).

Methane fluxes at 5 DAFR were 0.77, 1.2, and 2.5 mg CH_4-C/m^2/hr for the fertilized rice, unfertilized rice, and bare soil, respectively (Fig. 1). The post-flood-release methane flux was greater than the maximum fluxes observed during flood retention for both the bare-soil and unfertilized rice. The post-flood-release pulse was present, but less pronounced in the N fertilized rice. Cicerone et al. (1992) observed a similar trend where the post-flood-release pulse was greatest in the bare soil and least in the fertilized rice with methane fluxes comparable to maxima observed during flood retention from bare soil and unfertilized rice. This trend may be an indication that methane emissions from rice produced on clay soils are limited by the amount of methane capable of moving through the rice plants, resulting in significant methane accumulation in the soil where plants are absent or sparse. The accumulated methane is then released during dry-down as the soil cracks, allowing gases to be rapidly released.

SIGNIFICANCE OF FINDINGS

Although the estimate is based on only four field studies, none of which accurately represent Arkansas production practices, the United States EPA is currently using a methane emissions factor of 160 kg CH_4-C/ha/season to estimate all U.S. methane emissions from primary-cropped rice. This study estimated total seasonal methane emissions from rice produced on a clay soil under common Arkansas production practices to be approximately 25% of the EPA emissions factor. This may be a substantial difference when considering the magnitude of Arkansas rice production coupled with the fact that nearly half of Arkansas rice is produced on clay, silty-clay, and clay-loam soils. Data concerning methane emissions under common Arkansas production practices are limited to only a few recent studies. It is important to continue investigating the impact of certain physical properties, such as soil texture, and cultural practices, such as residue management and crop rotation, in an attempt to more accurately quantify methane emissions from Arkansas rice production.

ACKNOWLEDGMENTS

Research for this project was supported by the Arkansas Rice Research and Promotion Board. We would also like to thank Taylor Adams and Doug Wolf for their assistance in the field and laboratory throughout this study.

LITERATURE CITED

Bossio, D.A., W.R. Horwath, R.G. Mutters, and C. van Kessel. 1999. Methane pool and flux dynamics in a rice field following straw incorporation. Soil Biol. Biochem. 31:1313-1322.

Cicerone R.J., C.C. Delwiche, S.C. Tyler, and P.R. Zimmerman. 1992. Methane emissions from California rice paddies with varied treatments. Global Biogeochem. Cycles 6:233-248.

Denier van der Gon, H.A.C., and H. Neue. 1995. Influence of organic matter incorporation on the methane emission from a wetland rice field. Global Biogeochem. Cycles 9:11-22.

EPA, Environmental Protection Agency. 2006. Global anthropogenic non-CO_2 greenhouse gas emissions: 1990 - 2020 [on-line]. Available at http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=2000ZL5G.PDF (Accessed 15 January, 2013).

EPA, Environmental Protection Agency. 2012. Inventory of U.S. greenhouse gas emissions and sinks: 1990 - 2010 [on-line]. Available at http://www.epa.gov/climatechange/ Downloads/ghgemissions/US-GHG-Inventory-2012-Main-Text.pdf (Accessed 15 October, 2012).

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland. 2007. Changes in atmospheric constituents and in radiative forcing. *In:* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, and H.L. Miller (eds.). Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, N.Y., U.S.A.

Gee, G.W. and D. Or. 2002. Particle size analysis. pp. 255-293. *In:* J.H. Dane and G.C. Topp (eds.). Methods of soil analysis: Physical Analysis. Soil Sci. Soc. Am., Madison, Wis.

Holzapfel-Pschorn, A., R. Conrad, and W. Seiler. 1985. Production, oxidation, and emissions of methane in rice paddies. FEMS Microbiol. Ecol. 31:343-351.

Lindau, C.W., P.K Bollich, and R.D. DeLaune. 1995. Effect of rice variety on methane emission from Louisiana rice. Agric. Ecosys. Environ. 54:109-114.

Linquist, B.A., K.J. van Groenigen, M.A. Adviento-Borbe, C. Pittelkow, and C. van Kessel. 2011. An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biol. 18:194-209.

Linquist, B.A., M.A. Adviento-Borbe, C.M. Pittelkow, C. van Kessel, and K. van Groenigen. 2012. Fertilizer management practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. Field Crop Res. 135:10-21.

Maclean, J.L., D.C. Dawe, B. Hardy, and G.P. Hettel (eds). 2002. Rice almanac. Source book for the most important economic activity on Earth (3rd Ed.). CABI Publishing, Wallingford, United Kingdom.

Masscheleyn, P.H., R.D. Delaune, and W.H. Patrick Jr. 1993. Methane and nitrous oxide emissions from laboratory measurements of rice soil suspension: effect of soil oxidation-reduction status. Chemosphere 26:251-260.

Parkin, T. and R. Venterea. 2010. Chamber-based trace gas flux measurements. *In:* R. Follett (ed.). Sampling Protocols [on-line]. Available at www.ars.usda.gov/research/GRACEnet (accessed 25 January, 2012).

Rogers, C.W., K.R. Brye, R.J. Norman, and T. Gasnier. 2012. Methane emissions from a silt-loam soil under direct-seeded, delayed-flood rice management. *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. 600:240-247. Fayetteville.

Sass, R.L. and F.M. Fisher. 1997. Methane emissions from rice paddies: A process study summary. Nutr. Cycl. Agroecosys. 49:119-127.

Sass, R.L., F.M. Fisher, P.A. Harcombe, and F.T. Turner. 1990. Methane production and emissions in a Texas rice field. Global Biogeochem. Cycles 4:47-68.

Sass, R.L., F.M. Fisher, P.A. Harcombe, and F.T. Turner. 1991a. Mitigation of methane emissions from rice fields: Possible adverse effects of incorporated rice straw. Global Biogeochem. Cycles 5:275-287.

Sass, R.L., F.M. Fisher, F.T. Turner, and M.F. Jund. 1991b. Methane emissions from rice fields as influenced by solar radiation, temperature, and straw incorporation. Global Biogeochem. Cycles 5:335-350.

Sass, R.L., F.M. Fisher, Y.B. Wang, F.T. Turner, and M.F. Jund. 1992. Methane emissions from rice fields: The effect of flood water management. Global Biogeochem. Cycles 6:249-262.

Sass, R.L., F.M. Fisher, S.T. Lewis, F.T. Turner, and M.F. Jund. 1994. Methane emissions from rice fields: Effects of soil properties. Global Biogeochem. Cycles 8:135-140.

Schutz, H., W. Seiler, and H. Rennenberg. 1990. Soil and land use related sources and sinks of methane (CH_4) in the context of the global methane budget. *In:* A.F. Bouwman (ed.). Soils and the greenhouse effect. pp. 269-285. John Wiley, Chichester, United Kingdom.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, and O. Sirotenko. 2007. Agriculture. *In:* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.). Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, N.Y., U.S.A.

Wassmann, R., H. Papen, and H. Rennenberg. 1993. Methane emission from rice paddies and possible mitigation strategies. Chemosphere 26:201-217.

Yagi, K. and K. Minami. 1990. Effects of organic matter applications on methane emission from Japanese paddy fields. *In:* A.F. Bouwman (ed.). Soils and the Greenhouse Effect. pp. 467-473. John Wiley, Chichester, United Kingdom.

Table 1. Mean soil physical and chemical properties (n = 12) prior to flood establishment in the top 4 inches of a Sharkey clay soil during the 2012 growing season at the Northeast Research and Extension Center in Keiser, Ark.

Soil property	Mean (± standard error)
pH	7.6 (0.02)
Sand (g g^{-1})	14.5 (0.26)
Silt (g g^{-1})	35.3 (0.27)
Clay (g g^{-1})	50.2 (0.36)
Bulk Density (g cm^{-3})	0.83 (0.03)
Electrical Conductivity (µmhos cm^{-1})	299 (20.6)
Mehlich-3 Extractable Nutrients (mg kg^{-1})	
P	80 (3.7)
K	346 (6.3)
Ca	4671 (34)
Mg	857 (4)
Fe	412 (5.6)
Mn	70 (3)
Na	65 (1.3)
S	19 (1.1)
Cu	5 (0.05)
Zn	3.6 (0.05)
B	1 (0.02)
NO_3-N (mg kg^{-1})	5.5 (0.55)
NH_4-N (mg kg^{-1})	11.9 (1.4)
Organic Matter (g kg^{-1})	34 (0.6)
Total N (g kg^{-1})	1.2 (0.001)
Total N (Mg ha^{-1})	1.0 (0.04)
Total C (g kg^{-1})	14 (0.03)
Total C (Mg ha^{-1})	11.4 (0.6)
C:N Ratio	11.2 (0.1)

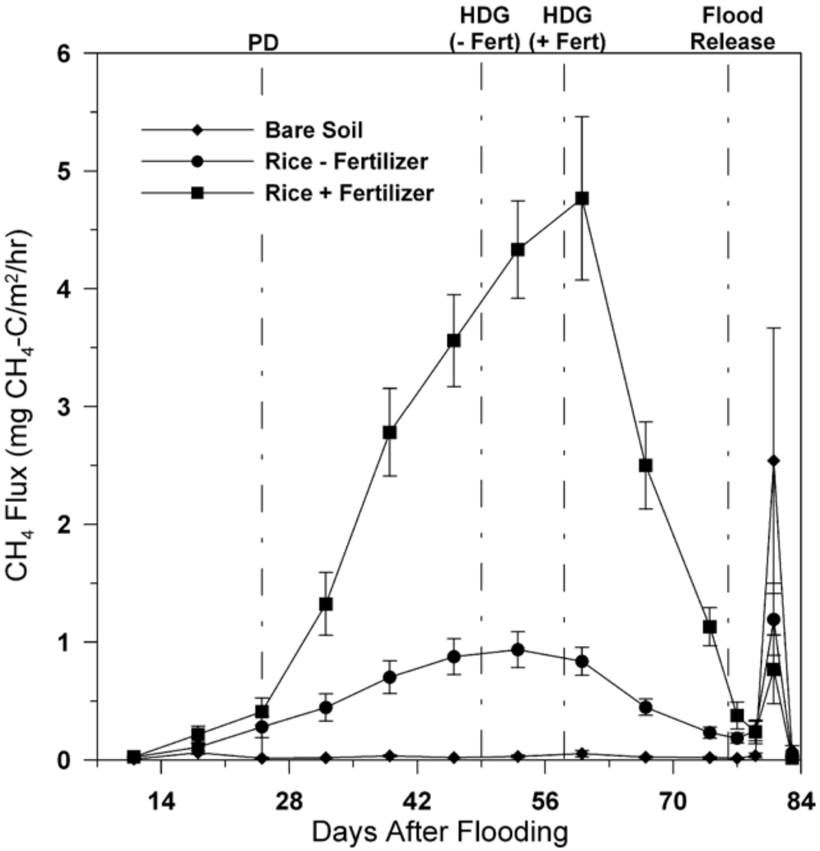


Fig. 1. Growing-season methane fluxes for bare soil, unfertilized rice (Rice - Fertilizer), and fertilized rice (Rice + Fertilizer) measured from a Sharkey clay soil at the Northeast Research and Extension Center in Keiser, Ark. Vertical lines on the graph indicate dates of panicle differentiation (PD), 50% heading for the unfertilized (HDG - Fert) and nitrogen (N) fertilized (HDG + Fert) rice, and flood release. Error bars represent plus/minus one standard error.

Impacts of Thickness Grading on Milling Yields of Long-Grain Rice

B.C. Grigg and T.J. Siebenmorgen

ABSTRACT

As variations in kernel uniformity can affect rice milling performance, limited thickness-grading to remove thin kernels was evaluated for effects on milling yields. Along with unfractioned (UNF) rice of four long-grain cultivars, rough rice was mechanically sieved, resulting in two thickness fractions, Thick (>0.079 inch) and Thin (<0.079 inch). Milled rice yield (MRY) and head rice yield (HRY) were determined for each cultivar/fraction. Thickness grading resulted in between 67% and 90% Thick kernels. Milled rice yield of Thick kernels was greater than that of Thin kernels, and were generally greater than UNF. Moreover, HRYs of Thick kernels were greater than both Thin and UNF. Thickness-grading improved milling-yield parameters, and showed a trend for reducing chalkiness of Thick kernels when compared to UNF. Although it would create an extra process operation and flow, benefits to milling yield could justify this procedure.

INTRODUCTION

Milling yield, either milled rice yield (MRY) or head rice yield (HRY), largely determines the economic value of rough rice. Milled rice yield represents the mass fraction of unprocessed, rough rice that remains as milled rice, which includes both head rice and broken kernels. Head rice yield represents the mass fraction of rough rice that remains as head rice, defined as the well-milled rice kernels three-fourths or more of the original kernel length. The goal of the milling operation is to maximize MRY and HRY while processing to a desired degree of milling.

Surface lipid content (SLC) of milled rice is an indicator of degree of milling (Hogan and Deobald 1961), with SLC declining as degree of milling increases. Elevated

SLC values negatively impact sensory properties of stored milled rice (Wadsworth, 1994). Therefore, it is important to carefully control degree of milling during processing (Wadsworth, 1994), and to monitor and adjust for lot-to-lot milling variability (Siebenmorgen et al., 2006).

Chen et al. (1998) showed that when rice was milled in bulk, and the milled rice subsequently thickness-fractioned, the thinner kernels tended to mill at a slower rate, thus having greater SLC than thicker kernels. As such, commercial milling operators tend to over-mill the thick kernels in a bulk lot in order to process the thin kernels to the desired degree of milling, thus reducing both MRY (Wadsworth, 1994) and HRY (Sun and Siebenmorgen, 1993). Size-exclusion techniques could reduce milling variability inherent within lots (Chen et al., 1998).

Thickness grading has been proposed as a means of improving kernel uniformity by removing thin, rough rice kernels, and designating the thin kernels for alternate use, such as parboiling (Matthews et al., 1982). Sun and Siebenmorgen (1993) showed greater HRYs for thicker kernels of rice when compared to bulk, unfractioned rice of three long-grain cultivars. Rohrer et al. (2004) reported that, when fractioned as rough rice prior to milling, thin kernels milled to a lower SLC and HRY compared to thicker kernels at the same milling duration. Thus, if size-fractioning were implemented, millers could potentially reduce over-milling of thicker kernels, while reducing the milling duration for the additional thin-kernel processing stream, and ultimately increasing overall MRY and HRY. As such, the goal of this research was to examine limited thickness-grading to increase MRY and HRY, in a manner potentially compatible with commercial-scale milling operations.

PROCEDURES

Four long-grain rice cultivars, two pure-lines (CL151 and Wells) and two hybrids (CLXL729 and CLXL745), were evaluated. Three of the cultivar lots (CL151, CLXL729, and CLXL745) were combine-harvested in 2011 from large-scale strip-trials near Jonesboro, Ark. The Wells lot from the University of Arkansas Rice Research and Extension Center, Stuttgart, Ark., was also combine-harvested. Lots were cleaned, conditioned to approximately 12.5% (wet basis) moisture content, and stored at 40 ± 2 °F prior to thickness grading. One day prior to thickness grading, bulk samples were removed from refrigerated storage and equilibrated to room temperature (72 ± 2 °F).

In addition to unfractioned (UNF) rice, a portion of each bulk rice lot was thickness graded using a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.) equipped with a No. 24 screen (0.079 × 0.47 inch slot) in the top-most, vertically-oscillating position. A No. 22 screen (0.059 × 0.47 inch slot) was used in the underlying, laterally-oscillating position, and was the final screen, allowing passage of only fines and unfilled kernels. Bulk rice was screened only once, and split into only two thickness fractions, Thick (> 0.079 inch) and Thin (< 0.079 inch) rough rice. This thickness-grading procedure was designed to approximate what could potentially occur at a milling facility with high rough rice throughput.

Four replicate 150-g samples of rough rice of each cultivar/fraction were prepared. The samples were dehulled in a laboratory sheller (THU 35B, Satake, Hiroshima, Japan) with a clearance of 0.019 inch between the rollers, and milled for 30 s using a laboratory mill (McGill No. 2 mill, RAPSCO, Brookshire, Texas) equipped with a 1.5-kg weight on the lever arm, situated 6 inches from the milling chamber centerline. Milled rice yield was determined, and then head rice was separated from brokens to determine HRY. As an indicator of degree of milling, SLC was quantified for head rice kernels of each cultivar/fraction sample using a lipid extraction system (Avanti 2055, Foss North America, Eden Prairie, Minn.).

Analysis of variance (ANOVA, $\alpha = 0.05$), and means separation using Fisher's least significant difference procedure (LSD) at a significance level of 0.05 were conducted using statistical software (JMP release 9.0, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Thickness-grading of rough rice resulted in Thick fractions ranging from 67% to 90% of the bulk rice on a mass basis (Fig. 1). Clearfield 151, CLXL729, and CLXL745 had 85% or greater Thick kernels, while the Wells cultivar, had only 67% Thick kernels. Thickness grading of commonly produced, long-grain rice cultivars in the mid 1970s (Matthews and Spadaro, 1976) resulted in only 2% to 54% kernels equivalent to the Thick-kernel fraction herein. Sun and Siebenmorgen (1993) report between 20% and 70% Thick kernels for three long-grain rice cultivars. In contrast, the range of 67% to 90% Thick kernels from this current study was narrower, and approached or exceeded the maximum proportion of Thick kernels of cultivars reported previously. Thus, there appears to be a shift toward greater kernel thickness with current long-grain rice cultivars produced in the mid-South region of the United States. As a result, the simplified thickness-grading approach presented here should provide for a minimal thin-fraction processing stream.

The 30-s milling duration resulted in a degree of milling close to the target 0.4% SLC for UNF and Thick rice of all cultivars. Thickness grading resulted in a trend of greater MRY of Thick kernels when compared to UNF rice, with the exception of Wells (Fig. 2). In the case of both CL151 and CLXL729, MRY for Thick kernels was significantly greater than that of UNF rice. The MRY for Thick kernels of CLXL745 followed the same trend as the CL151 and CLXL729 cultivars, but the difference from UNF rice was not significant. The MRYs for both Thick kernels and UNF rice were significantly greater than that of Thin kernels at the 30-s milling duration for all cultivars (Fig. 2). Although significant, the difference in MRYs of Thick and Thin kernels for the Wells lot was less than that observed for the other three cultivars.

Also at this 30-s milling duration, HRY of the Thick kernels was significantly greater than that of UNF rice for all cultivars (Fig. 2). As observed for MRY, HRYs of the Thin kernels were significantly lower than either Thick or UNF rice for all cultivars (Fig. 2). With the exception of Wells, this was partially the result of greater degree of milling (lower SLC) of the Thin kernels relative to Thick kernels and UNF rice (Fig. 3).

Rohrer et al. (2004) also reported a similar trend, where thin kernels milled faster than thick kernels when milled separately. However, Thin kernels of all cultivars, including Wells, had significantly lower MRY and HRY than Thick kernels or UNF rice (Fig. 2). Thus, the reduced MRY and HRY of Thin kernels were attributed primarily to greater breakage of Thin kernels during the milling process. Because of the relative proportions of Thin kernels generated from thickness-grading the selected bulk samples, there were insufficient Thin kernels to allow additional, shorter milling durations to achieve the target 0.4% SLC, which would have invariably increased both MRY and HRY for the Thin fraction.

SIGNIFICANCE OF FINDINGS

The procedure presented here for single-pass, thickness grading generally resulted in greater MRY, and always resulted in significantly greater HRY, of Thick kernels when compared to UNF rice. Moreover, these four cultivars currently popular in the mid-South United States have a sufficiently large fraction of Thick kernels to minimize the secondary process flow of Thin kernels. While thickness-grading would create a secondary process flow, improved milling yields and greater kernel uniformity could justify this procedure.

ACKNOWLEDGMENTS

The authors acknowledge the Arkansas Rice Research and Promotion Board and corporate sponsors of the University of Arkansas Rice Processing Program for financial support.

LITERATURE CITED

Chen, H., T.J. Siebenmorgen, and K. Griffin. 1998. Quality characteristics of long-grain rice milled in two commercial systems. Cereal Chem. 75(4):560-565.

Hogan, J.T. and H.J. Deobald. 1961. Note on a method of determining the degree of milling of whole milled rice. Cereal Chem. 38(3):291-293.

Matthews, J. and J.J. Spadaro. 1976. Breakage of long-grain rice in relation to kernel thickness. Cereal Chem. 53(1):13-19.

Matthews, J., J.I. Wadsworth, and J.J. Spadaro. 1982. Characteristics of the thin rice kernels before and after parboiling. Trans. ASAE. 25(3):818-819.

Rohrer, C.A., A.L. Matsler, and T.J. Siebenmorgen. 2004. Comparison of three extraction systems for determining surface lipid content of thickness-fractionated milled rice. Cereal Chem. 81(4):544-548.

Siebenmorgen, T.J., A.L. Matsler, and C.F. Earp. 2006. Milling characteristics of rice cultivars and hybrids. Cereal Chem. 83(2):169-172.

Sun, H. and T.J. Siebenmorgen. 1993. Milling characteristics of various rough rice kernel thickness fractions. Cereal Chem. 70(6):727-733.

Wadsworth, J.I. 1994. Chapter 7: Degree of Milling. pp. 139-176 *In:* W.E. Marshall and J.I. Wadsworth (eds.). Rice Science and Technology. New York, N.Y.: Marcel Dekker, Inc.

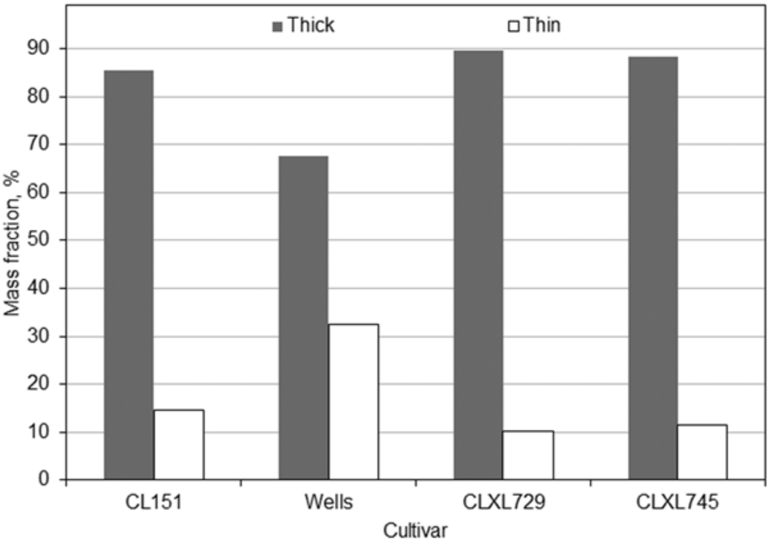


Fig. 1. Mass fractions resulting from thickness-grading of rough rice of four long-grain cultivars using a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.) equipped with a No. 24 screen (0.079 × 0.47 inch slot) in the top-most, vertically-oscillating position. Fractions comprise thickness >0.079 inch (Thick) and <0.079 inch (Thin).

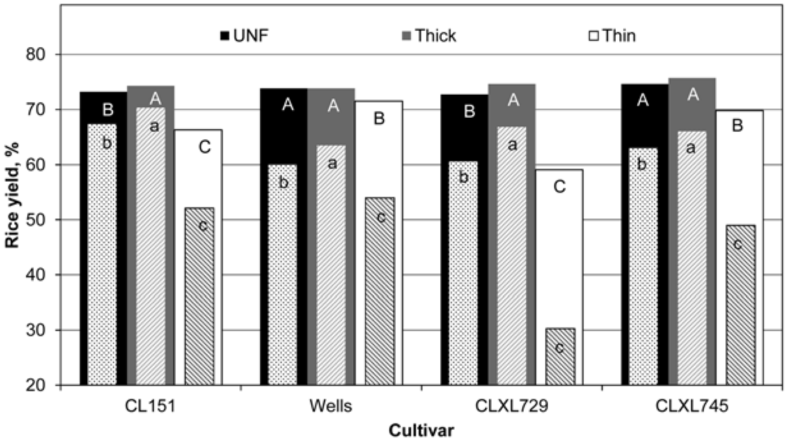


Fig. 2. Rice yield [milled rice yield (MRY) or head rice yield (HRY); milling duration of 30 s] of thickness fractions, in response to thickness-grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>0.079 inch), Thin (<0.079 inch), and unfractioned (UNF) rice. Solid bars indicate MRY and inset, crosshatched bars indicate HRY. Letters inset within each bar facilitate the comparison of means within a cultivar; uppercase letters are associated with MRY, and lowercase letters with HRY; means with the same letter were not significantly different (*P* >0.05).

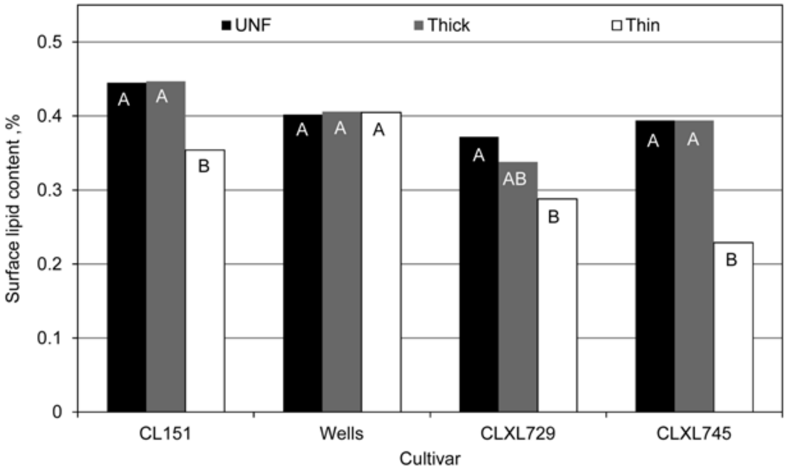


Fig. 3. Surface lipid contents of head rice (milled kernels; milling duration of 30 s) in response to thickness-grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>0.079 inch), Thin (<0.079 inch), and unfractioned (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different (*P* > 0.05).

RICE QUALITY AND PROCESSING

Pre-Harvest Nighttime Temperatures Affect Head Rice Color

S.B. Lanning and T.J. Siebenmorgen

ABSTRACT

Elevated nighttime temperatures during the grain-filling stages of kernel development impacted the color of milled rice kernels. Six cultivars, grown at multiple field locations from northern to southern Arkansas during 2007 to 2010, were evaluated for head rice whiteness (*L**), yellowness (*b**), and chalk. Nighttime air temperatures (NTATs) were recorded throughout production at each location, and the 95th percentiles of NTAT frequencies (NT_{95}) were calculated for each cultivar's reproductive (R) stages. Head rice color was analyzed in relation to NT_{95} occurring during the grain-filling stages (R6 to R8) and to percent chalkiness. Whiteness increased with increasing NTAT, and with increasing chalkiness. Moreover, kernel whiteness increased even when measured in the absence of chalky kernels. Yellowness decreased as chalk increased. Cultivars varied in their susceptibility to the effect of NTAT on color.

INTRODUCTION

Rice color is an important indicator of milled rice quality, and thus impacts the commercial value of rice. It has been anecdotally observed that rice lots of the same cultivar but from different crop years vary in color as a result of environmental growing conditions. Research indicates that elevated nighttime air temperatures (NTATs) occurring during critical rice reproductive stages have deleterious effects on kernel formation and resultant milling quality and physicochemical properties. Early studies showed strong correlations of yield decrease with NTATs above 70 °F (24 °C) during the grain-filling stages (Downey and Wells, 1975). More recently, a 4-year field study of six cultivars grown in Arkansas showed that elevated NTAT during the grain-filling stages increased levels of some physicochemical properties, such as chalk and lipid contents, while reducing levels of others, including amylose and protein contents (Lanning et al., 2011, 2012). It stands to reason that kernel color also may be impacted by disruptions in kernel development, thus explaining some of the observed cultivar and year variation. The following analysis, based on the same 2007-2010 data set used by Lanning et al. (2011), evaluated the effects of NTAT on the color of milled rice.

PROCEDURES

Six cultivars (Bengal, Jupiter, LaGrue, Cypress, Wells, and XL723) were grown in triplicate plots at the locations shown in Table 1 from 2007 to 2010 as part of the Arkansas Rice Performance Trials (ARPT). Reproductive (R) growth stages (Counce et al., 2000) were either visually identified or estimated from weather data, as described by Ambardekar et al., 2011. Nighttime temperature levels were quantified by NT_{95}, the temperature value below which 95% of all NTATs fell for a given year/location/cultivar/R-stage (Ambardekar et al., 2011). This value was determined as a means of providing one temperature value with which to correlate color values that were measured for each year/location/cultivar combination (Figs. 1 and 4).

In each study year and location, samples of each cultivar were hand-harvested over a range of moisture contents. Samples were cleaned (Carter-Day Dockage Tester, Carter-Day Co., Minneapolis, Minn.) and dried in a temperature- and humidity-controlled chamber (AA5582, Parameter Generation & Control, Inc., Black Mountain, N.C.) to 12.0 ± 0.5% MC[1].

Rough rice (100 g) from each harvest lot was de-hulled in a laboratory sheller (THU, Satake, Tokyo, Japan) with a clearance of 0.048 cm (0.019 inch) between the rollers. Chalk measurements were performed on duplicate, 100-kernel brown rice sets from each harvest year/location/cultivar/replication/HMC combination using an image analysis system (WinSeedle Pro 2005a™, Regent Instruments Inc., Sainte-Foy, Quebec, Canada; Ambardekar et al., 2011). For each 100-kernel set, the imaging system measured and recorded the number of pixels representing the entire kernel area from the scanned images of the 100 kernels, as well as the number of pixels corresponding to those areas color-classified for chalk. Percent chalk in a sample was determined as the ratio of the total chalky area (pixels) of the 100-kernel set to the total projected area of the kernels, multiplied by 100.

Duplicate, 150-g rough rice sub-samples from each harvest lot were de-hulled as described above. The resultant brown rice samples were milled for 30 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) with a 1.5-kg weight on the lever arm situated 15 cm from the milling chamber. Head rice was then separated from broken pieces using a double-tray sizing device (Seedburo Equipment Co., Chicago, Ill.).

Color of the duplicate head rice samples was measured using a colorimeter (Colorflex EZ 45°/0°, Hunterlab, Reston, Va.). Initial measurements were taken with chalky kernels included. Approximately 35 g of each sample were placed in a 6-cm

---

[1] Moisture contents are expressed on a wet basis, unless otherwise specified.

diameter clear plastic sample cup, centered over a 3-cm sample port, and covered with an opaque cup to block ambient light. The illuminant and observer settings were D65 and 10°, respectively. The *L** (black to white) and *b** (blue to yellow) color indices were measured simultaneously. After the first color measurement was taken, the sample cup was rotated 90° and a second measurement was performed. An average of the two readings for each color index was recorded for each sample.

A subset of head rice samples was re-evaluated for color after chalky kernels were removed. Three cultivars, Cypress, LaGrue, and XL723, were selected due to their reported susceptibility to the effect of elevated NTATs on chalk formation (Ambardekar et al., 2011; Lanning et al., 2011). For each cultivar, samples from two harvest years (2009 and 2010) and four locations (Northeast Research and Extension Center, Keiser, Ark.; Pine Tree Research Station, Colt, Ark.; Rohwer Research Station, Rohwer, Ark.; and Rice Research and Extension Center, Stuttgart, Ark.) were selected to encompass a broad range of NTATs. Samples were limited to those with harvest moisture contents of approximately 19% to 22% (w.b.) in order to minimize the number of immature and/or fissured kernels, resulting in a total of 78 samples. Chalky kernels, those with approx. 10% or more of the total area appearing opaque white by visual observation, were removed from each sample. The 10% limit was set to minimize the amount of chalk in a sample, and thus evaluate the effect of NTAT on kernel color, exclusive of chalk formation. After removal of chalky kernels, the remaining head rice was analyzed for color as described above.

Head rice whiteness (L^*) and yellowness (b^*) values were plotted against NT_{95} during each R-stage. Statistical significance of the correlations was determined by analysis of variance at $\alpha = 0.05$ using polynomial regression analysis (JMP release 8.2, SAS Institute, Inc., Cary, N.C.). Means were compared using Tukey significance tests at a 5% level of probability to indicate significant differences in L^* and b^* values of head rice samples with and without chalky kernels.

RESULTS AND DISCUSSION

Based on field temperatures recorded throughout the study, harvest years 2007 and 2010 were warmer than 2008 and 2009 (Table 1). As expected, average NTATs measured during the critical grain-filling stages (R6 to R8) increased from northern to southern locations. Analysis of the four-year data set shows that L^* values increased significantly as NT_{95} increased during each of these stages, as illustrated for the R8 stage in Fig. 1.

Across all years, certain cultivars exhibited greater positive correlations than others (Table 2). Jupiter and Bengal, which have been shown to be fairly resistant to the effects of elevated NTAT (Cooper et al., 2008, Ambardekar et al., 2011, Lanning et al., 2011), showed weak or no significant correlations between L^* and NT_{95}. Cypress and Wells showed significant and relatively strong correlations in R7 and R8 and XL723 and LaGrue showed significant correlations in all three stages. These observations paralleled those of Ambardekar et al. (2011) and Lanning et al. (2011), wherein cultivars varied in their degree of susceptibility to chalk formation when exposed to elevated NTATs during these reproductive stages.

Results of the four-year data analysis also indicated a significant positive relationship between whiteness (L^*) and chalk (Fig. 2), suggesting that increases in whiteness with NTATs were due to corresponding increases in chalk with NTAT, as shown by Ambardekar et al. (2011) and Lanning et al. (2011). However, the colorimetric analysis of head rice measured with and without chalky kernels revealed that L^* values did not change significantly with the exclusion of chalky kernels. Figure 3 provides an example of the trends observed; head rice samples of Cypress collected in 2010 from two growing locations (Keiser and Rohwer) were analyzed for whiteness with and without chalky kernels. Whiteness values trended slightly lower with the exclusion of chalky kernels, but the differences were not statistically significant. Moreover, whiteness of the sample grown at Rohwer, where NT_{95} (R8) was 90 °F (32 ºC), was significantly greater than that of the sample grown at Keiser, where NT_{95} (R8) was only 81 °F (27 ºC), even when chalky kernels were excluded from the sample, confirming the trends shown in Fig. 1. These findings suggest that the correlation between increasing NTAT and increasing whiteness may not be related solely to the presence of chalk in individual kernels. Rather, the effects of NTAT on kernel formation may influence overall translucency and whiteness of kernels.

Trends relating b^* to NT_{95} during the R8 stage were parabolic (Fig. 4), suggesting that yellowness was less apparent at both low and high NTATs than in the intermediate NTAT range. It is notable that the temperature at which yellowness values peaked was approximately 81 °F (27 °C), corresponding to the temperature at which chalk formation begins to increase exponentially (Lanning et al., 2011). Furthermore, b^* values generally decreased with increasing chalk in each year of the study (data not shown). Across all cultivars and locations, b^* values were significantly lower in 2009, the coolest year of the study. However, b^* values collected in 2008, another cool year, tended to be similar to 2007 and 2010 values ($\alpha > 0.05$), although with a much smaller range of values observed. While the results of the current study do not explain the difference in b^* values from 2008 to 2009, they do suggest that multiple environmental factors may influence yellow color formation in rice kernels, and that their effects may be superseded by the impact of elevated NTAT as it relates to kernel formation and chalkiness.

SIGNIFICANCE OF FINDINGS

The findings of this 4-year study offer a possible explanation for year-to-year variation in milled rice kernel color. Elevated nighttime temperatures occurring during the critical grain-filling stages of kernel development resulted in increased whiteness values of head rice. Whiteness generally increased, while yellowness decreased, with increasing chalkiness. Moreover, kernel whiteness increased with increasing NTAT, even in the absence of chalky kernels, suggesting that overall kernel formation was affected. Cultivars varied in their susceptibility to this response, such that in general, the susceptibility of a cultivar to changes in whiteness due to NTAT corresponded to that observed for milling quality and functional properties (Lanning et al., 2011, 2012).

ACKNOWLEDGMENTS

The authors acknowledge the Arkansas Rice Research and Promotion Board and the corporate sponsors of the University of Arkansas Rice Processing Program for financial support of this project.

LITERATURE CITED

Ambardekar, A.A., T.J. Siebenmorgen, P.A. Counce, S.B. Lanning, and A. Mauromoustakos. 2011. Impact of field-scale nighttime air temperatures during kernel development on rice milling quality. Field Crops Res. 122(3):179-185.

Cooper, N.T.W., T.J. Siebenmorgen, and P.A. Counce. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. Cereal Chem. 85(3):276-282.

Counce, P.A., T.C. Keisling, and A.J. Mitchell. 2000. A uniform, objective, and adaptive system for expressing rice development. Crop Sci. 40(2):436-443.

Downey, D.A. and B.R. Wells. 1975. Air temperatures in Starbonnet rice canopy and their relationship to nitrogen timing, grain yield, and water temperature. University of Arkansas Agricultural Experiment Station Bulletin 796. Fayetteville.

Lanning, S.B., T.J. Siebenmorgen, P.A. Counce, A.A. Ambardekar, and A. Mauromoustakos. 2011. Extreme nighttime air temperatures in 2010 impact rice chalkiness and milling quality. Field Crops Res. 124(1):132-136.

Lanning, S.B., T.J. Siebenmorgen, A. Ambardekar, P.A. Counce, and R.J. Bryant. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties. Cereal Chem. 89(3):168-175.

Table 1. Nighttime air temperatures (NTATs)[a] recorded during the R6 to R8 stages, averaged across all cultivars, at the indicated Arkansas growing locations from 2007-2010.

	Average (Avg) NTAT (°F) by location						Avg. NTAT
Year	Keiser	Corning	Newport	Pine Tree	Stuttgart	Rohwer	(°F) by year
2007	NA[b]	75	73	NA	75	76	75
2008	NA	69	NA	60	70	67	67
2009	NA	NA	NA	67	70	68	65
2010	71	NA	67	73	78	80	74

[a] Average of ambient temperatures recorded at 30-min intervals during the time of day extending from 8:00 p.m. to 6:00 a.m.

[b] NA = not a growing location in the indicated year.

Table 2. Coefficients of determination (R^2) of whiteness (L^*) and yellowness (b^*) values versus the 95th percentiles of nighttime air temperature frequencies during the R6-R8 reproductive stages for the indicated rice cultivars grown throughout Arkansas from 2007-2010.

	R-Stage	Bengal	Jupiter	Cypress	LaGrue	Wells	XL723
R^2							
L^*	R6	NS	NS	NS	0.525	NS	0.556
	R7	NS	NS	0.545	0.602	0.620	0.487
	R8	NS	0.410	0.700	0.755	0.818	0.739
b^*	R6	NS	NS	NS	NS	NS	NS
	R7	NS	NS	0.368	NS	NS	0.567
	R8	0.469	0.514	0.397	0.269	0.369	0.545

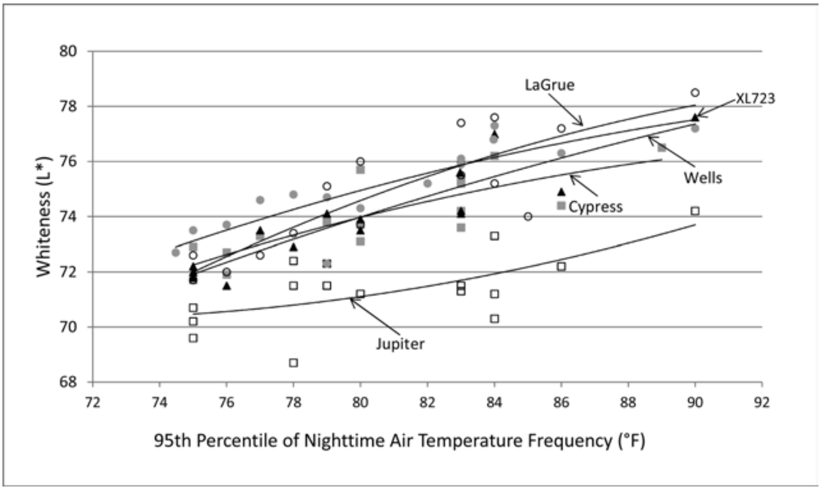


Fig. 1. Relationship of whiteness (L^*) values and 95th percentiles of nighttime air temperature frequencies during the R8 stage for the indicated cultivars grown from 2007-2010. (Cultivar Bengal did not exhibit a significant relationship at any R-stage.)

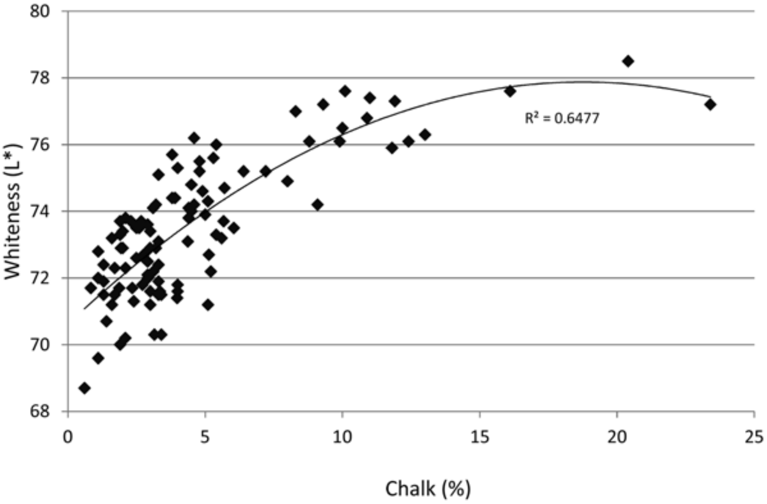


Fig. 2. Effect of chalk on whiteness values (*L) of head rice from six cultivars (Table 2) grown across six Arkansas locations (Table 1) from 2007-2010. Chalk and *L** values were averaged across a range of harvest moisture contents for each cultivar-location combination.**

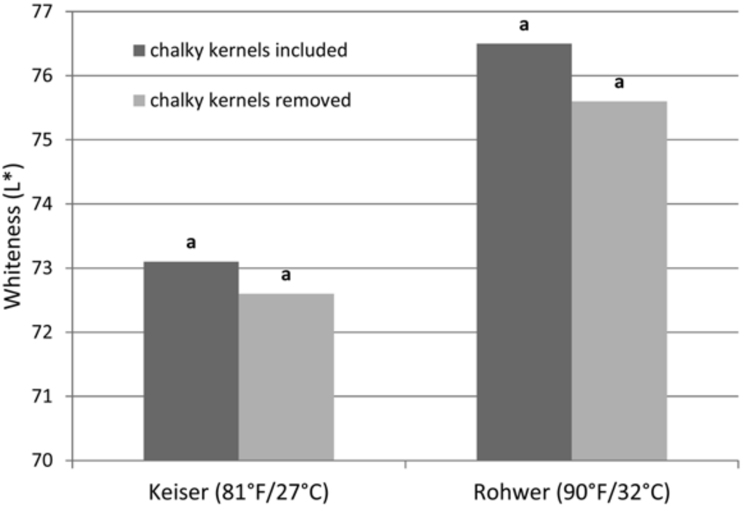


Fig. 3. Whiteness values of Cypress head rice sampled from the indicated growing locations in 2010 and analyzed for whiteness (*L) with and without chalky kernels. Temperatures noted in the x-axis labels represent 95th percentile temperatures observed during the R8 stage from each respective location.**

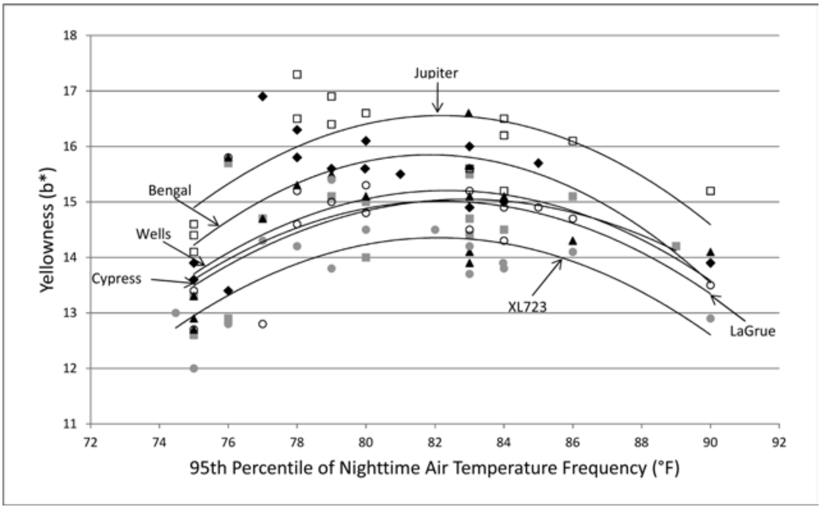


Fig. 4. Relationship of yellowness (*b) values and 95th percentiles of nighttime air temperature frequencies during the R8 stage for the indicated cultivars grown from 2007-2010.**

Differential Grain Development and Endosperm Gene Expression as Tools to Understand Rice Cultivar Responses to Increased Nighttime Air Temperatures

N.L. Lawson, L.D. Nelson, P.A. Counce,
K.A.K. Moldenhauer, T.J. Siebenmorgen, and K.L. Korth

ABSTRACT

Mounting evidence has made it clear that increasing nighttime air temperatures contribute to decreased head rice yields and decreased grain quality due to chalkiness and altered physicochemical properties. Our goal is to determine some of the fundamental changes that occur in developing rice kernels as they respond to high air temperatures, especially at night. Panicles collected from field-grown plants of six cultivars at growth stages R6, R7, and R8 show that as the overall reproductive growth stage progresses, there are a larger proportion of kernels at filling stages. We used rice gene chips to examine the total gene expression profiles of Cypress and LaGrue endosperm treated at high (30 °C) and low (18 °C) nighttime temperatures. We observed substantial differences in accumulation of some gene transcripts when comparing samples across the two cultivars, at either temperature. However, we observed fewer differences in gene expression when comparing tissues within a cultivar when plants were treated at the two different nighttime temperatures.

INTRODUCTION

High nighttime air temperatures can be especially harmful to rice during critical stages of grain filling, and result in lower overall yields and excessive chalkiness of grain endosperm. Long-term increases in nighttime temperatures decrease rice yields by 10% for every 1 °C increase in the minimum (nighttime) air temperature (Peng et al., 2004). The opaque appearance of chalk results from a loose packing of starch granules and amyloplasts throughout the endosperm. In addition to increased chalk formation following exposure to high nighttime temperatures during the reproductive stage, total amylose content can be decreased (Lanning et al., 2012). Interestingly, U.S. rice cultivars can vary substantially in their response to high temperatures, indicating that there is a genetic basis for chalk formation in response to environmental changes (Cooper et al., 2008). In addition, other starch profiles are impacted by changes in air temperature, such as the proportion of amylopectin at chain-lengths 13 to 24 increasing in response to high nighttime temperatures (Counce et al., 2005). Significant quantitative trait loci (QTL) have been associated with environmentally responsive chalk formation in rice (Zhou et al., 2009), providing a potential target for the presence of genetic components controlling this trait. Starch formation in endosperm tissue suggests that regulation of rice starch biosynthesis pathways are finely tuned and ultimately responsible for grain quality (Tian et al., 2009). Several genes involved in sucrose and starch synthesis have been shown to have a decreased expression pattern in response to high temperature, whereas some involved in starch degradation, such as the gene encoding amylase, have been show to increase (Yamakawa and Hakata, 2010). Likewise, endosperm protein profiles also change in response to high temperature (Mitsui et al., 2013). To assess the genetic control of starch deposition in developing kernels of U.S. rice cultivars, a study of grain development in field-grown plants and global gene expression assays from plants grown in temperature-controlled conditions was conducted.

PROCEDURES

Plant Growth and Tissue Collection

Field plots from four replications of the Arkansas Rice Performance Trial were sampled at the R6, R7, and R8 plant growth stages for panicles at those growth stages. Individual kernels from those panicles were separated and classified as R4, R5, R6, R7, or R8. Counts of the individual grains by growth stage were made and percentages were determined. Panicles were collected from Bengal, Jupiter, LaGrue, Cypress, Roy J, and Taggart at plant growth stages R6, R7, and R8 and then frozen. Individual kernels on these panicles were separated into groups of R5 and below, R6, R7, and R8, frozen in liquid nitrogen and stored at -80 °C until counting and enzyme analysis. The R6 grains from different plant growth stages were analyzed for sucrose synthase and starch synthase activity. The R6 grains from the 2012 experiments will be assayed for starch synthase and sucrose synthase in the coming months.

For controlled-temperature treatments, Cypress and LaGrue plants were maintained in flooded pots, five sibling plants per pot, in a greenhouse until plant stage R4. At R4, one-half of the pots for each cultivar were transferred to each of two identical growth chambers. Daytime temperatures were identical in each chamber, 0600 h to 1200 h at 25 °C; 1200 h to 1600 h at 27 °C; and 1600 h to 2100 h at 25 °C. Nighttime (dark) temperatures were set at either 18 °C or 30 °C from 2100 h to 0600 h. When individual grains reached the R6 to R7 (soft to hard dough stages), they were collected at 1000 h and endosperm fractions were frozen in liquid nitrogen.

Microarray and RT-PCR Analyses

Total RNA was isolated from endosperm material using a Masterpure Plant RNA purification kit (Epicentre Inc., Madison, Wis.). Total RNA from three independent samples from each treatment (Cypress 18 °C, Cypress 30 °C, LaGrue 18 °C, and LaGrue 30 °C) was analyzed via Affymetrix® US Rice Gene 1.1 ST Array Strips at the University of Michigan. Expression values were analyzed for each gene using a robust multi-array average (Irizarry et al., 2003). The expression values are $\log_2$ transformed data, fit to linear models designed for microarray analysis, and contrasted. All statistical analysis was done using Affymetrix and Limma packages of Bioconductor™ software implemented in the R statistical environment.

For reverse-transcription polymerase chain reaction (RT-PCR), cDNA was generated with iScript cDNA synthesis kits (Bio-Rad, Hercules, Calif.). Gene-specific primers (Table 1) were used in standard PCR reactions with a 1:5 dilution of each cDNA as template (1 µl/reaction) for each reaction performed with the following conditions: 2 min at 95 °C; followed by 25 cycles of 30 sec each at 95 °C, 56 °C, 72 °C; followed by 5 min at 72 °C. RT-PCR products were separated on 1.2% TAE agarose gels stained with GelRed™ dye.

RESULTS AND DISCUSSION

Panicles from six different rice cultivars collected at later stages of plant reproduction contained a larger proportion of grains at filling stages. Filling occurs for individual grains primarily during the R6 grain growth stage. For the medium-grain cultivars Bengal and Jupiter, the proportion of R6 grains increased between the R6 and R7 plant growth stages (Fig. 1). For the long-grain cultivars Cypress, LaGrue, Roy J, and Taggart, percentages of R6 grains decreased between the R6 and R7 plant growth stages. For all cultivars, percentages of R6 grains decreased between the R7 and R8 growth stages. Starch synthase and sucrose synthase activities for R6 grains at the R6, R7, and R8 plant growth stages did not differ (data not shown). The percentages of R6 grains at the different plant growth stages will potentially have greatly different characteristics including lower head rice yield and lower individual kernel weights.

The use of DNA gene chips provides a glimpse of gene expression patterns of nearly all the genes that are active in a given tissue. This provides a useful tool to compare genetic activity in different tissues or cultivars. Carefully replicated Affymetrix® array analyses provided us with a list of candidate genes that are differentially expressed in endosperm of the two cultivars tested. We observed a greater number of differentially expressed genes when comparing across cultivar samples at either temperature treatment, than we did when comparing temperature treatments within a cultivar. For example, a gene encoding a rice protein of unknown function and another encoding a storage protein were more highly expressed in Cypress than LaGrue (Table 2). In contrast, a gene encoding a putative glycerophosphoryl diester phosphodiesterase family member was much more highly expressed in LaGrue. The differential expression of these genes indicated by transcriptome analysis was confirmed by using RT-PCR (Fig. 2). The signal for actin gene transcript RT-PCR products confirms the equal loading and expression pattern for this control gene.

SIGNIFICANCE OF FINDINGS

The rate at which kernels fill differs with developmental stage of the plant, and this could have important implications for the length of time grains at a given stage are subject to exposure to high air temperatures. Measuring grain development in medium- and long-grain field plants showed that at the R8 crop growth stage, fewer individual grains were at R6 than at R7 or R8. Our hypothesis was that filling kernels (R6) at the R6, R7, and R8 plant growth stages would have greatly differing starch synthase and sucrose synthase enzyme activities. This was not the case for tissue collected in 2011, and we will repeat these tests on R6 grains collected at different plant growth stages for the 2012 crop. The starch synthase enzyme assay does not distinguish between activities of different isoforms of starch synthase that elongate different chain lengths of amylopectin. Since nighttime air temperatures at plant growth stage R8 have a dramatic effect on head rice yield, it is possible that the different isoforms are affected differently by nighttime air temperatures. There is also significant evidence that starch structure is greatly affected by day length (or possibly night length) as well as temperature. With these factors in mind, revised experiments and measurements are planned for 2013. Climate-controlled treatments of rice cultivars were conducted keeping daytime temperatures identical, but varying nighttime temperatures during the reproductive stage at either 18 °C or 30 °C. By utilizing rice gene chips, we identified several genes that showed significantly different expression patterns in the cultivars Cypress and LaGrue, which differ significantly in their chalk formation in response to high nighttime temperatures. These genes might provide useful indicators of genetic basis for differential chalk formation between cultivars.

ACKNOWLEDGMENTS

We thank the Arkansas Rice Research and Promotion Board for their generous support, and additional support came from the Arkansas ASSET II Initiative P3 project.

LITERATURE CITED

Cooper, N.T.W., T.J. Siebenmorgen, and P.A. Counce. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. Cereal Chem. 85:276-282.

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.C. Meullenet. 2005. Rice milling quality, grain dimensions, and starch branching as affected by high night temperatures. Cereal Chem. 82:645-648.

Irizarry, R.A., B. Hobbs, F. Collin, Y.D. Beazer-Barclay, K.J. Antonellis, U. Scherf, and T.P. Speed. 2003. Exploration, normalization, and summaries of high density oligonucleotide array probe level data. Biostatistics 4:249-64.

Lanning, S.B., T.J. Siebenmorgen, A.A. Ambardekar, P.A. Counce, and R.J. Bryant. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties. Cereal Chem. 89:168-175.

Mitsui, T., T. Shiraya, K. Kaneko, and K. Wade. 2013. Proteomics of rice grain under high temperature stress. Front. Plant Sci. 4:1-5.

Peng, S., J. Huang, J.E. Sheehy, R.C. Laza, R.M. Visperas, X. Zhong, G.S. Centeno, G.S Khush, and K.G. Cassman. 2004. Rice yields decline higher night temperature from global warming. Proc. Nat. Acad. Sci. USA 101:9971-9975.

Tian, Z., Q. Qian, Q. Liu, M. Yan, X. Liu, C. Yan, G. Liu, Z. Gao, S. Tang, D. Zeng, Y. Wang, J. Yu, M. Gu, and J. Li. 2009. Allelic diversities in rice starch biosynthesis lead to a diverse array of rice eating and cooking qualities. Proc. Natl. Acad. Sci. USA 106:21760-21765.

Yamakawa, H. and M. Hakata. 2010. Atlas of rice grain filling-related metabolism under high temperature: joint analysis of metabolome and transcriptome demonstrated inhibition of starch accumulation and induction of amino acid accumulation. Plant Cell Physiol.51:795-809.

Zhou, L., L. Chen, L. Jiang, W. Zhang, L. Liu, X. Liu, Z. Zhao, S. Liu, L. Zhang, J. Wang, and J. Wan. 2009. Fine mapping of the grain chalkiness QTL qPGWC-7 in rice (*Oryza sativa* L.) Theor. Appl. Genet. 118:581-590.

Table 1. Gene-specific primers for rice endosperm reverse-transcription polymerase chain reaction.

Primer name[†]	Primer sequences	Predicted product size
GPD-F	5’-AATCCCTATTCTCCCGTGTGCCTT-3’	711
GPD-R	5’-AAGCTAGGTCAGTGCAATCTGGGT-3’	
DUF-F	5’-ATATTGACCCAGGTGGACGA-3’	352
DUF-R	5’-CACGAGCGGATGATCTTACCAT-3’	
Glutelin-F	5’-ACAATGAAGGCGATGCACCAGTTG-3’	336
Glutelin-R	5’-CCTGCTGTTGTGCTTGTTCCTGTT-3’	
RAcII-F	5’-CTTCAACACCCCTGCTATG-3’	310
RAcII-R	5’-TCCATCAGGCTCGTAG-3’	

[†] Gene target abbreviations: DUF, plant protein of unknown function; GPD, glycerophosphoryl diester phosphodiesterase family; RAcII, actin.

Table 2. Differentially expressed genes in the rice cultivars Cypress and LaGrue, as determined by analysis of Affymetrix® U.S. Rice Gene 1.1 ST Array Strips.

Gene. ID	Annotation	logFC[†]	*P*-value
LOC_Os09g12970	plant protein of unknown function domain containing protein	-4.67	6.35E-06
LOC_Os02g16820	glutelin	-4.13	5.30E-05
LOC_Os02g37590	glycerophosphoryl diester phosphodiesterase family protein	4.90	7.50E-08

[†] logFC is the log value of signal fold-change comparing expression in LaGrue18 with Cypress18.

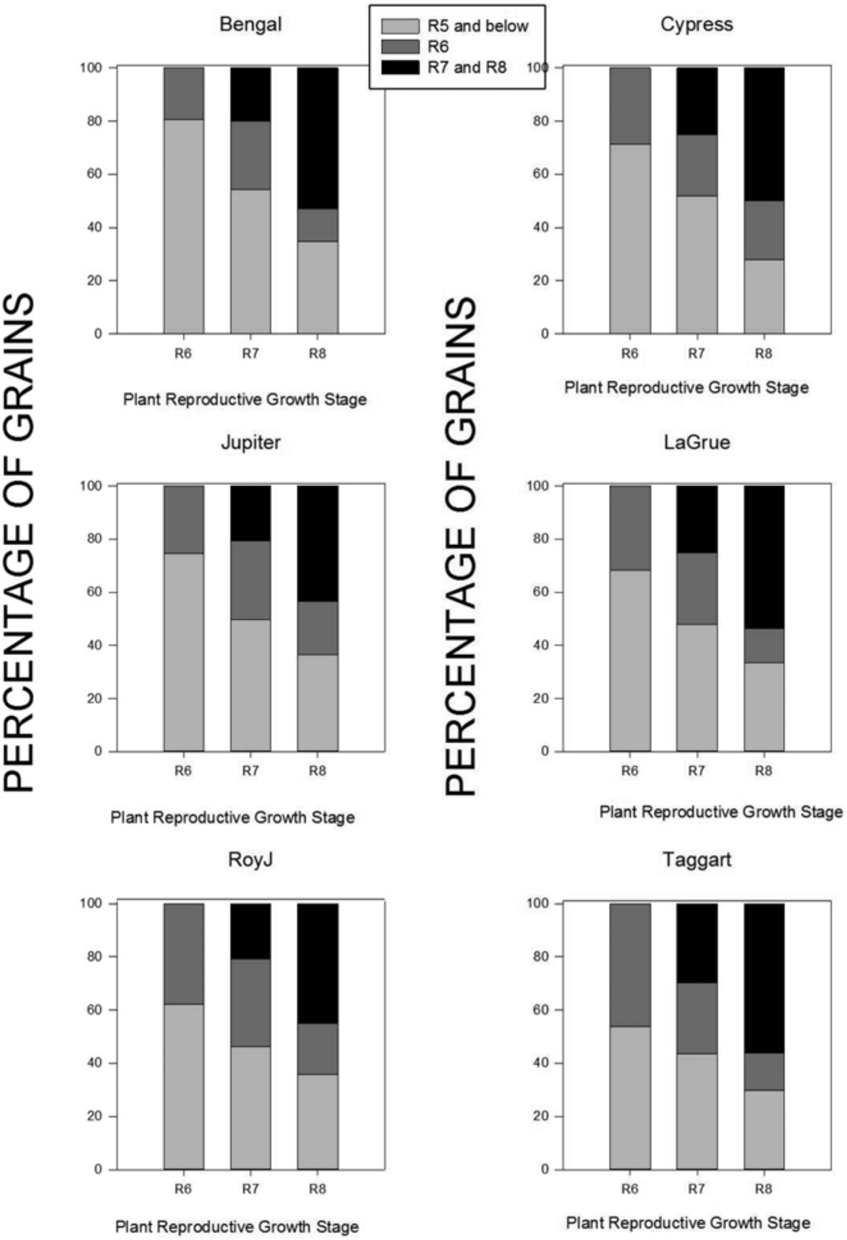


Fig. 1. Graphs indicate percentage of individual grains on panicles of six field-grown rice cultivars, as indicated, at various developmental maturities when measured at plant growth stages R6, R7, and R8.

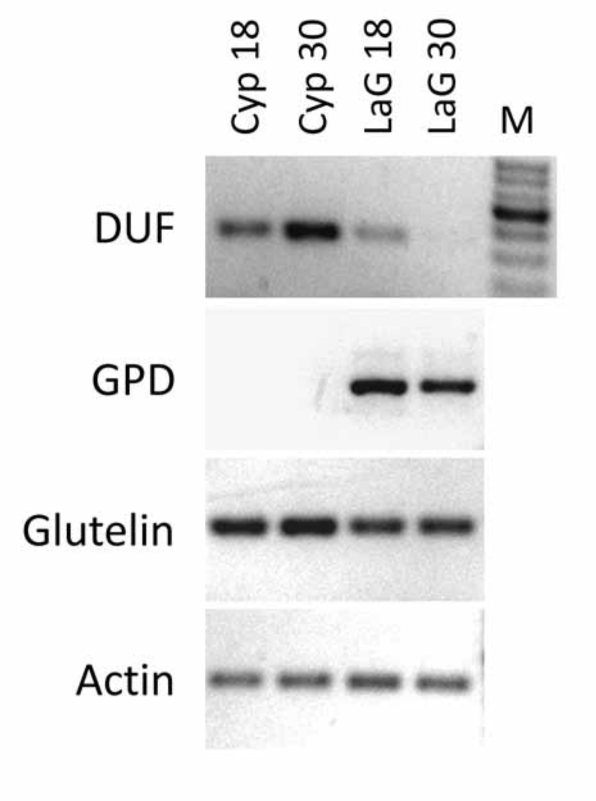


Fig. 2. Gene expression levels in developing rice grains as measured by semi-quantitative reverse-transcription polymerase chain reaction (RT-PCR). The RT-PCR was run for 25 cycles and products were analyzed on agarose gels. Gene-specific primers were used to amplify transcripts encoding products listed in Table 1, and as shown: DUF, plant protein of unknown function; GPD, glycerophosphoryl diester phosphodiesterase family; Glutelin; and the internal control Actin. M indicates a 100-bp molecular weight ladder.

Impact of Rapid Moisture Adsorption on Milling Yields

S. Mukhopadhyay and T.J. Siebenmorgen

ABSTRACT

Fissuring induced by moisture adsorption in low moisture content (MC) rice causes breakage and thus reduces milling yields considerably. This study investigated how rapid moisture adsorption affects rice kernel fissuring of five popular cultivars in Arkansas. Each cultivar was conditioned to five initial MC (IMC) levels (9[1], 11, 13, 15, and 17%), soaked in water at 86 °F (30 °C) for 2 h to simulate rainfall conditions, dried to 12.0 ± 0.5% MC, and milled to a surface lipid content of 0.4%. Milled rice yield (MRY), head rice yield (HRY), and percentage of fissured kernels were determined. Results showed that, although slight cultivar differences existed, as IMC prior to rewetting decreased, the extent of fissuring increased and hence, HRY decreased, corroborating previous research using past cultivars. At very low IMCs (9% to 11%), there was also substantial loss in MRY. This research showed that if rice at a MC below 15% is rapidly rewetted, fissuring occurs, with drastic fissuring occuring at IMCs less than 13%. This leads to HRY reduction, and in severe instances, reductions in MRY as well. Hence, allowing rice to dry in the field to a MC below 15% should be avoided.

INTRODUCTION

Fissuring caused by rapid moisture adsorption has been shown to be a major cause of milling-yield reduction, thereby reducing the economic value of rice. Stahel (1935) reported that fissuring generally occurred when rice kernels at or below 13% to 14% bulk initial moisture content (IMC) rapidly adsorbed moisture from the environment. Similar observations were reported by Kik (1951), as well as Kunze and Choudhury (1972).

---

[1] Unless otherwise specified, all moisture contents are reported on a wet-basis.

Siebenmorgen et al. (1992) defined the critical moisture content (CMC) as the moisture content (MC) below which a kernel will fissure when rapidly rewetted. Jindal and Siebenmorgen (1986) reported the occurrence of fissures when rice at bulk IMC below 13% was rewetted, but found that there was no fissuring on remoistening rice at bulk IMCs greater than 16%. They found that CMC levels ranged from 12% to 15%.

Jindal and Siebenmorgen (1986), Chen and Kunze (1982), and Siebenmorgen et al. (1998) showed that individual kernel MCs vary within a panicle and there is a high probability that kernels with lower MC will fissure when exposed to wet environments. Bautista and Bekki (1997) and Bautista et al. (2000) showed that fissuring was significant when individual kernel MC was less than 14%. Stahel (1935), Chen and Kunze (1982), and Bautista and Bekki (1997) also reported that such fissure formation varied with environmental conditions and to a certain extent with cultivars.

No research was found that quantifies how current cultivars, or cultivars grown under elevated ambient temperatures such as those experienced in the mid-South U.S. in recent years, react to rapid moisture adsorption. The objectives of this study were to evaluate the impacts of water adsorption on fissuring levels, milling yields, and CMCs of currently grown rice cultivars in Arkansas.

PROCEDURES

Milling yield is typically quantified by the milled rice yield (MRY) and head rice yield (HRY). Rough rice kernels are dehulled and milled to remove the hulls and bran, respectively. Milled rice contains head rice (kernels retaining three-fourths or more of their original length) and brokens. Milled rice yield is quantified as the mass of milled rice expressed as a percentage of the original, dried rough rice mass. After the brokens are removed, HRY is quantified as the mass of head rice, expressed as a percentage of the original, rough rice mass. Both MRY and HRY change with the degree of milling, which in turn changes with milling duration. For this study, surface lipid content (SLC) was used to indicate degree of milling and an SLC of 0.4% was selected.

Five rice cultivars, Cheniere, Taggart, and CL151 (pure-line, long-grains), and XL753 and CLXL745 (hybrid, long-grains) were combine-harvested at Arkansas locations at 18.5% to 21% MC. For each cultivar, approximately 12 kg of rough rice was cleaned using a grain cleaner/tester (MCI® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and stored in sealed containers at 4 °C until use.

Samples of each cultivar 10-kg in size were used to study the extent of fissuring induced by rapid moisture adsorption as a function of IMC. Each cultivar sample was divided into five sub-lots of 2 kg each; these were placed in a conditioning chamber with temperature and relative humidity control to dry to IMC levels of 9%, 11%, 13%, 15%, and 17%. Each of these sub-lots was then subjected to rewetting in a water bath to simulate rainfall in rice fields. Samples were wrapped in vinyl screen cloth and soaked for 2 hours in a water bath (Precision 280, Precision Scientific, Winchester, Va.) with the water held at 30 °C, drained for 0.5 h, allowed to air-dry on screened trays for 1 h, and then slowly dried to approximately 12.0 ± 0.5% MC inside the conditioning chamber.

From each of the 25, cultivar/IMC soaked/treated samples, triplicate, 150-g subsamples were randomly selected and milled to an SLC of 0.4%, as described below. In addition, triplicate subsamples of 300 rough rice kernels each were randomly selected from each of the 25 treated samples, manually dehulled, and examined visually for fissures using a fissure-inspection box (TX-200 Grainscope, Kett Electric Laboratory, Tokyo, Japan). Fissured kernels were enumerated and expressed as a number percentage of the 300 rough rice kernels.

In order to mill the treated samples to the desired SLC level, a preliminary milling investigation was conducted in which 2-kg subsamples from each of the five, untreated cultivar lots were slowly conditioned to 12.0 ± 0.5% MC inside the chamber. The following milling procedure was conducted: subsamples (150 g) of rough rice were dehulled using a laboratory huller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) and milled using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas) with a 1.5-kg weight placed on the lever arm 15 cm from the center of the milling chamber. The subsamples were milled for 10, 20, 30, or 40 seconds and MRY was determined. Then, head rice was separated from the brokens using a sizing device (Grain Machinery Manufacturing Co., Miami, Fla.), and HRY was determined. The SLC of each head rice subsample was measured by extraction (Avanti 2055, Foss North America, Eden Prairie, Minn.), following the method described by Matsler and Siebenmorgen (2005). The SLC was then plotted as a function of milling duration for each cultivar. From these curves, the milling duration required to reach an SLC of 0.4% was recorded for each cultivar and these durations were used to mill the treated samples.

RESULTS AND DISCUSSION

The millability curves of all cultivars showed that SLC decreased approximately exponentially with milling duration (Fig. 1). The hybrid cultivars XL753 and CLXL745 required shorter milling durations to achieve an SLC of 0.4% compared to the pure-line cultivars Cheniere and CL151. Interestingly, the pure-line cultivar Taggart had a millability curve comparable to that of the hybrids. From the millability curves, Table 1 gives the milling durations required to achieve an SLC of 0.4%, as well as the MRYs and HRYs of the untreated samples of each cultivar at that SLC. The overall milling yields of the lots represented mid-range (51% to 55%) to very high (69%) HRYs. The milling durations in Table 1 were used for all subsequent milling-yield determinations.

Figure 2 shows MRY, HRY, fissured kernels (FK), and non-fissured kernels (NFK) versus IMC for Cheniere. There was no change between the MRYs and HRYs of treated samples and those of the untreated samples when IMC was 15% or greater. The MRY did not change appreciably until IMC was below 11%. However, IMC had a marked effect on HRY; HRY decreased considerably for IMC levels below 15%, reaching a value of zero (no head rice) at 9% IMC. The FK curve showed that the lower the IMC of the rice when it is rewetted, the more the fissuring and consequent breakage in kernels, and hence, the more the reduction in HRY. The NFK represents the percentage of kernels that did not fissure due to moisture adsorption and hence represented the fraction that makes up the HRY. Hence, the NFK curve followed the same trend as that of HRY, while that of FK was inverse.

The intra-kernel moisture gradients established in kernels as rice at low MCs is suddenly introduced to a high-moisture environment causes the outer kernel layers to adsorb moisture, expand, and experience compressive stress. Because water has not diffused to the kernel interior, the kernel core cannot expand as rapidly as the surface and thus experiences tensile stress. The kernel endosperm is much weaker in tensile strength than compressive strength and thus the kernel fails due to tensile stress at the kernel core. Thus, these intra-kernel stress differences result in material failure and fissure development.

The percentage of fissured kernels increased exponentially as IMC decreased, as increasing numbers of dry kernels were exposed to rapid moisture adsorption; this trend was observed in all the cultivars (Fig. 3a). At greater IMC levels, the moisture gradient between the kernels and the moisture-laden environment was less than that at lower IMC levels, resulting in less fissuring and hence less reduction in HRY.

For all cultivars, the MRY did not change as IMC decreased from approximately 16% to 11% but decreased appreciably as IMC declined to 9%, as indicated in Fig. 3b. This suggests that with severe fissuring and breakage during milling, some endosperm leaves with the bran stream.

Figure 3c shows that for all cultivars, HRYs were stable above 15% IMC. Head rice yield started declining when rice at IMCs below 15% was rewetted, and decreased drastically at IMCs below 13%. Head rice yield reduced to 0% when 9%-IMC rice of any cultivar was rewetted. Each cultivar responded slightly differently to rapid moisture adsorption, but all followed the same general trend. As expected, FK percentage was inversely related to HRY.

The bulk CMC levels in this study were 14% to 16%, similar to those reported in earlier studies. These results support the observations of Siebenmorgen et al. (1992) in that rice should be harvested at MCs greater than 15% to avoid the risk of HRY reduction due to rewetting.

SIGNIFICANCE OF FINDINGS

This study showed that the lower the IMC prior to rewetting, the greater the reduction in HRY; and for low IMCs, there was significant reduction in MRY as well. This knowledge is necessary to prevent milling-yield reductions since low-MC grain may be exposed to moisture adsorbing environments such as rainfall or high-humidity conditions in fields before harvest.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board and the University of Arkansas Rice Processing Program Industry Alliance Group for the financial support of this project.

LITERATURE CITED

Bautista, R.C. and E. Bekki. 1997. Grain fissures in rough rice drying: Differences of fissuring behavior in selected Japonica and Indica varieties. J. of Jap. Soc. of Ag. Mach., Japan. 50(4):87-108.

Bautista, R.C., T.J. Siebenmorgen, and A. Cnossen. 2000. Characteristics of rice individual moisture content and size distributions at harvest and during drying. Proceedings of the 12th International Drying Symposium IDS2000, Elsevier Science, Amsterdam, Paper No. 325.

Chen, N.N. and O.R. Kunze. 1982. Moisture content variation among harvested rice grains. Trans. of the ASAE. 25(4):1037-1040.

Jindal, V.K. and T.J. Siebenmorgen. 1986. Effects of moisture adsorption on the head rice yields of long-grain rough rice. Trans. of the ASAE. 29(6):1767-1771.

Kik, M.C. 1951. Nutritive studies on rice. Agricultural Experiment Station Bulletin 508.

Kunze, O.R. and M.S.U. Choudhury. 1972. Moisture adsorption related to tensile strength of rice. Cereal Chem. 49(6):684-696.

Matsler, A.L. and T.J. Siebenmorgen. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a Soxtec system. Cereal Chem. 82(3):282-286.

Siebenmorgen, T.J., P.A. Counce, R. Lu, and M.F. Kocher. 1992. Correlation of head rice yield with individual kernel moisture content distribution at harvest. Trans. of the ASAE. 35:1879-1884.

Siebenmorgen, T.J., A.A. Perdon, X. Chen, and A. Mauromoustakos. 1998. Relating rice milling quality changes during adsorption to individual kernel moisture content distribution. Cereal Chem. 75(1):129-136.

Stahel, G. 1935. Breaking of rice in milling in relation to the condition of the paddy. Tropical Agriculture. 10(2):267-271.

Table 1. Milling durations required to reach a surface lipid content (SLC) of 0.4% and the milling yields at that SLC level for untreated (unsoaked) samples of the indicated cultivars.

Cultivar	Milling duration	Milled rice yield	Head rice yield
	(seconds)	------------------ (%)	------------------
Pure-lines			
Cheniere	29	73.8	64.0
Taggart	24	71.9	55.4
CL151	29	72.5	65.0
Hybrids			
XP753	25	73.0	51.0
CLXL745	26	74.9	68.9

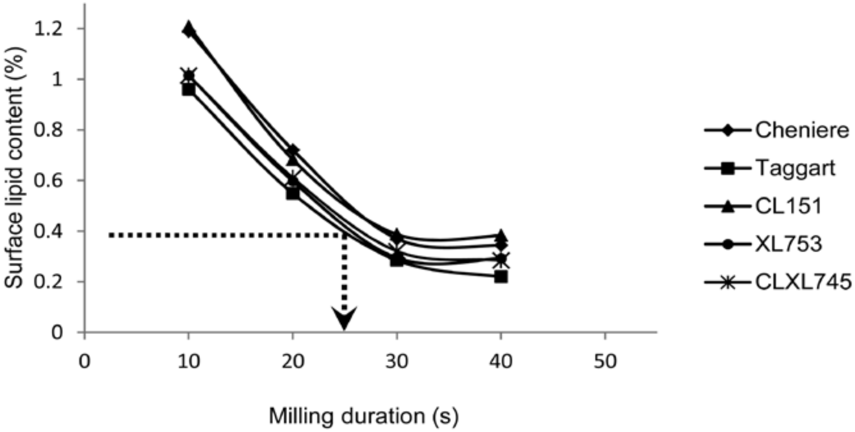


Fig.1. Surface lipid contents of the indicated cultivars milled for varying durations.

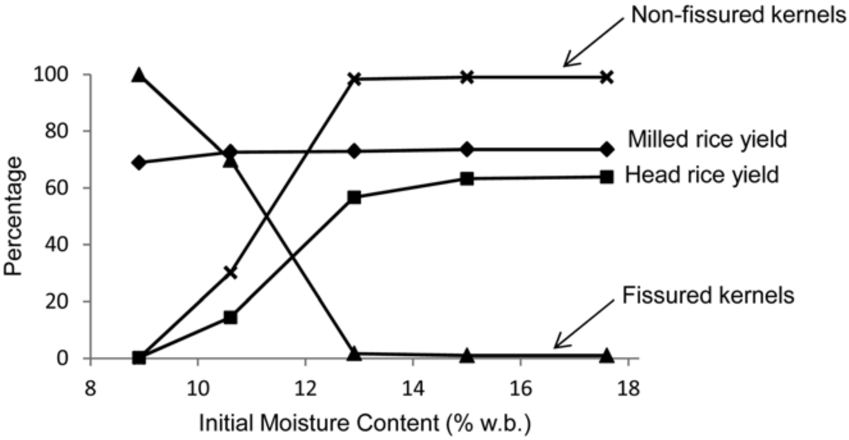


Fig. 2. Milling yields and fissuring responses of the long-grain cultivar Cheniere at the indicated initial moisture contents to soaking in water at 30 °C for 2 h.

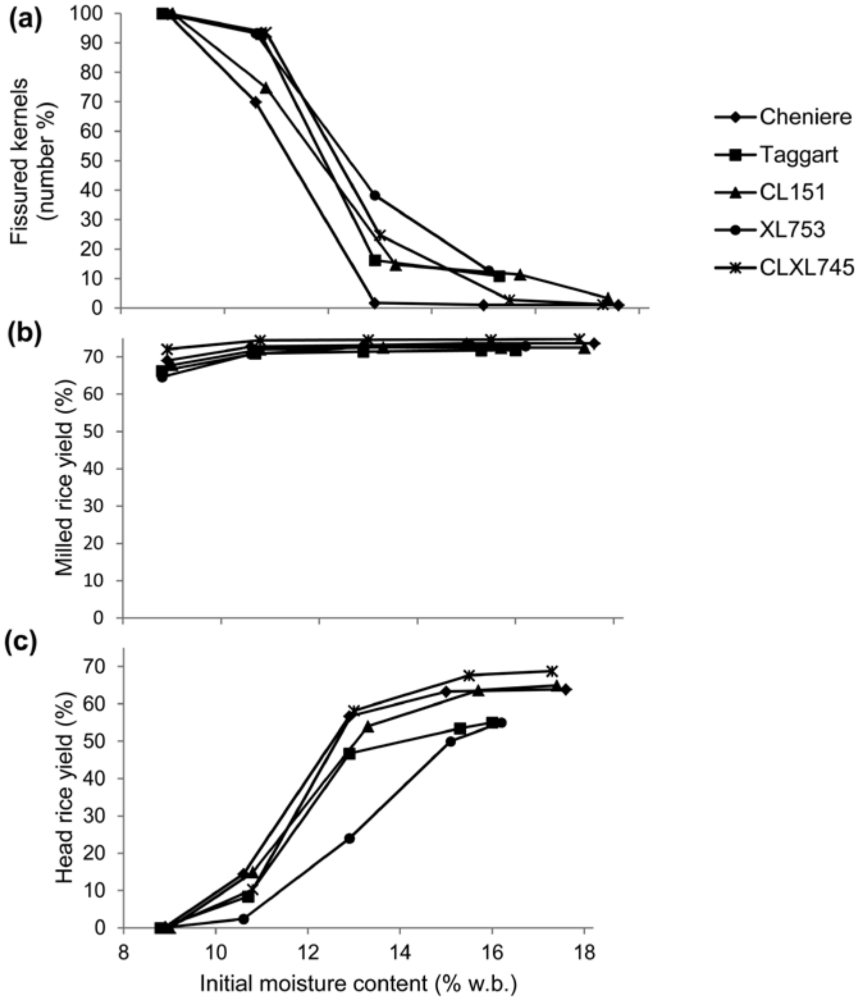


Fig. 3. Responses of the five cultivars at the indicated initial moisture contents to soaking in water at 86 °F (30 °C) for 2 hours in terms of: (a) numbered percentage of fissured kernels, (b) milled rice yield, and (c) head rice yield.

Description and Processing Performance of a Pilot-Scale Parboiling Unit

J.A. Patindol, T.J. Siebenmorgen, and A.G. Duffour

ABSTRACT

A partially automated parboiling unit (PU) tank that can process approximately 2 kg of rough rice per cycle was recently developed and is described. The system components include a stainless-steel tank, a water-circulation pump, a hot-water supply tank, a steam regulator, four cylindrical sample containers, and a computer interface. Conditions used in evaluating the processing performance of the PU were: soaking at 70 °C and 138 kPag for 2 h; steaming at 120 °C and 69 kPag for 10 min; and gentle drying at 26 °C and 65% relative humidity until a moisture content of ~12%[1] was attained. Differences in the percentage of deformed kernels were observed due to the effect of sample size and location of the sample containers in the tank. Milling yields and milled kernel color were minimally affected. In general, the quality attributes of parboiled rice obtained by the PU were either similar or better than those of the product obtained by autoclave steaming.

INTRODUCTION

Parboiling rice involves a series of unit operations, the foremost of which are soaking, steaming, and drying. The success or performance of a parboiling system is typically measured by the quality of the parboiled rice produced. Among the important parboiled rice quality indicators are milling yield and milled kernel color. Maximizing head rice yield (HRY) is a priority of rice processors since broken kernels are worth approximately 60% or less the value of head rice (Siebenmorgen et al., 2007). Parboiling

---

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

mends fissures due to the gelatinization of rice starch and thus improves milling yield (Bhattacharya, 1985). Milled parboiled rice is ideally light yellow or amber; yellowness increases, whereas whiteness decreases, under high parboiling temperatures (Bhattacharya, 1985). Variability in processing behavior often exists, such that parboiling operations must be routinely adjusted to account for changes in properties. A small-scale PU tank would be useful in estimating optimal, commercial-scale parboiling conditions for various rice lots. Such a unit would be useful in research efforts to characterize the impacts of cultivars and production factors on parboiling performance. At present, no small-scale PUs are commercially available, hence, a prototype unit was developed. The objectives herein are to provide a technical description of this prototype, report tests that investigated PU control capabilities, and evaluate sources of parboiling performance variability within the system.

PROCEDURES

Parboiling Unit Description

Figure 1 shows a photograph of the PU tank. The system comprises a stainless-steel tank, a water-circulation pump, a steam regulator, a hot-water supply tank, four cylindrical sample containers, and a computer interface. The system is designed to automate soaking, draining, steaming, and venting. The horizontally oriented, 20.0-cm internal diameter, 40.0-cm long, 304 stainless-steel tank opens on the front-facing flat end with a swing-bolt-hinged closure. An immersion heater is plumbed into the back, flat side of the tank. A steam regulator is capable of maintaining steam pressure from 21 to 103 kPag, and a water pressure regulator is capable of maintaining water pressure from 172 to 517 kPag. The hot-water supply tank can heat water from a municipal source up to 90 °C. The sample containers of the unit comprise four cylinders (32.0 cm long; 7.4 cm diameter) constructed of round-hole, 304 stainless-steel perforated sheet (0.95-mm thickness; 1.59-mm hole diameter; and 2.38-mm center spacing between holes). Each container has a capacity of 480 g of rough rice at 12% moisture content (MC). An interactive computer user interface monitors processing functions and is used to develop visual representation of the data and processes occurring during the parboiling cycle.

Parboiling Unit Operation

A preheating step is first performed to ensure uniform initial conditions from one parboiling cycle to another. Preheating involves passing steam through the sealed PU tank for 5 min before inserting the rice samples and is initiated by engaging a "preheat" button on the control panel. Soaking temperature and duration, as well as steaming temperature, pressure, and duration are set on the control panel prior to a parboiling cycle. Samples are then inserted into the tank, the door is sealed, and the soaking process is initiated by pressing a "start" option. When the soaking duration has elapsed, water circulation stops automatically and the soaking water is drained through a solenoid valve at the bottom of the PU. The steam solenoid valves at the top and bottom of the PU allow steam to flow through the PU tank during the steaming step. The steam solenoid valves automatically close to terminate steam access to the tank. An air solenoid valve then opens, allowing air to enter and steam to vent the PU tank. After venting for one minute, the parboiled samples in the cylindrical containers are removed for drying.

Performance Testing

Rough rice of the long-grain cultivar, CL151, was harvested at 17.0% MC from Weona, Ark., in 2011, cleaned (Carter-Day Dockage Tester, Carter-Day Co., Minneapolis, Minn.), sealed in plastic containers, and stored at 4 °C. The lots used for the parboiling experiments were gently dried to ~12.0% MC. To determine the effect of sample container location inside the tank, each cylinder (cylinders 1, 2, 3, and 4 in Fig. 2) was filled with 320 g of rough rice. The parboiling process comprised soaking the rough rice for 2 h at 70 °C with a water pressure of 138 kPag (20 psi_g); followed by steaming for 10 min at 116-120 °C and a pressure of 69 kPag (10 psi_g); and then gently drying to 12.5% at 26 °C and 65% relative humidity. For comparison, a 320-g rough rice sample was parboiled using an autoclave (Patindol et al., 2008). Tests were conducted in duplicate. The effect of sample size was investigated by performing three parboiling cycles that each comprised loading the four sample containers with 170, 320, or 470 g of rough rice. Samples were parboiled using the same conditions for soaking, steaming, and drying as described earlier; these tests were also duplicated.

Parboiled Rice Evaluation

Dehulling of 150-g rough rice samples was conducted using a laboratory sheller (THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan). Resulting brown rice was milled for 75 s in a laboratory mill (McGill Miller #2, Rapsco, Brookshire, Texas). The milling duration was chosen based on a degree of milling curve procedure (Lanning and Siebenmorgen, 2011). A two-screen sizing device (Grain Machinery Mfg., Miami, Fla.) was used to separate broken kernels from head rice. Head rice samples were aspirated for 2 min to remove residual bran particles using an aspirator (Seedburo Equipment Company, Chicago, Ill.). The percentage of deformed kernels was evaluated by visual inspection using a 50-g head rice sample. Deformed kernels included those that were at least three-fourths their original length but were either bent, flattened, jagged, wrinkled, tapered, or elongated. Head rice color was measured by the lightness (L^*)-redness (a^*)-yellowness (b^*) color space principle using a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, Va.). Surface lipid content was determined using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, Minn.) according to AACC method 30-20 (AACC International, 2000), with modifications by Matsler and Siebenmorgen (2005).

RESULTS AND DISCUSSION

Visual inspection of parboiled rough rice samples indicated that bursting, which is characterized by splitting of hulls due to extensive kernel expansion and leaching of some endosperm components (Bhattacharya, 1985; Islam et al., 2002), was most evident in the samples placed in cylinder 1 (C1; Fig. 2), followed by the samples in cylinder 2 (C2), and then those in cylinders 3 and 4 (C3 and C4). Visually, the extent of bursting was in the order, C1 > C2 > C3 = C4. The literature emphasizes that the MC of parboiled rough rice is typically around 35%; a greater value may result in bursting and extensive starch gelatinization (Bhattacharya, 1985; Islam et al., 2002). As shown in Table 1, the MC of freshly parboiled samples from the PU exceeded 35%, and was greatest for the sample loaded in C1, followed by that in C2, and then those in C3 and C4 (C1 > C2 > C3 = C4). This trend in MC completely agreed with the visual observations of the extent of rough rice bursting. Bursting is unfavorable as it contributes to deformed kernels upon subsequent drying and milling (Bhattacharya, 1985), as well as milling-yield reduction (Islam et al., 2002). The trend in percentage of deformed kernels was identical to that of parboiled rice MC (C1 > C2 > C3 = C4). The MRY did not differ among the four cylinders (data not shown). However, HRY was greater for the samples loaded in C3 and C4 than in C1 and C2 (Table 1). For color parameters (L^* and b^* values), the effect of location of the sample containers in the tank was statistically insignificant. Variations in sample MC, HRY, and percentage of deformed kernels are indicative of skewed exposure to the temperature-pressure treatment. The C1 and C2 containers were positioned on the upper section of the tank, whereas the C3 and C4 containers were positioned at the bottom. Hot water and steam were introduced through inlets at the top of the PU tank. This design may initially expose the samples in positions C1 and C2 to hot water and/or steam with greater temperatures for greater durations than those in the C3 and C4 locations, and consequently affect the rate of heat transfer, water absorption, and starch gelatinization.

Similar trends were observed on the effect of sample size on parboiled rice properties, regardless of the position of the containers (C1, C2, C3, or C4) in the PU tank. For ease of discussion, only the data collected from the container positioned in C3 is presented in Table 2. The most noticeable effect attributed to sample size was on MC and percentage of deformed kernels, which were greater for the 170-g batches than the 470-g counterparts. Parboiling with 320-g sample loads resulted in values that were between the 170-g and 470-g batches. The difference in MC and percentage of deformed kernels may be attributed to the rates of hydration and heat transfer that may likely be more efficient with a small sample size (170 g vs 470 g). Table 2 also indicates that the effect of sample size on HRY was not significant. However, considerable improvements in HRY due to parboiling relative to the non-parboiled sample were observed. Head rice yield increased by 4.4-4.8% (in percentage points).

The lot parboiled using an autoclave had lesser MC than the PU counterparts, regardless of sample container position or sample size (Tables 1 and 2). Moisture may have been lost in transit from soaking, to draining, and to steaming, as these process operations were carried out in three separate pieces of equipment. The autoclaved sample was comparable to the PU samples in milling yields (C3 and C4 positions) and percentage deformed kernels (C2), although its head rice appeared relatively darker (less *L** but greater *b**). Steaming with an autoclave required 9-12 min to attain the steam temperature and pressure setpoints as opposed to the PU that required less than 3 min. The longer transition time may have caused the darker color of the autoclaved samples, as previous studies (Bhattacharya, 1985; Islam et al., 2002) have indicated that longer steam exposure increases kernel yellowness and decreases whiteness.

SIGNIFICANCE OF FINDINGS

The PU tank described herein could be reproduced and used at various sites, including both research laboratories and commercial production facilities. Having a PU on site would allow research to determine processing set-points and conditions before industrial-scale runs are made, possibly improving parboiled rice quality. The PU could also be used to explore the potential processing characteristics of new rice cultivars on a small scale and, therefore, allow experimentation that would be less expensive and not limited by plant logistics.

LITERATURE CITED

AACC International. 2000. Approved methods of analysis, 10th ed. AACC International, St. Paul, Minn.

Bhattacharya, K.R. 1985. Parboiling of rice. pp. 289-348. *In:* B.O. Juliana (ed.). Rice Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minn.

Islam, R., P. Roy, N. Shimizu, and T. Kimura. 2002. Effect of processing conditions on physical properties of parboiled rice. Food Sci. Technol. Res. 8(2):106-112.

Lanning S.B. and T.J. Siebenmorgen. 2011. Comparison of milling characteristics of hybrid and pureline rice cultivars. Applied Eng. Agric. 27(5):787-795.

Matsler, A.L. and T. J. Siebenmorgen. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a Soxtec system. Cereal Chem. 82(3):282-286.

Patindol, J., J. Newton, and Y.-J. Wang. 2008. Functional properties as affected by laboratory-scale parboiling of rough rice and brown rice. J. Food Sci. 73(8): E370-377.

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. in Agric. 23(4):517-527.

Table 1. Effect of sample container location inside the tank of the parboiling unit on the properties of CL151 parboiled rice[†].

Sample/ container location	Moisture content[‡]	Deformed kernels	Head rice yield	*L**	*b**
	----------------------	(%)	-----------------------	(lightness)	(yellowness)
1	41.8 ± 1.2^{a}[§]	32.1 ± 0.8^{a}	66.4 ± 0.8^{b}	53.3 ± 0.8^{ab}	24.7 ± 0.6^{b}
2	39.9 ± 1.2^{b}	25.5 ± 1.3^{b}	67.9 ± 0.8^{b}	54.0 ± 0.7^{a}	24.4 ± 0.6^{b}
3	36.6 ± 0.7^{c}	16.8 ± 2.1^{c}	70.8 ± 0.6^{a}	54.1 ± 1.1^{a}	24.0 ± 0.5^{b}
4	36.0 ± 1.0^{c}	16.6 ± 1.2^{c}	70.5 ± 1.1^{a}	54.5 ± 1.3^{a}	23.5 ± 0.4^{b}
Autoclaved[¶]	33.2 ± 1.0^{d}	25.9 ± 1.1^{b}	70.9 ± 1.5^{a}	52.9 ± 1.3^{b}	26.2 ± 0.4^{a}

[†] Values are means from duplicate measurements of two replicate tests ± standard deviations. See Fig. 2 for a description of the location of sample containers.

[‡] Rough rice moisture content (wet basis) immediately after parboiling.

[§] Means in a column followed by a common superscript letter(s) are not significantly different at $P < 0.05$ based on Tukey's honestly significant difference test.

[¶] Sample parboiled by autoclave steaming.

Table 2. Effect of sample size (mass of rough rice per container at the C3 position) on the properties of parboiled rice[†].

Sample load mass	Moisture content[‡]	Deformed kernels	Head rice yield	*L**	*b**
(g)	----------------------	(%)	-----------------------	(lightness)	(yellowness)
170	37.7 ± 0.9^{a}[§]	17.3 ± 0.7^{a}	70.6 ± 1.0^{a}	54.4 ± 1.4^{b}	25.0 ± 0.6^{ab}
320	36.6 ± 0.7^{ab}	16.8 ± 1.2^{ab}	70.8 ± 0.7^{a}	54.1 ± 0.8^{b}	24.0 ± 0.5^{b}
470	36.0 ± 0.8^{b}	15.0 ± 1.1^{b}	70.5 ± 0.6^{a}	54.7 ± 1.2^{b}	24.0 ± 0.6^{b}
Autoclaved[¶]	33.2 ± 1.0^{c}	25.9 ± 1.1^{c}	70.9 ± 1.5^{a}	52.9 ± 1.2^{c}	26.2 ± 0.4^{a}
Non-parboiled	---	---	66.1 ± 0.6^{b}	73.5 ± 0.3^{a}	15.7 ± 0.3^{c}

[†] Values are means from duplicate measurements of two replicate tests ± standard deviations. See Fig. 2 for a description of the location of sample containers.

[‡] Rough rice moisture content (wet basis) immediately after parboiling.

[§] Means in a column followed by a common superscript letter(s) are not significantly different at $P < 0.05$ based on Tukey's honestly significant difference test.

[¶] Sample parboiled by autoclave steaming.

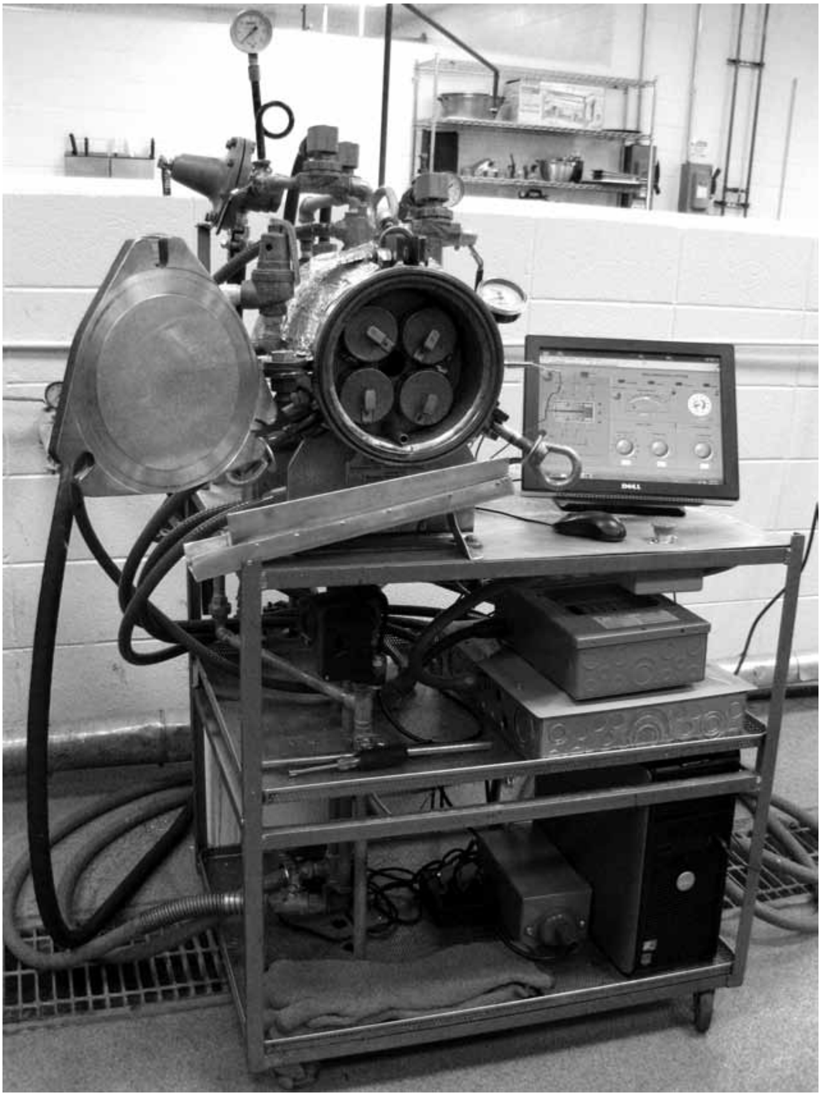


Fig. 1. A photograph of the recently developed pilot-scale parboiling unit tank.

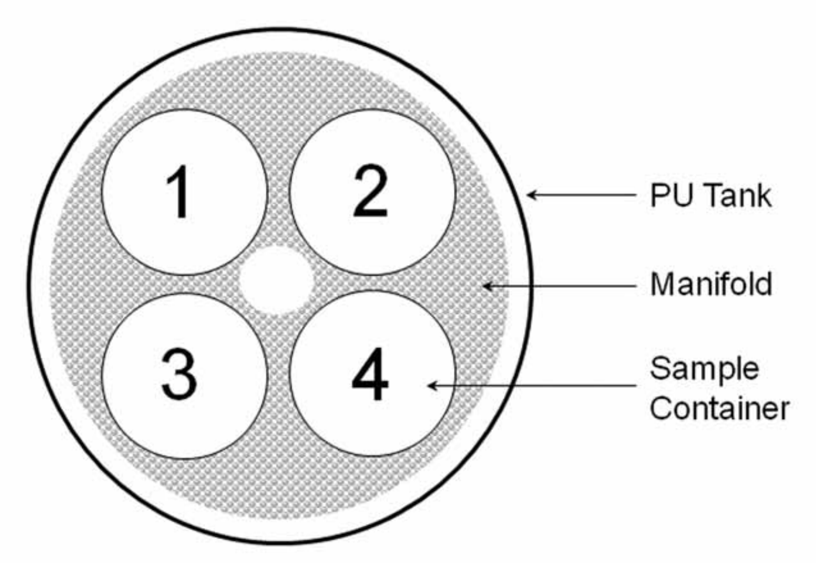


Fig. 2. Location of the four cylindrical sample containers inside the partially-automated parboiling unit (PU) tank.

Impact of Elevated Nighttime Air Temperature During Kernel Development on Starch Properties of Field-Grown Rice

J.A. Patindol, Y.-J. Wang, and T.J. Siebenmorgen

ABSTRACT

The structural features of starch were examined to better understand the causes of variability in rice quality resultant to nighttime air temperature (NTAT) incidence during kernel development. Starch samples were isolated from head rice of four cultivars (Bengal, Cypress, LaGrue, and XL723) field grown in four Arkansas locations (Northeast Research and Extension Center, Keiser, Ark.; Pine Tree Research Station, Colt, Ark.; Rohwer Research Station, Rohwer, Ark.; and Rice Research and Extension Center, Stuttgart, Ark.) in 2009 and 2010. Average NTATs recorded during the R6-R8 stages of rice reproductive growth in the four locations were 3.0-8.4 °C greater for the 2010 crops. Means pooled across cultivars and locations showed that amylose content was 3.1% (percentage points) less for the 2010 crop. The elevated NTAT in 2010 resulted in a decrease in the percentage of amylopectin short chains (DP6-18) and a corresponding increase in the percentage of amylopectin long chains (DP19-65) by an average of 1.3%. The pasting temperature of starch from 2010 increased by 2.8 °C, and all paste viscosity parameters (peak, final, breakdown, setback, and total setback) likewise increased. Onset gelatinization temperature increased by 3.5 °C, and gelatinization enthalpy was greater by 1.3 J/g for the 2010 starch samples. Elevated NTAT altered the deposition of starch in the rice endosperm. Year × cultivar × location interaction effects of the data were statistically insignificant to indicate that the four cultivars evaluated all showed some degree of susceptibility to the effects of elevated NTAT during kernel development, regardless of the growing location.

INTRODUCTION

The average nighttime air temperatures (NTATs) recorded during the kernel development stages (R6-R8) of six rice cultivars field grown in five Arkansas locations were approximately 5 °C greater in 2010 than in 2009 (Lanning et al., 2012). Such elevated NTAT instigated some significant changes in rice quality traits: reduced milling yields, amylose content, and total protein content; and increased milled rice whiteness, chalkiness, total lipid content, gelatinization temperature, and flour paste peak viscosity (Lanning et al., 2011; Lanning et al., 2012; Lanning and Siebenmorgen, 2013). All cultivars analyzed showed some degree of susceptibility to high-temperature incidence. Most of the quality changes in field-grown rice due to elevated NTAT paralleled those of experiments conducted in greenhouses or other controlled-temperature environments (Counce et al., 2005; Cooper et al., 2008). Among the effects of elevated NTAT, the decreased amylose content and increased gelatinization temperature pattern are especially noteworthy because the literature has indicated that these two starch-related properties usually have a positive linear correlation (Wani et al., 2012). Starch functionality depends on the proportion of amylose and amylopectin in its granules, and the percentage distribution of amylopectin branch-chains. Amylopectin, being the major component of starch, needs to be thoroughly examined to better understand the mechanisms behind the unfavorable impact of elevated NTAT on rice processing characteristics and functionality.

PROCEDURES

Rice Samples

The rice samples used in this research were part of the field experiments described by Lanning et al. (2012). The samples comprised four cultivars (Bengal, Cypress, LaGrue, and XL723) field grown in four Arkansas locations (Northeast Research and Extension Center, Keiser, Ark.; Pine Tree Research Station, Colt, Ark.; Rohwer Research Station, Rohwer, Ark.; and Rice Research and Extension Center, Stuttgart, Ark.) in 2009 and 2010 through the Arkansas Rice Performance Trials. Throughout the course of the field experiments, ambient temperatures were measured at 30-min intervals and those from 8:00 pm to 6:00 am were considered as NTATs. Ambient temperatures were recorded using two temperature/relative humidity sensors (HOBO Pro/Temp Data Logger, Onset Computer Co., Bourne, Mass.) positioned at each growing location.

Starch Chemical Analyses

Powdered head rice samples were prepared and stored as described by Lanning et al. (2012). Total starch content in powdered head rice was determined enzymatically using a Megazyme kit of Total Starch Assay (Megazyme International Ireland, Co. Wicklow, Ireland). Starch samples were prepared from powdered head rice by extraction with dilute alkali (0.1% NaOH) followed by lipid removal with water-saturated n-butyl alcohol (Patindol and Wang, 2002). Apparent amylose content was determined by iodine colorimetry. Amylopectin chain-length distribution was characterized by high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) using isoamylase-debranched starch samples.

Starch Pasting and Thermal Properties

Starch pasting properties were determined with a Rapid Visco-Analyzer ((RVA Model 4, Newport Scientific Instruments, Warriewood, Australia). Rice starch slurry (10%) was prepared by mixing 2.8 g of rice starch (12% moisture content basis) with 25.2 mL of deionized water in a canister. The slurry was heated from 50 °C to 95 °C at 3 °C/min, held at 95 °C for 10 min, cooled to 50 °C at 3 °C/min, and held at 50 °C for 10 min. The pasting properties measured included pasting temperature, peak viscosity, peak time, hot paste viscosity (trough), final viscosity, viscosity differences (breakdown, setback, and total setback).

Thermal properties were assessed by a differential scanning calorimeter (DSC; Pyris Diamond, Perkin Elmer Instruments, Shelton, Conn.). Starch (~4.0 mg, dry basis) was weighed into an aluminum DSC pan, and 8 µL deionized water was added by a microsyringe. The mixture was hermetically sealed and equilibrated at room temperature for at least 1 h before analysis. Thermal scans comprised heating the sample from 25 °C to 130 °C with a temperature increase rate of 10 °C/min.

RESULTS AND DISCUSSION

Milled rice total starch content, which nominally accounts for ~88% of head rice dry mass, was not affected by cropping year, cultivar, location, and treatments interactions (Table 1). Inukai and Hirayama (2010), however, reported that high temperature during rice ripening results in the reduction of starch dry mass per kernel caryopsis because the density of endosperm starch relative to the other parts of the caryopsis (glumes, lemma, palea, and germ) also decreases. Present findings imply that total starch mass deposition per caryopsis could have been reduced as a result of elevated NTAT, but starch content (expressed as a percentage) relative to other head rice components (e.g., proteins, lipids, and minerals) was not significantly affected.

Starch composition was affected by elevated NTAT as evidenced by the lower amylose content of purified starch samples from 2010 versus those from 2009 (Table 1). Similarly, previous field-level (Lanning et al., 2012) and temperature-controlled experiments (Cheng et al., 2005; Counce et al., 2005; Cooper et al., 2008; Inukai and Hiyarama, 2010) observed that elevated NTATs decreased milled rice amylose content. The decrease has been ascribed to reduced activity of the enzyme that catalyzes amylose biosynthesis-granule bound starch synthase or GBSS (Cheng et al., 2005).

Differential plots of amylopectin chain-length distribution of 2009 and 2010 samples (Fig. 1) show that the degree of polymerization (DP) 6-18 tended to decrease from 53.8% to 52.5%; whereas, DP 19-65 tended to increase from 46.2% to 47.5% due to elevated NTATs. Treatment interaction effects were all insignificant to indicate that the four cultivars behaved similarly to NTAT incidence. Based on the conventional classification of amylopectin chain-length, DP 6-18 represents A and short B1 chains; whereas, DP 19-65 represents long B1, B2, and B3 chains. Changes in the proportion of short and long amylopectin branch-chains may be attributed to reduced activity of starch branching enzymes due to heat stress (Ohdan et al., 2011).

Changes in starch composition and amylopectin chain-length distribution were accompanied by some variations in starch pasting and thermal properties. The elevated NTATs of 2010 increased the pasting temperatures of starch slurries by 2.8 °C. All paste viscosity parameters (peak, final, breakdown, setback, and total setback) likewise increased (data not shown). Correlation analysis showed that the decrease in amylose content was highly associated with the changes in starch paste viscosity parameters (Table 2): negatively with peak, final, and breakdown viscosity, and positively with setback and total setback viscosity. Pasting temperature did not correlate with amylose content but was associated with the changes in amylopectin structural features. Onset gelatinization temperatures increased by 3.5 °C across cultivars and locations. Gelatinization enthalpy was also increased by 1.3 J/g for the 2010 starch samples. Changes in thermal properties were substantially explained by amylopectin chain-length parameters (Table 3). Increased gelatinization temperature (onset and peak) due to elevated NTAT was highly associated with the increased proportion of amylopectin long chains and average chain length.

SIGNIFICANCE OF FINDINGS

Elevated NTAT affects rice endosperm starch composition and fine structure, which in turn contributes to variability in rice quality and processing characteristics. This baseline information is useful in explaining trends in processing variability and could aid in designing strategies (for breeding, physiology, crop management, and postharvest processing) to mitigate the effects of NTAT incidence.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board and the corporate sponsors of the University of Arkansas Rice Processing Program for their financial support.

LITERATURE CITED

Cheng, F.M., L.J. Zhong, N.C. Zhao, Y. Liu, and G.P. Zhang. 2005. Temperature-induced changes in the starch components and biosynthetic enzymes of two rice varieties. Plant Growth Reg. 46:87-95.

Cooper, N.T.W., T.J. Siebenmorgen, and P.A. Counce. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. Cereal Chem. 85:276-282.

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.

Inukai, T. and Y. Hirayama. 2010. Comparison of starch levels reduced by high temperature during ripening in japonica rice lines near-isogenic for the Wx locus. J. Agron. Crop Sci.:296-301.

Lanning, S.B., T.J. Siebenmorgen, P.A. Counce, and A.A. Ambardekar. 2011. Extreme nighttime air temperatures in 2010 impact rice chalkiness and milling quality. Field Crops Res. 124:132-136.

Lanning, S.B., T.J. Siebenmorgen, A.A. Ambardekar, P.A. Counce, and R.J. Bryant. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties of rice. Cereal Chem. 89(3):168-175.

Lanning, S.B. and T.J. Siebenmorgen. 2013. Effects of pre-harvest nighttime air temperatures on whiteness of head rice. Cereal Chemistry (*in press*, accepted on 14 Oct. 2012).

Ohdan, T., T. Sawada, and Y. Nakamura. 2011. Effects of temperature on starch branching enzyme properties of rice. J. Appl. Glycosci. 58:19-26.

Patindol, J. and Y.J. Wang. 2002. Fine structures of starches from long-grain rice cultivars with different functionality. Cereal Chem. 79:465-469.

Wani, A.A., P. Singh, M.A. Shah, U. Schweiggert-Weisz, K. Gul, and I.A. Wani. 2012. Rice starch diversity: Effects on structural, morphological, thermal, and physicochemical properties - A review. Comp. Rev. Food Sci. Technol. 11:417-436.

Table 1. Treatment variable means (year, cultivar, and location) for milled rice starch content, amylose content, and amylopectin fine structure.

Treatment		Starch	Amylopectin chain length distribution§¶							
variable	Level†	content‡	Amylose§	ACL	A	B1	B2	B3+	DP 6-18	DP 19-25
	---------- (%) ----------									
Year	2009	87.8^{a}	20.6^{a}	20.4^{b}	24.9^{a}	49.1^{a}	14.6^{b}	11.4^{a}	53.8^{a}	46.2^{b}
	2010	87.2^{a}	17.5^{b}	20.9^{a}	24.1^{b}	48.9^{a}	15.1^{a}	11.9^{a}	52.5^{b}	47.5^{a}
Cultivar	Bengal	87.4^{a}	12.5^{d}	20.4^{b}	27.2^{a}	46.2^{b}	15.0^{a}	11.6^{a}	53.9^{a}	46.1^{b}
	Cypress	87.0^{a}	21.2^{b}	20.7^{ab}	23.9^{b}	49.7^{a}	14.8^{a}	11.6^{a}	53.0^{ab}	47.0^{ab}
	LaGrue	87.8^{a}	22.6^{a}	20.7^{ab}	24.0^{b}	49.7^{a}	14.6^{a}	11.6^{a}	53.3^{ab}	46.7^{ab}
	XL723	87.8^{a}	19.9^{c}	20.9^{a}	23.0^{c}	50.4^{a}	14.8^{a}	11.8^{a}	52.5^{b}	47.5^{a}
Location	Keiser	87.9^{a}	20.2^{a}	20.4^{b}	24.9^{a}	49.9^{a}	14.3^{b}	10.9^{b}	54.3^{a}	45.7^{c}
	Pine Tree	87.6^{a}	19.7^{a}	20.3^{b}	24.6^{ab}	49.3^{ab}	14.9^{b}	11.2^{b}	53.5^{ab}	46.5^{bc}
	Rohwer	87.5^{a}	17.9^{b}	21.0^{a}	24.2^{b}	48.1^{c}	15.7^{a}	12.0^{ab}	51.9^{c}	48.1^{a}
	Stuttgart	87.0^{a}	18.4^{b}	21.0^{a}	24.3^{ab}	48.7^{bc}	14.4^{b}	12.6^{a}	52.9^{b}	47.1^{b}

[†] For the levels of each treatment variable in each block, means with a common superscript letter are not significantly different at $P < 0.05$ based on Tukey's honestly significant difference test.

[‡] Measured on powdered head rice samples.

[§] Measured on purified starch samples.

[¶] Abbreviations: ACL-average chain length in glucose units; DP-degree of polymerization ; A chain (DP 6-12); B1 Chain (DP 13-24); B2 Chain (DP 25-36); B3+ Chain (DP 37-65).

Table 2. Correlation coefficients for the association of starch structural features with pasting characteristics.

Starch property[†]	Pasting temp.	Peak viscosity	Final viscosity	Breakdown viscosity	Setback viscosity	Total setback
Starch content	0.17	0.20	0.06	0.23	-0.22	-0.10
Amylose content	0.34	-0.92**	-0.60**	-0.89**	0.91**	0.70**
A chains	-0.79**	0.64**	0.27	0.66**	-0.67**	-0.50*
B1 chains	0.57**	-0.80**	-0.48**	-0.77**	0.79**	0.64**
B2 chains	0.15	0.27	0.23	0.22	-0.25	-0.33
B3 chains	0.27	0.24	0.34	0.18	-0.18	-0.12
DP 6-18	-0.57**	0.01	-0.18	0.07	-0.05	0.04
DP 19-65	0.57**	0.01	0.18	-0.07	-0.05	-0.04
Ave. chain length	0.57**	0.02	0.15	-0.02	0.02	0.05

[†] Abbreviations: DP-degree of polymerization; A chain (DP 6-12); B1 Chain (DP 13-24); B2 Chain (DP 25-36); B3+ Chain (DP 37-65).

* Significant at 95% probability (*P* < 0.05; n = 32).

** Significant at 99% probability (*P* < 0.01; n = 32).

Table 3. Correlation coefficients for the association of starch structural features with thermal properties[†].

Starch property	Onset GT	Peak GT	Conclusion GT	Gelatinization enthalpy
Starch content	0.33	0.36	0.18	0.22
Amylose content	0.35	0.28	0.12	-0.15
A chains	-0.90**	-0.86**	-0.43*	-0.32
B1 chains	0.60**	0.55**	0.36	0.03
B2 chains	0.14	0.17	0.15	0.42*
B3 chains	0.45**	0.45**	-0.03	0.31
DP 6-18	-0.68**	-0.69**	-0.29	-0.54**
DP 19-65	0.66**	0.68**	0.28	0.44*
Ave. chain length	0.75**	0.74**	0.27	0.44*

[†] Abbreviations: GT-gelatinization temperature; DP-degree of polymerization; A chain (DP 6-12); B1 Chain (DP 13-24); B2 Chain (DP 25-36); B3+ Chain (DP 37-65).

* Significant at 95% probability (*P* < 0.05; n = 32).

** Significant at 99% probability (*P* < 0.01; n = 32).

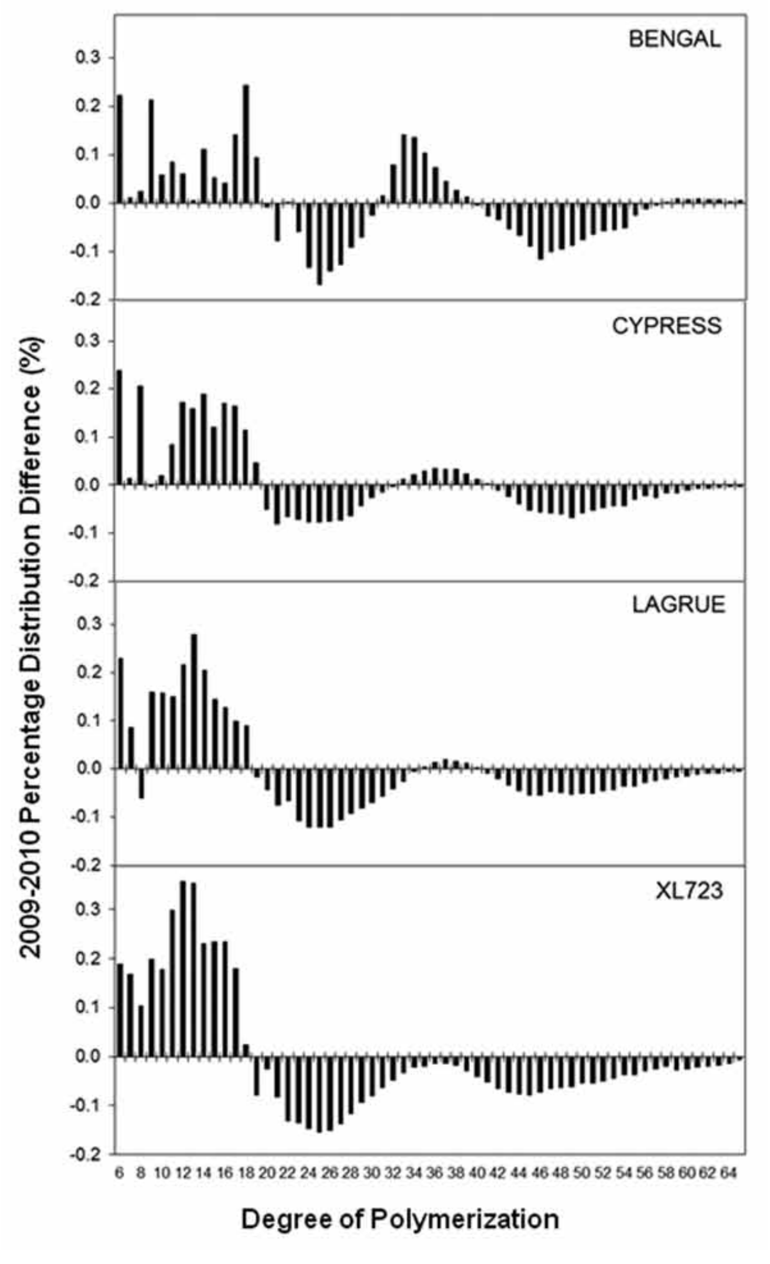


Fig. 1. Differences (2009 minus 2010) in the proportion of amylopectin branch chains (DP6 to DP65) of the starch samples isolated from four rice cultivars field grown at the Rohwer Research Station, Rohwer, Ark., in 2009 and 2010.

Milling Characteristics of Current Long-Grain Pure-Line and Hybrid Rice Cultivars

T.J. Siebenmorgen, S.B. Lanning, and B. Grigg

ABSTRACT

Milling characteristics of four pure-line cultivars and five hybrid cultivars were compared. Samples of rough rice from each cultivar were milled for durations of 10, 20, 30, or 40 s. Milled rice yields (MRYs) and head rice yields (HRYs) were calculated. Head rice from each cultivar/milling duration combination was measured for surface lipid content (SLC) as an indicator of degree of milling (DOM). Hybrid cultivars generally reached a target SLC in a shorter duration than pure-line cultivars, with the exception of CLXL745. Milled rice yields and head rice yields decreased linearly with increasing DOM (decreasing SLC), but at different rates for each cultivar. These findings support other studies suggesting that SLC should be considered when comparing milling performance among rice cultivars.

INTRODUCTION

Degree of milling (DOM) refers to the amount of bran remaining on kernels after the milling process and is often measured in terms of surface lipid content (SLC), the mass percentage of lipids on the surface of milled kernels (Siebenmorgen et al., 2006). Degree of milling has a strong effect on several rice quality parameters, including milled rice yield (MRY), head rice yield (HRY) (Lanning and Siebenmorgen, 2011; Cooper and Siebenmorgen, 2007), sensory aspects of cooked rice (Lyon et al., 1999; Saleh and Meullenet, 2007), beer quality (Monsoor and Proctor, 2004), and rice pasting properties (Perdon et al., 2001).

Rice milling performance can vary for several reasons. Among them are physiological differences among cultivars (Lanning and Siebenmorgen, 2011), pre-harvest conditions (Kunze and Prasad, 1978; Siebenmorgen et al., 2007; Ambardekar et al., 2011), and post-harvest drying (Cnossen et al., 2001) and storage (Daniels and Marks, 1998) conditions. Siebenmorgen et al. (2006) and Lanning and Siebenmorgen (2011) illustrated that cultivars mill at different rates; the milling duration required to achieve a target SLC was generally less for hybrids than for pure-line cultivars.

New hybrid and pure-line cultivars are continually introduced in an effort to improve plant structure, agronomic yield, disease resistance, milling yields, and processing behavior. Information quantifying the milling performance of these new cultivars is valuable to rice producers, millers, and end-users of rice. Thus, the objective of the current study was to quantify the milling characteristics of several current hybrid and pure-line rice germplasm lines.

PROCEDURES

Long-grain cultivars (four pure-lines and five hybrids) were harvested in the fall of 2010 from two locations; pure-line cultivars Wells and CL181 and hybrid cultivars CLXL745 and CLXL729 were harvested near Keiser, Ark.; pure-line cultivars Cheneire and Taggart and hybrid cultivars CLXP4534, CLXP752, and CLXP756 were harvested near Harrisburg, Ark. The harvest moisture contents (MCs) of the lots ranged from 14% to 23%. Each lot was cleaned (Carter-Day Dockage Tester, Carter-Day Co., Minneapolis, Minn.) and conditioned to an equilibrium MC of approximately 12.5% using 25 °C (77 °F) and 62% relative humidity air. Conditioned samples were then stored at 4 °C (39 °F) in plastic bags.

Prior to milling, samples were removed from storage and equilibrated to room temperature (approx. 21 °C/70 °F) for 12 h. Subsamples (150-g) from each rough rice sample were dehulled in a laboratory sheller (THU, Satake, Tokyo, Japan) with a clearance of 0.048 cm (0.019 inch) between the rollers. The resultant brown rice was milled in a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) with a 1.5 kg (3.3 lb) mass placed on the lever arm 15 cm (6 inches) from the milling chamber centerline for durations of 10, 20, 30, or 40 s to achieve a range of DOM levels. Head rice, defined as milled kernels at least three-fourths of their original length (USDA, 2009), was separated from broken kernels using a sizing device (Seedburo Equipment Co., Chicago, Ill.). Milled rice yield was calculated as the mass fraction of the initial 150-g rough rice mass remaining as milled rice, comprising both head rice and broken kernels. Head rice yield was calculated as the mass fraction of the 150-g rough rice sample remaining as head rice. Milled samples were stored in plastic bags at 4 °C (39 °F) pending further analysis. This milling procedure was replicated three times for each cultivar/milling duration treatment.

Surface lipid content of the head rice from each cultivar/milling duration combination was measured with a lipid extraction system (Avanti 2055, Foss North America, Eden Prairie, Minn.) as described by Matsler and Siebenmorgen (2005). The SLC was calculated as the mass ratio of extracted surface lipid to the original head rice.

Statistical software (JMP Pro 9.0, SAS Institute, Inc., Cary, N.C.) was used to perform analysis of variance (ANOVA) with least significant differences (α level = 0.05) to determine the significance of MRY and HRY vs. SLC relationships.

RESULTS AND DISCUSSION

Figure 1 depicts head rice SLC vs. milling duration curves of pure-line and hybrid cultivars milled for 10, 20, 30, or 40 seconds. As expected, SLC decreased exponentially as milling duration increased. Hybrid SLCs were generally lower than pure-line SLCs for any given milling duration. One exception was hybrid cultivar CLXL745, which behaved more similarly to the pure-line cultivars than to the other hybrids tested. Figure 1 indicates that approximately 17 s of milling was required to reach a head rice SLC of 0.4% for hybrid CLXL729, while 27 s was required for CLXL745; the remaining hybrids required less than 22 s. Conversely, the pure-line cultivars required from 22 to 28 s to attain an SLC of 0.4%. The findings of this study corroborate the findings of Lanning and Siebenmorgen (2011), wherein hybrid cultivars generally milled to a given SLC faster than pure-lines and, among the hybrid cultivars tested, CLXL745 required the greatest duration to attain a given SLC.

As reported by Cooper and Siebenmorgen (2007) and Lanning and Siebenmorgen (2011), HRY is linearly and directly related to SLC. It was hypothesized that MRY would be similarly affected by DOM as a function of SLC, so both MRY and HRY were plotted vs. SLC to explore those relationships among the current cultivars in this study (Figs. 2 and 3, respectively). As expected, both yields decreased as SLC decreased for all cultivars. It is notable that milling performance differed among cultivars, as illustrated by the differences between MRY and HRY across cultivars. For example, pure-line cultivars Taggart and Cheniere both achieved high MRYs, but Taggart had one of the lowest HRYs, while Cheniere maintained a high HRY. Both MRY and HRY levels can be impacted by nighttime air temperatures incurred during kernel formation (Ambardekar et al., 2011). The overall level of HRY can be impacted by several factors, such as the amount of fissuring of dried kernels due to rapid moisture adsorption, which in turn is impacted by the MC level that is reached prior to harvest (Siebenmorgen et al., 2007). These observations reflect the high degree of variability in milling yields anecdotally observed by the industry within a given year and growing location.

Figures 2 and 3 indicate that MRY and HRY, respectively, are impacted by the degree to which the rice is milled, as quantified by the SLC of the head rice. The extent to which both milling-yield parameters are impacted is quantified by the slopes of the regression lines for each cultivar, which are presented in Table 1. These slopes represent the change in MRY or HRY per unit change in SLC. Overall, MRY slopes ranged from a 0.63 percentage-point (pp) yield decrease (Wells) to 1.21 pp yield decrease (CLXP756) per 0.1 pp decrease in SLC. Hybrid slopes were generally greater than those of pure lines, with the exceptions of CLXP752 and CLXL745. Similar trends were observed in HRY vs. SLC slopes; pure-line cultivar slopes ranged from 0.87 (Cheniere) to 1.31 (Wells), while hybrid-cultivar slopes ranged from 1.04 (CLXL729) to 1.83 (CLXP4534). Greater slopes indicate a greater impact on each milling-yield parameter by changing SLC, thus underscoring the need to prevent over milling of some cultivars compared to others.

SIGNIFICANCE OF FINDINGS

Results from this study corroborate reports of differences in milling characteristics between hybrid and pure-line cultivars reported by Siebenmorgen et al. (2006) and Lanning and Siebenmorgen (2011). Increased DOM, as measured by SLC, significantly decreased MRY and HRY, but at different rates for each cultivar, as indicated by the slopes of the milling yields and SLC. These differences in slope suggest that different milling characteristics among cultivars can significantly impact MRY and HRY, providing further evidence that milling parameters should be controlled with respect to SLC in order to compare HRYs among cultivars.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board and the corporate sponsors of the University of Arkansas Rice Processing Program for the financial contributions to this research.

LITERATURE CITED

Ambardekar, A.A., T.J. Siebenmorgen, P.A. Counce, S.B. Lanning, and A. Mauromoustakos. 2011. Impact of field-scale nighttime air temperatures during kernel development on rice milling quality. Field Crops Res. 122(2011):179-185.

Cnossen, A.G., T.J. Siebenmorgen, W. Yang, and R.C. Bautista. 2001. An application of glass transition temperature to explain rice kernel fissure occurrence during the drying process. Drying Techn. 19(8):1661-1682.

Cooper, N.T.W. and T.J. Siebenmorgen. 2007. Correcting head rice yield for surface lipid content (degree of milling) variation. Cereal Chem. 84(1):88-91.

Daniels, M.J. and B.P. Marks. 1998. Effects of long-grain rough rice storage history on end-use quality. J. of Food Sci. 63(5):832.

Kunze, O.R. and S. Prasad. 1978. Grain fissuring potentials in harvesting and drying of rice. Trans. of the ASAE 21(2):361-366.

Lanning, S.B. and T.J. Siebenmorgen. 2011. Comparison of milling characteristics of hybrid and pureline rice cultivars. Appl. Eng. in Ag. 27(5):787-795.

Lyon, B.G., E.T. Champagne, B.T. Vinyard, W.R. Windham, F.E. Barton II, B.D. Webb, A.M. McClung, K.A. Moldenhauer, S. Linscombe, K.S. McKenzie, and D.E. Kohlwey. 1999. Effects of degree of milling, drying condition, and final moisture content on sensory texture of cooked rice. Cereal Chem. 76(1):56-62.

Matsler, A.L. and T.J. Siebenmorgen. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a soxtec system. Cereal Chem. 82(3):282-286.

Monsoor, M.A. and A. Proctor. 2004. Volatile component analysis of commercially milled head and broken rice. J. of Food Sci. 69(8):632-636.

Perdon, A.A., T.J. Siebenmorgen, A. Mauromoustakos, V.K. Griffin, and E.R. Johnson. 2001. Degree of milling effects on rice pasting properties. Cereal Chem. 78(2):205-209.

Saleh, M.I. and J.-F. Meullenet. 2007. Effect of moisture content at harvest and degree of milling (based on surface lipid content) on the texture properties of cooked long-grain rice. Cereal Chem. 84(2):119-124.

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. in Ag. 23(4):517-527.

Siebenmorgen, T.J., A.L. Matsler, and C.F. Earp. 2006. Milling characteristics of rice cultivars and hybrids. Cereal Chem. 83(2):169-172.

USDA. 2009. United States standards for rice, revised. Federal Grain Inspection Service. Washington, D.C.

Table 1. Slopes of linear relationships between head rice surface lipid content and milled rice yield (Fig. 2) and head rice yield (Fig. 3), representing the percentage points of yield change per one-tenth percentage point of head rice surface lipid content change for the indicated cultivars milled for 10, 20, 30, and 40 s using a McGill No. 2 laboratory mill.

Cultivar	Milled rice yield	Head rice yield
Pure-line		
Cheniere	0.73 CD[†]	0.87 E
CL181	0.83 C	0.91 E
Taggart	0.82 C	0.95 DE
Wells	0.63 D	1.31 C
Hybrid		
CLXL729	1.02 B	1.04 DE
CLXL745	0.70 CD	1.19 CD
CLXP4534	1.05 B	1.83 A
CLXP752	0.80 C	1.42 BC
CLXP756	1.21 A	1.62 AB
$LSD_{0.05}$[‡]	0.16	0.27

[†] Slopes followed by the same letter are not significantly different. Comparisons are valid within a column.

[‡] Fisher's least significant difference (α = 0.05).

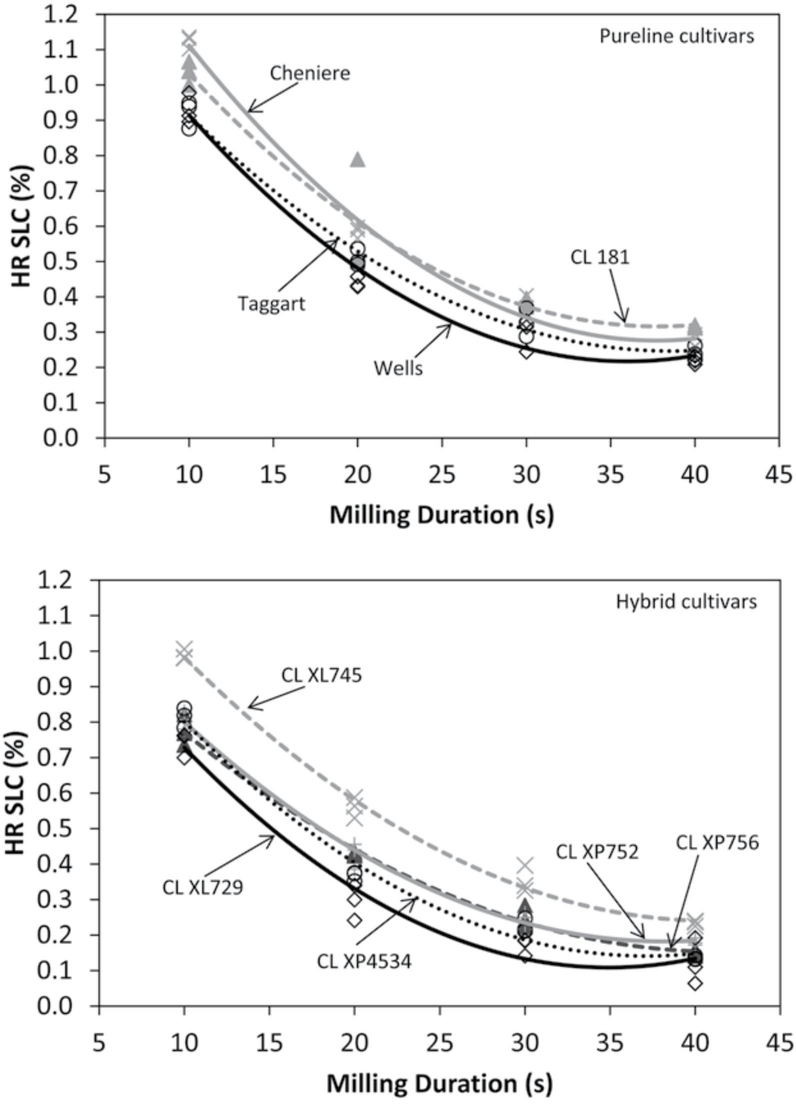


Fig. 1. Head rice surface lipid content (HR SLC) vs. milling duration of the indicated cultivars milled for 10, 20, 30, and 40 s using a McGill No. 2 laboratory mill.

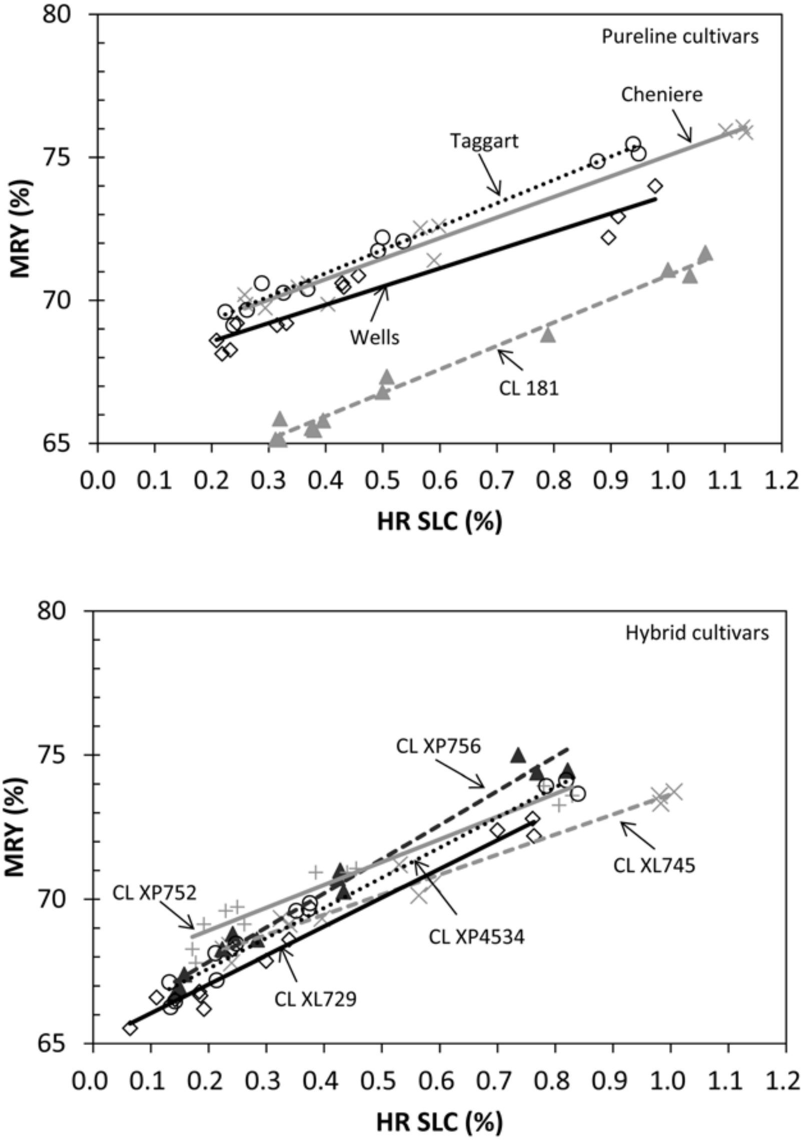


Fig. 2. Milled rice yield (MRY) vs. head rice surface lipid content (HR SLC) of the indicated cultivars milled for 10, 20, 30, and 40 s using a McGill No. 2 laboratory mill.

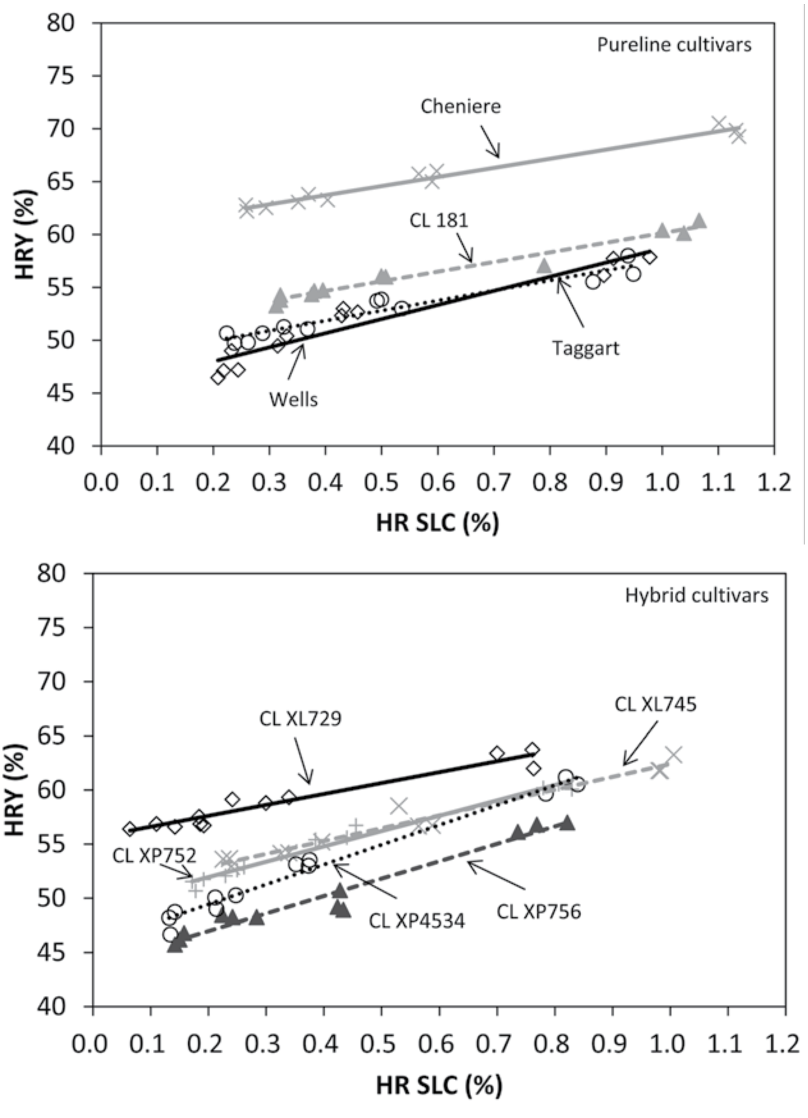


Fig. 3. Head rice yield (HRY) vs. head rice surface lipid content (HR SLC) of the indicated cultivars milled for 10, 20, 30, or 40 s using a McGill No. 2 laboratory mill.

Effects of Field Characteristics and Management on Technical, Allocative, and Economic Efficiency of Rice Production in Arkansas

T. Hristovska, K.B. Watkins, R. Mazzanti, and C.E. Wilson Jr.

ABSTRACT

Rice is a high-cost crop relative to other field crops in Arkansas, more efficient rice production management is pertinent to maintaining long-term profitability. This study assesses the important factors leading to higher technical, allocative, and economic (cost) efficiency in rice production by analyzing the 2005 to 2011 Rice Research and Verification Program (RRVP) data with the Tobit model. Using a Clearfield hybrid seed was found to have a positive statistically significant effect, as well as a relatively large marginal effect on all three efficiencies.

INTRODUCTION

Arkansas is the top domestic rice producer, representing nearly half of total U.S. rice production. In 2011 approximately 1.15 million acres of rice were harvested in Arkansas, valued at approximately $1.1 billion (USDA, NASS 2012). Rice however is a high-cost crop relative to other field crops in Arkansas, and production costs for rice have increased significantly since the mid 2000s due to rapidly increasing fuel and fertilizer prices (Fig. 1).

Flanders and Dunn (2012), also found rice to have the highest cost of production inputs of $550.92/acre. Production inputs include: seeds, fertilizers, chemicals, custom applications, diesel fuel, electricity, supplies, surveying levees, and labor, but the greatest portion of the costs in rice production comes from fertilizer and fuel costs. More specifically, the 2011 Rice Research and Verification Program (RRVP) study (Runsick et al., 2011) found the average operating expense for the 17 participating fields (used in this analysis) to be \$616.56/acre. Fertilizers accounted for the largest share of operating expenses on average (23.5%) followed by seed (14.2%), pesticides (13.6%), and irrigation energy costs (12.3%).

Given the increasing input costs, rice producers are required to use production inputs in the most efficient manner to minimize production costs and remain profitable. Rice producers currently make management decisions based on agronomic factors such as high yield, good disease resistance, and ease of management. The analysis contained in this study will provide rice producers with stronger information about the types of management practices and field conditions that improve economic (cost) efficiency, in the form of a more efficient combination of inputs and lower input costs, by identifying how different management practices and field characteristics affect technical, allocative, and economic (cost) efficiency of rice production in Arkansas. Technical efficiency refers to using minimum inputs to produce a given level of output. Allocative efficiency occurs when inputs for a given level of output and a set of input prices are chosen to minimize the cost of production assuming the organization is fully technically efficient. Economic (cost) efficiency is the product of both technical and allocative efficiency and refers to the production of a given quantity of output at the minimum possible cost. Therefore an economically (cost) efficient rice farm is both technically and allocatively efficient.

PROCEDURES

This study uses data for 137 rice fields enrolled in the University of Arkansas RRVP for the period 2005 to 2011. There are seventeen 2011 fields, twenty-two 2010, 2009, 2008 and 2005 fields (each), twelve 2007 fields, and twenty 2006 fields. The efficiency measures were provided by Watkins et al. (2012). They were calculated using a Data Envelopment Analysis (DEA), which is a non-parametric, linear programming approach that measures relative efficiency among a set of decision making units (rice fields in this case). The DEA approach followed by a Tobit model has been extensively used in the past to calculate efficiency scores and analyze the factors that affect different efficiencies. The studies by Kiatpathomchai (2008), Brázdik (2006), Dhungana et al. (2004), and Wu and Prato (2006) used the same technique to assess the economic and environmental efficiency of rice production systems in southern Thailand, West Java, Nepal, and crop and diversified production systems in Missouri (USA), respectively.

The Tobit model, first proposed by Tobin in 1958, was used because of the nature of the dependant variables which are in the 0 to 1 range, thus requiring a two limit model such as the censored Tobit. Following Greene (1990), the Tobit model for this analysis is defined as:

$$y_i^* = \beta_0 + \sum_{m=1}^{k} \beta_m x_{im} + \varepsilon_i \, , \quad \varepsilon_i \sim IN(0, \sigma^2)$$

where: y_i* is latent variable representing technical, economic, or allocative efficiency score of field *j*; β is a vector of unknown parameters; x_{im} is a vector of explanatory variables m (m = 1,…,k) for field *i* which is known constant and hypothesized as determinants of efficiency; and ε_i is an error term independently normally distributed, with zero mean and constant variance σ^2.

The independent variables are the same in the three models, while the dependant variables change between technical, economic (cost), and allocative efficiency, assuming variable returns to scale for all efficiency scores. Table 1 provides a complete description of all variable used in the analysis. The following variables were omitted from the model as those are base comparisons: year 2011 (YR11), Central West geographical region (CW), conventional variety of rice (CONV), silt loam soil (SLOAM), previous crop soybeans (SB), contour levees (CONTUR), well irrigation (WELL), and not multiple inlet (NOMI).

The effect of field size on efficiency scores is important because it is significant to know the optimal field size to achieve the optimum efficiency. Given management practices, experience has shown farms of about 50 acres tend to be the most efficient to manage. Years 2005 to 2011 are expected to capture mainly the weather effects and special conditions of each year, therefore compared to 2011, it is expected for years 2005 and 2010 to have a negative impact due to dry weather conditions whereas 2008 is expected to have a positive impact on efficiency scores due to high crop prices. Rice varieties such as hybrid and Clearfield hybrid are expected to have a positive effect on all efficiencies compared to the conventional varieties due to higher rice yields. Clay soil texture is expected to have a negative effect on efficiency scores relative to silt loam soil. Rice grown on clay soil requires more nitrogen fertilizer than rice grown on silt loam soil. Previous field crop being rice or any other crop (except soybeans) in the rotation is expected to have a negative effect on efficiency scores compared to cases when the previous crop was soybean. The rice-soybean rotation has been proven to the most profitable. Straight levees and zero-grade are expected to have a positive impact on efficiency scores relative to contour levee. Both zero-grade and straight levee fields are precision leveled to allow for better water delivery than contour levees. Multiple inlet irrigation is expected to have positive impact on all efficiency scores. Multiple inlet irrigation uses poly pipe to distribute irrigation water to all paddies simultaneously and allows the field to be flooded up much faster than conventional flood irrigation.

RESULTS AND DISCUSSION

The analysis was conducted using Stata statistical software (StataCorp LP, College Station, Texas). Six fields were excluded from the final analysis due to having sandy soil texture (two fields) and furrow irrigation (four fields), resulting in final 131 fields/observations. The results presented in Table 2 show that technical efficiency is positively and significantly affected by year 2009 and 2008 compared to year 2011. It is also positively and significantly affected by the usage of Clearfield hybrid rice types compared with the conventional or pure-line rice type. The only variable that has a negative statistically significant effect to the technical efficiency is field size.

Economic efficiency, same as technical efficiency, is positively and significantly affected by year 2009 and 2008 compared with year 2011. The use of a medium-grain, hybrid and Clearfield hybrid seed also has a positive and significant effect compared conventional grain. Similarly, zero-grade topography compared to contour levees and using multiple inlet irrigation compared to not using it has a positive and significant effect on economic efficiency. Economic (cost) efficiency was found to be negatively affected by the following statistically significant factors: year 2010 and 2005 compared to 2011, and when a previous crop is rice compared to soybeans.

Allocative efficiency is positively and significantly affected by the following factors: using medium-grain, hybrid and Clearfield hybrid rice compared to conventional rice, zero-grade topography compared to contour levees and using multiple inlet irrigation compared to not using multiple inlet. Allocative efficiency scores were negatively affected by the following statistically significant factors: year 2010, year 2006, and year 2005 compared to 2011, by the geographical placement of the fields in the other regions (i.e., non-eastern Arkansas counties) compared to the central eastern counties (Grand Prairie Region), and when a previous crop is rice compared to soybeans.

Table 3 shows the marginal effects of each variable. For example, the results indicate that an increase in farm size of one acre will cause the technical efficiency to decline by 0.002 efficiency units, and the economic and allocative efficiency to not change. The marginal effect for binary variables represents a discrete change when the binary variable changes from 0 to 1. Binary variables having positive effects on all three efficiency measures are the year 2008, hybrids, Clearfield hybrids, medium-grain varieties, zero-grade, and multiple inlet irrigation.

SIGNIFICANCE OF FINDINGS

The results of the analysis were expected to provide better evidence supporting the use of specific management practices in rice production. As expected, this analysis has proven that efficiency scores are negatively affected by dry years such as 2010 and 2005, by previous crop being any other crop than soybeans and positively affected by the use of multiple inlet irrigation and the use of hybrid and Clearfield hybrid rice seed types. The magnitude of the marginal effects of the factors also supports the fact that combining appropriate management practices such as using more efficient irrigation practices, specific types of seed, and the appropriate rotation crops will significantly increase the efficiency of rice production in the form of a more efficient combination of inputs and lower input costs.

Field size is an important factor affecting efficiency however, the fields included in the analysis range between 9 and 183 acres with a mean field size of about 61 acres. The average Arkansas rice farm is about 453 acres (Baldwin et al., 2011); therefore the effect of this factor may be impacted by the field selection. The importance of irrigation practices in rice production has also been emphasized in this study as well as in many other studies. This implies that future studies using correctly measured water usage will be of a great importance to both farmers and scientists.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Baldwin, K., E. Dohlman, N. Childs, and L. Foreman. 2011. Consolidation and structural change in the U.S. rice sector. United States Department of Agriculture: Economic Research Service. Retrieved on 10 January 2012 at http://www.ers.usda.gov/media/111364/rcs11d01_1_.pdf

Brázdik, F. 2006. Non-parametric analysis of technical efficiency: Factors affecting efficiency of west Java rice farmers. Working Paper Series 286 (ISSN 1211-3298). Charles University, Center for Economic Research and Graduate Education, Academy of Sciences of the Czech Republic, Prague.

Dhungana. B.R., P.L. Nuthall, and G.V. Nartea. 2004. Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. Austr. J. Agric. Res. Econ. 48(2):347-369.

Flanders, A. and K.C. Dunn. 2012. Input costs trends for Arkansas field crops, 2006-2012. University of Arkansas Division of Agriculture. Retrieved on 10 December 2012 from: http://www.uaex.edu/depts/ag_economics/publications/AG1277.pdf

Greene W.H. 1990. Econometric Analysis. New York: Macmillan.

Kiatpathomchai, S. 2008. Assessing economic and environmental efficiency of rice production systems in southern Thailand: An application of data envelopment analysis. Doctoral Dissertation. Justus Liebig University Giessen-Institute of Agricultural Policy and Market Research, Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, Gissen, Germany

Runsick, S., R. Mazzanti, C.E. Wilson Jr., K.B. Watkins, and T. Hristovska. 2011. Rice Research Verification Program, 2011. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock.

(USDA, NASS) National Agricultural Statistics Service. 2012. 2011 State Agricultural Overview, Arkansas. November 15, 2012 http://www.nass.usda.gov/Statistics_by_State/Ag_Overview/AgOverview_AR.pdf

Watkins, K.B., T. Hristovska, R. Mazzanti, and C.E. Wilson Jr. 2012. Measuring technical, allocative, and economic efficiency of rice production in Arkansas using data envelopment analysis. SAEA Annual Meeting 2013

Wu, S. and T. Prato. 2006. Cost efficiency and scope economies of crop and livestock farms in Missouri. J. Agric. Appl. Econ. 38(3):539-553.

Table 1. Descriptive analysis of variables used.

Acronym	Description	Mean	StDev	CV	Min	Max
TEVRS	Technical Efficiency assuming Variable Returns to Scale	0.89	0.16	17.48	0.46	1
EEVRS	Economic (Cost) Efficiency assuming Variable Returns to Scale	0.62	0.19	30.20	0.32	1
AEVRS	Allocative Efficiency assuming Variable Returns to Scale	0.70	0.16	22.45	0.32	1
FLDSIZE	Field Size (acres)	61.14	33.08	54.11	9	183
YR11	Year 2011	0.12	0.33	269.12	0	1
YR10	Year 2010	0.17	0.38	223.44	0	1
YR09	Year 2009	0.16	0.37	229.75	0	1
YR08	Year 2008	0.17	0.38	223.44	0	1
YR07	Year 2007	0.08	0.27	349.19	0	1
YR06	Year 2006	0.14	0.35	251.52	0	1
YR05	Year 2005	0.17	0.38	223.44	0	1
NE	Northeast (NASS Crop Reporting District 3 counties)	0.37	0.49	129.86	0	1
CW	Central West (Grand Prairie counties of Arkansas, Lonoke, and Prairie in NASS Crop Reporting District 6 counties)1	0.20	0.40	201.73	0	4
CE	Central, East (Non Grand Prairie counties in NASS Crop Reporting District 6 counties)	0.19	0.39	206.70	0	1
SE	Southeast (NASS Crop Reporting District 9 counties)	0.15	0.36	236.49	0	1
OL	Other Location (Non-eastern Arkansas counties)	0.08	0.28	331.56	0	1
CONV	Conventional Variety	0.47	0.50	107.53	0	1
MG	Medium Grain Variety	0.09	0.29	316.12	0	1
CL	Clearfield Variety	0.10	0.30	302.44	0	1
HYB	Hybrid Variety	0.07	0.25	369.59	0	1
CLHYB	Clearfield Hybrid Variety	0.27	0.45	163.07	0	1
SLOAM	Silt Loam Soil Texture	0.63	0.49	77.60	0	1
CLAY	Clay Soil Texture	0.37	0.49	129.86	0	1
SB	Previous crop was Soybeans	0.66	0.47	71.39	0	1
RICE	Previous crop was Rice	0.23	0.42	184.19	0	1
OCROP	Previous crop was neither soybeans nor rice (corn, grain sorghum, fallow)	0.11	0.31	290.20	0	1
CONTUR	Contour Levee field topography	0.42	0.50	118.00	0	1
STRAIT	Straight Levee field topography	0.47	0.50	107.53	0	1
ZERO	Zero-Grade Field topography	0.11	0.32	279.16	0	1
WELL	Irrigation water supplied by well	0.82	0.39	47.54	0	1
SURFACE	Irrigation water supplied by surface water source	0.18	0.39	211.96	0	1
MI	Field has Multiple Inlet Irrigation	0.32	0.47	146.13	0	1
NOMI	Field does not have Multiple Inlet irrigation	0.68	0.47	68.96	0	1

Table 2. Tobit regression coefficients (n = 131).

	Regression coefficients β (Standard errors)		
Independent variables	TEVRS[a]	EEVRS	AEVRS
FLDSIZE	-0.0017**	-0.0003	0.0003
	(0.0008)	(0.0003)	(0.0003)
YR10	-0.0800	-0.1395***	-0.1367***
	(0.0891)	(0.0326)	(0.0378)
YR09	0.2642**	0.0855**	-0.0089
	(0.1025)	(0.0332)	(0.0385)
YR08	0.4088***	0.1630***	0.0308
	(0.1262)	(0.0369)	(0.0428)
YR07	0.1873	0.0222	-0.0568
	(0.1306)	(0.0429)	(0.0497)
YR06	0.1461	-0.0247	-0.1005**
	(0.1113)	(0.0383)	(0.0445)
YR05	0.0495	-0.1297***	-0.1591***
	(0.1087)	(0.0381)	(0.0443)
NE	0.0820	0.0278	-0.0050
	(0.0695)	(0.0233)	(0.0271)
CE	0.0696	-0.0254	-0.0509
	(0.0808)	(0.0274)	(0.0319)
SE	0.0781	0.0066	-0.0304
	(0.0990)	(0.0331)	(0.0385)
OL	0.0143	-0.0610	-0.0985**
	(0.1131)	(0.0388)	(0.0450)
MG	0.1427	0.1956***	0.1215***
	(0.1093)	(0.0365)	(0.0424)
CL	-0.0342	-0.0110	0.0096
	(0.0979)	(0.0348)	(0.0404)
HYB	0.1604	0.2526***	0.2207***
	(0.1219)	(0.0357)	(0.0417)
CLHYB	0.1674**	0.1646***	0.1108***
	(0.0822)	(0.0250)	(0.0291)
CLAY	0.0176	-0.02348	-0.0337
	(0.0617)	(0.0200)	(0.0232)
RICE	-0.0043	-0.0576**	-0.0565*
	(0.0765)	(0.0256)	(0.0297)
OCROP	0.0240	-0.0039	-0.0037
	(0.0816)	(0.0279)	(0.0324)
STRAIT	0.0002	-0.0072	-0.0157
	(0.0592)	(0.0198)	(0.0229)
ZERO	0.0266	0.0923**	0.1004**
	(0.1227)	(0.0374)	(0.0435)
SURFACE	0.0257	-0.0080	-0.0337
	(0.0784)	(0.0256)	(0.0298)
MI	0.0241	0.0466**	0.0410*
	(0.0622)	(0.0197)	(0.0229)
Constant	0.8557***	0.5697***	0.7260***
	(0.1154)	(0.0405)	(0.0470)

Asterisks *,** and ***, represent 10%, 5%, and 1% statistical significance, respectively.

[a] Definitions for all abbreviations can be found in Table 1.

Table 3. Marginal effects after Tobit regression.

	Marginal effects		
Independent variables	TEVRS[a]	EEVRS	AEVRS
FLDSIZE	-0.002	0.000	0.000
YR10*	-0.080	-0.140	-0.137
YR09*	0.264	0.086	-0.009
YR08*	0.409	0.163	0.031
YR07*	0.187	0.022	-0.057
YR06*	0.146	-0.025	-0.100
YR05*	0.049	-0.130	-0.159
NE*	0.082	0.028	-0.005
CE*	0.070	-0.025	-0.051
SE*	0.078	0.007	-0.030
OL*	0.014	-0.061	-0.099
MG*	0.143	0.196	0.121
CL*	-0.034	-0.011	0.010
HYB*	0.160	0.253	0.221
CLHYB*	0.167	0.165	0.111
CLAY*	0.018	-0.023	-0.034
RICE*	-0.004	-0.058	-0.056
OCROP*	0.024	-0.004	-0.004
STRAIT*	0.000	-0.007	-0.016
ZERO*	0.027	0.092	0.100
SURFACE*	0.026	-0.008	-0.034
MI*	0.024	0.047	0.041

(*) dy/dx is for discrete change of dummy variable from 0 to 1.

[a] Definitions for all abbreviations can be found in Table 1.

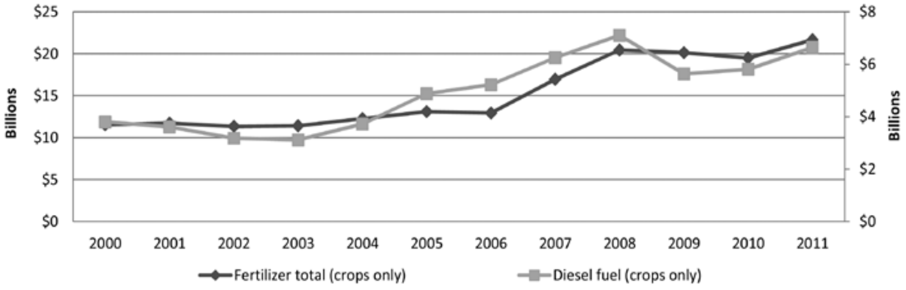


Fig. 1. United States historical fertilizer and fuel expenses (2011 dollars).

Arkansas Representative Panel Farm Analysis of the 2008 Farm Bill's One-Year Extension

V. Karov, E.J.Wailes, and K.B. Watkins

ABSTRACT

The 2008 Farm Bill expired on 30 September 2012. The 2012 Farm Bill negotiation and process was in limbo until the end of 2012. End of 2012 legislation titled, the American Taxpayer Relief Act of 2012 to avoid the fiscal cliff, included a 1 year extension for the farm bill. We examine the effect of this extension at the farm level in Arkansas. Specifically, we assess the effects of Title I (Commodity) programs during the 5-year period 2013-2017 assuming the same policies remain in place throughout this time span.

INTRODUCTION

The Food, Conservation, and Energy Act of 2008 (P.L. 110-246)[1], more commonly known as the 2008 Farm Bill, expired on 30 September 2012. During the political process of negotiating and writing a new comprehensive 5-year bill in the 112th United States (U.S.) Congress, the Senate and House Committee on Agriculture passed their versions of the 2012 Farm Bill in the summer of 2012. The Agriculture Reform, Food, and Jobs Act of 2012 (S. 3240)[2] passed the Senate on 21 June 2012 on a strong bipartisan 64-35 vote. The Federal Agriculture Reform and Risk Management Act of 2012 (H.R. 6083)[3] passed the House Committee on Agriculture on 12 July 2012, again

---

[1] Available online at: http://www.gpo.gov/fdsys/pkg/PLAW-110publ246/pdf/PLAW-110publ246.pdf (GPO, 2008).

[2] Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112s3240pp/pdf/BILLS-112s3240pp.pdf (GPO, 2012a).

[3] Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112hr6083rh/pdf/BILLS-112hr6083rh.pdf (GPO, 2012b).

with a strong bipartisan vote (35-11). Reluctance by the House leadership to bring the House Committee bill to the floor for a vote left the completion of the 2012 Farm Bill negotiation process in limbo until the end of 2012. On 1 January 2013, a bill, the American Taxpayer Relief Act of 2012 (H.R. 8)[4] was enacted to temporarily address the nation's $16 trillion debt and avoid the so-called "fiscal cliff". It contained both spending cuts and tax increases and also a 1-year extension of the 2008 Farm Bill. This extension applies only to the 2013 crop year. In effect, it extends certain programs of the 2008 legislation such as price and income safety net programs for grain producers for 9 months (through 30 Sept. 2013).

In each of the years 2008-2011, Arkansas producers received more than $230 million overall in direct payments (DPs). Because of the relatively high market price environment during this period, Arkansas producers received significantly less support from the counter-cyclical payments (CCPs) and loan-deficiency payments (LDPs) programs (Wailes, 2012). During the same time span, Arkansas farmers did not participate in the Average Crop Revenue Election (ACRE) program (Table 1) (EWG, 2013).[5]

The goal of this study is to assist Arkansas producers in making better-informed decisions regarding future participation in Federal agricultural programs (Wailes et al., 2012). The objective is to examine the economic impact of the 1-year extension of the 2008 Farm Bill at the farm level in the state of Arkansas. Specifically, we assess the effects of Title I (Commodity) programs of this legislation (DPs, CCPs, LDPs, and ACRE) during the 5-year period 2013-2017 assuming the same policies remain fully in place throughout this time span (Karov and Wailes, 2011).

PROCEDURES

This study employs the Arkansas representative panel farms framework. Representative farms are developed based on information jointly collected by extension economists from the Arkansas Cooperative Extension Service and Texas A&M University's Agricultural Food and Policy Center. Every 2 to 3 years, these professionals work closely with panels of farmers to update (or construct new) representative farms sharing common features with farms of a certain geographical location. During this process, information such as (but not limited to) planted acreage, crop mix, land tenure arrangements, participation in Federal farm programs, base acreage, historical yields, location-specific price wedges relative to the mean national prices, assets, costs, loan interest rates, and depreciation method is collected (Hignight, 2007). Table 2 shows characteristics for the five eastern Arkansas representative panel farms providing the framework for this analysis. Farm names start with AR, Arkansas' two-letter state label, and end with a number representing the total planted cropland acres specific to each farm. For example, ARHR3000 is a 3,000 acre rice, soybean, and corn farm located in Hoxie, and ARNC5000 is a 5,000 acre cotton farm in Leachville.

---

[4] Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112hr8enr/pdf/BILLS-112hr8enr.pdf (GPO, 2013).

[5] Karov and Wailes (2011) provide an in-depth summary of Title I of the 2008 Farm Bill and illustrate how payments are calculated for each of these four programs.

Following Richardson, Klose, and Gray (2000), a procedure for developing multivariate empirical (MVE) probability distributions for farm-related variables is employed. Specifically, 10-year historical data are used to develop MVE probability distributions for: national annual farm average and adjusted-world crop prices; farm-specific crop yields; and state (Arkansas)-specific crop yields. Simetar (Simetar, Inc., College Station, Texas) is used to simulate stochastic baseline 5-year projections for the period 2013-2017 with 500 iterations (random draws) per variable per year.

Historical national annual farm average and adjusted-world crop prices are obtained from the United States Department of Agriculture's National Agricultural Statistics Service (USDA/NASS) (USDA, NASS, 2013), the USDA's Economic Research Service (ERS) Rice Yearbook (USDA, ERS, 2012), the USDA's Agricultural Marketing Service (AMS) (USDA, AMS, 2012), and the Food and Agriculture Policy Research Institute (FAPRI)-University of Missouri (FAPRI, 2012). Actual historical farm-specific crop yields are obtained during the panel farm interview process. State-specific crop yields, on the other hand, are obtained from USDA/NASS (USDA, NASS, 2013). The 2008 Farm Bill policy variables (such as crop-specific direct payment rates, loan rates, and target prices) are obtained from the USDA/ERS 2008 Farm Bill Side-By-Side Comparison (USDA, ERS, 2009).

The latest baseline update (December, 2012) by FAPRI-University of Missouri is used to obtain projected national annual farm average and adjusted-world crop prices (FAPRI, 2012). Finally, projected farm and state-specific crop yields are calculated by the authors by assuming farm/state and crop-specific growth trends.

RESULTS AND DISCUSSION

The analysis of the CCPs program shows that none of the sample crops except cotton are projected to receive payments during the sample period. The main reason for this is that in most cases the established target prices are lower than the respective effective prices. The Leachville and the McGehee farms are the only farms in the sample that produce cotton (Table 2), and are the only farms that on average have a 46% chance to receive CCPs during the sample period for this crop. The calculated probabilities of receiving a payment for each of the years 2013-2017 are: 42%, 49%, 50%, 43%, and 44%, respectively. The calculated mean CCP rates (in $/lb) for each of the five sample years are: 0.02, 0.03, 0.03, 0.02 and 0.02, respectively.

The LDPs program analysis yields similar results. Again, relatively strong crop market prices are greater than the established loan rates with the only exception of cotton in some instances. The Leachville and the McGehee farms are the only farms that on average have a 26% chance to receive LDPs during the sample period for cotton. The calculated probabilities of receiving a payment for each of the years 2013-2017 are: 22%, 28%, 33%, 26%, and 23%, respectively. Calculated mean LDP rates (in $/lb) for each of the sample years are: 0.01, 0.02, 0.02, 0.02, and 0.01, respectively.

Since they are based on historical information and are not calculated based on current market data, DPs are fixed at the DP payment rate ($/unit) times the direct payment program yield (output/acre) established for each farm, for each of the years 2013-2017 (Table 3). On a per base acre basis, rice receives the most DPs among all sample crops. Long-grain rice payments are in the $90 to $111 range. The Hoxie farm, the only medium-grain rice producer in the sample, is projected to receive $92 per base acre in each of the five sample years for this crop. Expected DPs for all other crops are significantly lower. Such payments are in the $8 to $12 range for soybeans and the $27 to $36 range for cotton. Finally, only the Stuttgart farm receives payments for wheat, $19 per base acre, while none of the farms receive DPs for corn.

The probabilities of receiving an ACRE payment during the period 2013-2017 are low across all farm-crop combination pairs (Table 4). Such 5-year annual average probabilities are always below 20% for long-grain rice and 30% for medium-grain rice and soybeans. For cotton, such probabilities are in the 28% to 32% range. Finally, for wheat and corn the probabilities are relatively higher, but are always lower than 40% on average. Table 5 shows the average stochastic gross ACRE payments per planted acre for each of the years 2013-2017 on a by-farm and crop basis. It also illustrates the average 5-year expected gross ACRE payments for each farm-crop combination. Such payments are below $20 per planted acre for long-grain rice, irrigated/dryland soybeans and dryland cotton. For irrigated cotton, they are in the $23 to $28 range, and for wheat they are in the $20 to $22 range. For medium-grain rice, these expected payments are $37 per planted acre, and for corn they are relatively higher and are in the $43 to $47 range. Table 6 illustrates the average stochastic net ACRE payments per planted acre (gross ACRE payment less 20% loss of DP) for each of the years 2013-2017 on a by-farm and crop basis, and it shows the average 5-year estimated net ACRE payments for each farm-crop combination. The results suggest that for the 5-year sample period, on average, participation in ACRE provides some revenue support across all sample crops on these representative farms with the exception of long-grain rice and irrigated and dryland cotton.

SIGNIFICANCE OF FINDINGS

Southern producers gain relatively more as compared to farmers from the midwest as a result of the one-year extension of the 2008 Farm Bill. The main reason for this is that DPs remains in place for the 2013 crop year, and this program has traditionally provided a strong safety net for southern producers, particularly for rice. Due to the currently strong crop market price environment, producers for crops in the sample (except cotton) are not likely to receive CCPs and LDPs between the 2013 and 2017 crop years. We estimate that for the 2013 crop year, cotton producers have a 22% (42%) probability to receive LDPs (CCPs).

Once enrolled in ACRE for the 2013 crop year, producers: are ineligible to receive CCPs, will have their DPs reduced by 20%, and their loan rates reduced by 30%. With the exception of long-grain rice and cotton, participation in ACRE results in greater payments for all sample crops. However, across all farms in the state overall, it remains unclear whether or not a producer should potentially participate in ACRE and the decision to participate should be cautiously examined by each individual producer.

ACKNOWLEDGMENTS

We gratefully acknowledge funding for this study which was provided by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

(EWG) Environmental Working Group. 2013. Farm Subsidy Database. Available online at: http://farm.ewg.org/

(FAPRI) Food and Agricultural Policy Research Institute. University of Missouri. 2012. U.S. Available online at: http://www.fapri.missouri.edu/

(GPO) United States Government Printing Office. 2008. Food, Conservation, and Energy Act of 2008. Available online at: http://www.gpo.gov/fdsys/pkg/PLAW-110publ246/pdf/PLAW-110publ246.pdf Hignight, J.A. 2007. An economic comparison of alternative farm policies on Arkansas representative panel farms. M.S. thesis, University of Arkansas. Fayetteville.

(GPO) United States Government Printing Office. 2012a. Agriculture Reform, Food, and Jobs Act of 2012. Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112s3240pp/pdf/BILLS-112s3240pp.pdf

(GPO) United States Government Printing Office. 2012b. Federal Agriculture Reform and Risk Management Act of 2012. Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112hr6083rh/pdf/BILLS-112hr6083rh.pdf

(GPO) United States Government Printing Office. 2013. American Taxpayer Relief Act of 2012. Available online at: http://www.gpo.gov/fdsys/pkg/BILLS-112hr8enr/pdf/BILLS-112hr8enr.pdf

Karov, V. and E.J. Wailes. 2011. Farm Bill 2008 Policy Briefs: Effects on Arkansas." University of Arkansas Cooperative Extension Service. Available online at: http://www.aragriculture.org/agfoodpolicy/2008FarmBillPrimer_November2011_Wailes.pdf

Richardson, J.W., S.L. Klose, and A.W. Gray. 2000. An applied procedure for estimating and simulating multivariate empirical (MVE) probability distributions in farm-level risk assessment and policy analysis. J. Agric. Appl. Econ. 32(2):299-315.

(USDA, AMS) U.S. Department of Agriculture. Agricultural Marketing Service. 2012. Available online at: http://www.ams.usda.gov/AMSv1.0/

(USDA, ERS) U.S. Department of Agriculture. Economic Research Service. 2012. Rice Yearbook. Available online at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1229

(USDA, ERS) U.S. Department of Agriculture. Economic Research Service. 2009. The 2008 Farm Bill Side-By-Side Comparison. Available online at: http://www.ers.usda.gov/FarmBill/2008/

(USDA, NASS) U.S. Department of Agriculture. National Agricultural Statistics Service. 2013. Available online at: http://www.nass.usda.gov/

Wailes, E.J. 2012. Analysis for the next farm bill: Implications for the U.S. rice sector. Invited presentation. Meeting proceedings abstract, 34th Rice Technical Working Group. Hot Springs, Ark. February, 2012. pp. 39-40.

Wailes, E.J., K.B. Watkins, V. Karov, and E.C. Chavez. 2012. 2012 farm bill analysis of alternative programs for Arkansas agriculture. Department of Agricultural Economics and Agribusiness. At: http://www.aragriculture.org/agfoodpolicy/farmbill/05_Southcorp_Bank_Stuttgart_10.30.2012.pdf?

Table 1. Commodity subsidies received by Arkansas producers, by selected program.

Year	Direct payments	Counter-cyclical payments	Loan-deficiency payments	Marketing loan gains	Average crop revenue election
1995	$0	$0	$910,102	$21,750,177	$0
1996	$0	$0	$40,962	$52,357	$0
1997	$0	$0	$0	$9	$0
1998	$0	$0	$35,464,270	$5,824,261	$0
1999	$0	$0	$182,239,689	$45,133,006	$0
2000	$0	$0	$221,605,612	$93,042,788	$0
2001	$0	$0	$230,671,978	$55,783,666	$0
2002	$19,559,540	$18,531,189	$104,629,625	$102,070,647	$0
2003	$309,723,469	$260,133,664	$124,526,863	$63,770,283	$0
2004	$255,205,928	$76,848,159	$31,799,712	$17,600,986	$0
2005	$253,886,694	$79,518,631	$35,363,002	$26,899,214	$0
2006	$250,203,561	$125,730,036	$5,116,580	$21,669,415	$0
2007	$247,973,583	$82,859,346	$679,533	$144,532	$0
2008	$249,463,957	$43,050,650	$7,928,664	$0	$0
2009	$236,631,504	$82,000,218	$1,793,730	$15,337	$0
2010	$248,859,094	$11,578,625	$1,535	$0	$0
2011	$233,860,427	$17,774	$0	$0	$0

Source: Environmental Working Group, 2013. The Environmental Working Group's Farm Subsidy Database is constructed using USDA data pursuant to the Freedom of Information Act. The most-recent year for which data is available is 2011.

Table 2. Arkansas representative panel farm characteristics.

Farm name	ARHR3000[a]	ARNC5000	ARC7500	ARHR3240	ARWR1400
Location	Hoxie	Leachville	McGehee	Stuttgart	Wynne
County	Lawrence	Mississippi	Desha	Arkansas	Cross
Acres owned	1,000	1,000	1,200	648	420
Acres under crop share lease	1,500	3,200	5,985	1,552	490
Acres under cash lease	500	800	315	1,040	490
Cash rent for land ($/acre)	100	125	130	100	100
Planted acres	**3,000**	**5,000**	**7,500**	**3,240**	**1,400**
Medium-grain rice	150	0	0	0	0
Long-grain rice	1,300	0	1,875	1,620	700
Irrigated soybeans	1,125	0	1,625	1,296	650
Full-season irrigated soybeans	0	0	1,625	0	0
Double-crop irrigated soybeans	0	0	750	0	0
Dryland soybeans	125	0	0	0	50
Corn	300	0	1,500	0	0
Irrigated cotton	0	4,750	1,500	0	0
Dryland cotton	0	250	0	0	0
Wheat	0	0	1,000	324	0
Base acres					
Medium-grain rice	175	0	0	0	0
Long-grain rice	1,575	0	2,375	1,620	700
Irrigated soybeans	1,125	0	2,585	1,296	650
Full season irrigated soybeans	0	0	2,585	0	0
Double crop irrigated soybeans	0	0	0	0	0
Dryland soybeans	125	0	0	0	50
Corn	0	0	0	0	0
Irrigated cotton	0	4,250	2,375	0	0
Dryland cotton	0	225	0	0	0
Wheat	0	0	0	235	0

[a] Representative panel farm names start with AR, Arkansas' two-letter State label, and end with a number representing the total planted cropland acres specific to each farm. For instance, ARHR3000 is a 3,000 acre rice, soybean, and corn farm located in Hoxie.

Table 3. Annual direct payments received, in dollars per effective base acre (2013-2017).

	Farm location				
Crop	Wynne	Hoxie	Stuttgart	Leachville	McGehee
	------------ Annual average (2013-201-7), in $/acre, by crop -------------				
Long-grain rice	104	92	111	---	90
Medium-grain rice	---	92	---	---	---
Irrigated soybeans	12	12	12	---	8
Dry soybeans	12	12	---	---	---
Irrigated cotton	---	---	---	27	36
Dry cotton	---	---	---	27	---
Corn	---	---	---	---	---
Wheat	---	---	19	---	---

-

Table 4. Percentage probability of receiving an ACRE payment (2013-2017).[a]

	Stuttgart			Wynne			Leachville		Hoxie					McGehee					
Year	LGR	IRSB	W	LGR	IRSB	DLSB	IRCT	DLCT	LGR	MGR	CN	IRSB	DLSB	LGR	CN	W	IRCT	FSSB	DCSB
2013	8	38	42	8	36	35	42	42	7	29	53	29	35	6	53	42	42	36	38
2014	21	38	62	21	37	34	21	22	21	32	56	31	32	21	57	58	24	37	37
2015	23	26	47	23	25	21	27	28	22	30	27	21	19	22	27	46	32	25	25
2016	21	28	31	21	26	21	23	24	20	30	27	22	21	20	28	29	28	28	26
2017	18	19	20	17	20	15	28	28	17	28	25	15	17	17	28	23	34	20	20
Mean	18	30	40	18	29	25	28	29	17	30	38	23	25	17	38	39	32	29	29

[a] LGR, IRSB, W, DLSB, IRCT, DLCT, MGR, CN, FSSB, and DCSB stand for long-grain rice, irrigated soybeans, wheat, dryland soybeans, irrigated cotton, dryland cotton, medium-grain rice, corn, full-season soybeans and double-crop soybeans, respectively.

Table 5. Average stochastic gross ACRE payments per planted acre (2013-2017), in United States dollars.[a]

	Stuttgart			Wynne			Leachville		Hoxie					McGehee					
Year	LGR	IRSB	W	LGR	IRSB	DLSB	IRCT	DLCT	LGR	MGR	CN	IRSB	DLSB	LGR	CN	W	IRCT	FSSB	DCSB
2013	1	17	21	1	18	11	31	23	1	22	60	14	9	1	66	20	33	20	16
2014	11	19	39	12	22	13	14	10	11	35	66	18	9	12	73	37	18	24	17
2015	19	12	24	20	14	7	24	17	19	45	30	12	5	20	33	23	30	15	10
2016	18	12	14	18	13	6	19	14	18	39	27	11	6	19	29	12	25	15	11
2017	12	9	9	12	11	5	28	19	12	43	29	8	5	12	33	9	35	12	9
Mean	12	14	22	13	15	8	23	17	12	37	43	13	7	13	47	20	28	17	13

[a] LGR, IRSB, W, DLSB, IRCT, DLCT, MGR, CN, FSSB, and DCSB stand for long-grain rice, irrigated soybeans, wheat, dryland soybeans, irrigated cotton, dryland cotton, medium-grain rice, corn, full-season soybeans and double-crop soybeans, respectively.

Table 6. Average stochastic net ACRE payments per planted acre (2013-2017), in United States Dollars.[a]

	Stuttgart			Wynne			Leachville		Hoxie					McGehee					
Year	LGR	IRSB	W	LGR	IRSB	DLSB	IRCT	DLCT	LGR	MGR	CN	IRSB	DLSB	LGR	CN	W	IRCT	FSSB	DCSB
2013	-21	14	17	-20	15	9	9	2	-18	4	60	11	7	-17	66	20	6	18	16
2014	-11	17	36	-9	20	11	-13	-15	-7	17	66	16	7	-6	73	37	-16	22	17
2015	-3	9	21	-1	11	5	-4	-9	1	26	30	10	3	2	33	23	-5	13	10
2016	-4	10	10	-3	11	4	-4	-8	-1	21	27	9	3	1	29	12	-5	14	11
2017	-10	7	5	-9	8	2	4	-4	-7	24	29	6	2	-6	33	9	5	10	9
Mean	-10	11	18	-8	13	6	-2	-7	-6	18	43	10	4	-5	47	20	-3	15	13

[a] LGR, IRSB, W, DLSB, IRCT, DLCT, MGR, CN, FSSB, and DCSB stand for long-grain rice, irrigated soybeans, wheat, dryland soybeans, irrigated cotton, dryland cotton, medium-grain rice, corn, full-season soybeans, and double-crop soybeans, respectively.

United States Drought Impacts on the United States and International Rice Economies[1]

E.J. Wailes and E.C. Chavez

ABSTRACT

Drought is one of the weather-related uncertainties and risks inherent in the agricultural sector which potentially affects both producers and consumers. While the impact of the U.S. drought in the fall of 2012 is relatively muted for the global rice economy due to large stocks in China, India, and Thailand, there are nevertheless, challenges faced by key food deficit nations like the Philippines, Bangladesh, and Indonesia regarding food security as rice prices increase. For the U.S., China, and Indonesia, changes in the prices of corn, soybeans, and wheat relative to rice result in responses on rice production, consumption, and trade. It takes about three years before the drought-induced impact on the rice sector stabilizes.

INTRODUCTION

Extreme volatility of food commodity prices has been an overriding issue in various agricultural forums since the occurrence of the food price crisis in the 2007/08 season, which triggered riots in a number of countries. Price volatility affects the Arkansas and U.S. rice producers by increasing revenue risk. This in turn results in less than optimal investment and decision-making regarding crop choice and associated investments. The primary driver of concern in developing countries is food security, and price and income effects in general. Food security and food self-sufficiency issues are typically a priority for governments of many countries, especially the food-deficit economies in Asia.

---

[1] This material is based upon work supported in part with funding provided by the Arkansas Rice Research and Promotion Board.

Agriculture is prone to the vagaries of nature. Drought is one of the weather-related uncertainties and risks inherent in agricultural enterprises which could potentially affect both producers and consumers. The recent drought in the U.S. and other parts of the world caused spikes in prices of major agricultural commodities–corn, soybeans, and wheat. Figures 1 and 2 show two maps that give an indication of the intensity and progression of the drought in the U.S. from 21 August 2012 to 8 January 2013 (U.S. Drought Monitor, various issues).

In December 2012, the USDA reported that the most severe and extensive drought in at least 25 years is seriously affecting U.S. agriculture, with impacts on the crop and livestock sectors, and the potential to affect food prices at the retail level. A total of 2,000 counties were declared as disaster areas as of mid-September. Crop production estimates for several major crops declined throughout the summer as the drought intensified. By November, production estimates for corn declined by 27.5% and for soybeans by 7%, compared to the May estimates, as substantial reductions in both crop yields and share of harvested acres occurred (USDA, 2012).

Consequently, global food prices jumped 10% from June to July 2012, driven primarily by the severe Midwest drought (World Bank as cited by Lopez, 2012). Considering that the U.S. is the world's largest exporter of corn and soybeans, the current drought in the U.S. has global impacts. U.S. rice net trade, on the other hand, accounts for only about 7% of global rice trade.

The price of corn and wheat rose by 25%, and that of soybeans rose by 17% during the same period. Surprisingly, rice price was relatively stable during the same period (Figs. 3 and 4). In fact, the production estimate for U.S. rice increased in November 2012 above the May estimate by 8.6%. The reason is that rice is an irrigated crop and hence was relatively unaffected by drought.

Figure 3 indicates the monthly average prices for rice and the other commodities. The average rice price declined while the rest of the prices spiked and remained elevated at least through October 2012. In fact, rice prices continued to remain stable at the lower prices; and even declined further in December.

Another reason for the rice price behavior is that world rice has been a buyers' market due to abundant supplies in major exporting countries such as India, Vietnam, and Thailand–mainly from surplus stocks. As such, strong price competition for limited import market has emerged among the major players in global rice trade.

Soybean prices stabilized at the high level in August and September; and started to decline thereafter but remained higher than the pre-drought level by December. Wheat prices continued to climb until November, albeit slowly, before declining slightly in December. Corn prices stabilized at the high level in August and started a slight downward trend since then, although the level is still much higher than the pre-drought level.

This paper explores the impact of the recent substantial price spikes in corn, soybeans, and wheat on the U.S. and international rice markets, considering that these commodities are substitute crops for rice in the U.S. and other countries. Rice area competes with a number of crops including soybeans, corn, and cotton in rice-producing states of Arkansas, Louisiana, Missouri, Mississippi, Texas, and California.[2]

In China, rice competes with corn in the provinces of Guangxi, Heilongjiang, Jilin, and Liaoning; with wheat in the province of Jiangsu; and with both corn and wheat in the provinces of Anhui, Chongqing, Guizhou, Hubei, Ningxia, Sichuan, and Yunnan (Carriquiry, et al., 2012). In India, rice competes with wheat particularly in the northern states.

PROCEDURES

Using the Arkansas Global Rice Model (AGRM)[3] , a partial, non-spatial, multi-country statistical simulation and econometric analytical framework, we analyze the short-term and long-term impacts on the U.S. and international rice markets of the recent substantial increases in prices and net returns from crops that compete with rice, namely corn, soybeans and wheat. The AGRM interfaces with other commodity models maintained by the Food and Agricultural Policy Research Institute (FAPRI) for the needed data on commodity prices and net returns projections. The AGRM covers 45 key rice-producing and consuming countries; with all other countries not individually modeled included in one of the five rest-of-the-region (Africa, the Americas, Asia, Europe, and Oceania) models. The impact on rice is evaluated by analyzing changes in selected countries by variables, namely area, production, consumption, trade, and prices, by comparing the drought-price shock scenario numbers with the original baseline numbers.

To capture the dynamics of the current price changes, we collaborated with FAPRI-MO and obtained their most recent projections of commodity prices and net returns for the period 2012-2017 for the same set of commodities as of August 2012 (post-drought). The updated FAPRI commodity prices and net returns are transmitted into the different AGRM country models, including the six rice-producing U.S. states (Ark., Calif., La., Mo., Miss., and Texas). The percent changes of the prices and net returns from baseline (pre-drought) to post-drought period are presented in Table 1.

The scenario impact on selected variables by country is evaluated by the resulting levels and percent changes from the original pre-drought baseline numbers. While impact simulation results are available for all the 45 countries covered by AGRM, the discussion in this paper focuses on the impact of the drought on major rice-producing and-consuming countries such as the U.S., India, Thailand, Vietnam, China, Bangladesh, Indonesia, and the Philippines—along with discussion on the global effects.

---

[2] The estimated elasticities of the relative net returns from substitute crops vary by rice type (i.e., long grain or medium grain) and by location; and can be found in the AGRM documentation published online at http://ageconsearch.umn.edu/handle/102650.

[3] The structure and other details of AGRM can be found in the same online documentation as described in footnote 2 above.

RESULTS AND DISCUSSION

The results of the analysis on selected variables by country are summarized in Table 2 (level changes) and Table 3 (percent changes). As expected, the drought has larger impacts in the initial years as dynamic recovery and stabilization occurs thereafter. The major rice impacts of the U.S. drought in 2012 are on price, consumption and trade; and on area harvested and production in 2013. This is expected as crop supply response to shock typically has a 1-year lag while responses of the other variables are usually current. Results indicate that the drought-induced corn, soybeans, and wheat price shocks impact global long-grain rice prices by +6.2% in marketing year 2012, +3.2% in 2013, and +0.2% in 2014. The magnitude and pattern of changes are larger and different for medium-grain rice (at +3.1% in the first year, +9.4% in the second year, and +8.3% in the third year) than for the long-grain rice in global markets.

The long-grain prices continue to decline after the third year and stabilize by 2020 (Tables 2 and 3). However, the medium-grain prices remain relatively strong over the next 7 years. These results indicate that the medium-grain rice price is more responsive to the scenario than the long-grain rice price, the reason being that international trade in medium-grain is much smaller than the long-grain and increasingly more important in China's rice consumption. As mentioned earlier, there is a lagged supply response of one year hence the impact in area harvested starts in 2013. Rice area harvested in the U.S. contracts by -6.1% in 2013, -5.3% in 2014, and -2.8% in 2015, before stabilizing in 2016. U.S. area harvested increases thereafter, as medium-grain area responds positively to the relatively strong medium-grain prices.

The declines in U.S. rice area harvested in 2013 and 2014 are accounted for largely by the three rice-producing states of California (-48 thousand acres in 2013 and -66 thousand acres in 2014), Louisiana (-44 thousand acres in 2013 and -38 thousand acres in 2014), and Texas (-30 thousand acres in 2013 and -38 thousand acres in 2014)–due to their relatively higher substitution elasticities (Tables 2 and 3). These two-year area declines are equivalent to -14% and -12% for California; -10% and -8% for Louisiana; and -22%, and -24% for Texas. On average, the area declines are -12.8% for California, -8.9% for Louisiana, and -22.9% for Texas. The percent impact on Texas rice area harvested is relatively large because the positive impact of increased returns from rice due to higher rice price is overshadowed by the negative impact of increased returns from the substitute crop (corn) due to much higher corn price. The same story is true for Louisiana (soybean as a substitute crop for rice) and California (corn as a substitute crop for rice), albeit to a lesser degree. The rates of decline in the harvested area of Arkansas, Missouri, and Mississippi during the same period are much milder, ranging from 0.5% to 2.1%—due to relatively lower substitution elasticities. In particular, harvested area in Arkansas declines by 12,400 acres (or -1.0%) in 2013 and 6,300 acres (or -0.5%) in 2014.

United States rice production declines by -6.6% in 2013, -5.8% in 2014, and -3.1% in 2015 and stabilizes in 2016, after which it increases in tandem with area harvested (Tables 2 and 3). Downward change on U.S. consumption due to higher prices is less than 1% in the first five years; and then consumption increases steadily thereafter. United

States net trade increases by nearly 5% the first year, then decline by 6% to 12% the following four years before stabilizing. China's rice area harvested declines by -4.7% in 2013, -2.6% in 2014, and -1.0% in 2015-with the 2013 impact alone amounting to a decline of 1.4 million hectares which translates to a contraction of 6.7 million metric tons (mt) of production. China's area stabilizes starting 2016. About 80% of the decline in China's rice area harvested is accounted for by long-grain as a result of substitution from both corn and wheat; medium-grain rice is substituted by corn.

World rice area harvested declines by 1.3 million hectares (or -0.8%) in 2013 and 564 thousand hectares (or -0.4%) in 2014, before relatively stabilizing thereafter (Tables 2 and 3). Global rice production is down by 6.3 million mt (or -1.3%) in 2013 and 2.9 million mt (or -0.6%) before stabilizing. The downward changes in world rice area and output are accounted for largely by the declines in China and the U.S. which are only partially offset by minor increases in the rest of the world where there is less substitution between rice and corn, soybeans, and wheat. The changes in relative international prices also induce an expansion in global rice net trade of 682 thousand mt (or +2.2%) in 2012 and 249 thousand mt (or +0.7%) in 2013. World net trade declines in the following two years; before resuming expansion. World rice consumption expands by 1.8 million mt (or 0.4%) in 2012, 725 thousand mt (or 0.2%) in 2013, then stabilizes thereafter.

These results highlight the impact of possible area substitution from rice to corn, soybean, and wheat, as the relative returns from growing rice become unfavorable. For China, India, and Indonesia, wheat is a substitute staple food crop for rice. The impact of drought in these countries is positive for rice consumption, as the higher prices of wheat encourages shifting to rice. The increases in wheat prices in these countries dominate the increases in rice prices. China's rice consumption expands by 1.4 million mt in the first year which does not translate to substantial increase in net trade, as the country draws down from its substantial domestic stockpile (Tables 2 and 3). India's rice consumption increases only slightly with practically no change in trade, as the country withdraws from its large rice stocks. Indonesia's rice consumption is up nearly 1.5 million mt (or +3.7%) in 2012 and 1.1 million mt (or +2.6%) in 2013 which is supplied by increased net imports. In the Philippines and Vietnam, the impact of the drought on rice consumption is negative as neither of the other crops is a substitute for rice. As expected, the higher rice prices dampen rice consumption. Consumption in the Philippines declines by 222 thousand mt (or -1.7%) in 2012 and by 118 thousand mt (or -0.9%) in 2013, resulting in lower imports. Vietnam's consumption is down by nearly 300 thousand mt (or -1.5%) in 2012 and by 158 thousand mt (or -0.8%) in 2013, allowing the country to expand its exports. The impacts of the drought in rice consumption in Bangladesh and Thailand are relatively small.

As expected, the average impact of the drought is muted beyond the third year, as dynamic adjustments occur in the rice market (Tables 2 and 3). There is a mild recovery in world rice area harvested, production, and consumption during the same period. As in any typical market shock, eventually the normal forces of supply and demand in the market set in. This is evident in the much lower level of impact in most of the countries for the period beyond the third year, with the exception of India. India's area harvested comes back strongly starting in 2015 driven by expansion in rice exports, as declining long-grain prices makes the country more competitive in the global rice market. This situation comes in tandem with resumption of release of its larger-than-normal national rice stockpile.

In general, the impact of the recent U.S. drought appears to be relatively muted for the global rice economy due to large stocks in China, India, and Thailand. Nevertheless, the food-deficit economies including Bangladesh, Indonesia, and Philippines remain faced with food security challenges brought about by risks and uncertainties related to weather, government policies, and politics, among other factors. The current price surges in corn, soybeans, and wheat as a result of the recent drought in the U.S., and the relative stability in rice price during the same period have consequent changes in relative net returns and competitiveness of the crops—with potential substantial rice supply responses in the U.S. and China. Important demand responses also occur in the Philippines and Vietnam—where rice consumption declines as rice price increases; and in Indonesia—where shifting to rice consumption occurs due to higher wheat prices.

SIGNIFICANCE OF FINDINGS

Given that Arkansas is the major rice-producing state in the U.S and nearly half of the state's annual rice crop is exported to the foreign market, it is quite important for Arkansas rice producers and other stakeholders to have a better understanding of the relevant market forces that drive both the state crop economy and the global rice market. Market prices received by Arkansas rice producers are primarily determined by the factors that affect international trade. One of these factors is the economics of alternative crops (corn, soybeans, and wheat) which is analyzed in this report.

It is also useful to understand the potential impact on the global rice market of the recent substantial price spikes in corn, soybeans, and wheat considering that rice is the staple food of more than half of the world's population. These commodities are substitute crops for rice in the U.S. and other countries—competing for land and other resources, and also in peoples' diets.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board who provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model which is used in the analysis presented in this report.

LITERATURE CITED

Carriquiry, M., A. Elobeid, E. Wailes, E. Chavez, S. Pan, and D. Hayes. 2012. "Impact of Removal of China's Production and Input Subsidies and Price Supports for Crops and Livestock on U.S. and World Agricultural Markets." A special joint study between Global Agricultural Market and Policy Research Services, Arkansas Global Rice Economics Program, World Agricultural Economic and Environmental Services, and Iowa State University.

Lopez, R. 2012. World food prices rose 10% in July, pushed by midwest drought. L.A. Times, 30 August 2012. Published at: http://www.latimes.com/business/money/la-fi-mo-world-food-prices-rose-10-percent-july-pushed-by-midwest-drought-20120830,0,1812447.story

U.S. Drought Monitor. 2013. National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.

USDA. U.S. Drought 2012: Farm and Food Impacts. Published at http://www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts.aspx

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 2011-1. Published at http://ageconsearch.umn.edu/handle/102650

Table 1. Percent changes in Food and Agricultural Policy Research Institute (FAPRI) prices and net returns by commodity, post-drought versus baseline.

	Changes in prices					
Commodity	2012	2013	2014	2015	2016	2017
	(%)					
Corn	68.4	10.6	1.3	-1.9	-2.3	-1.0
Wheat	38.1	24.5	7.2	-0.5	-2.1	-1.0
Soybeans	43.1	-0.8	-2.1	-0.8	-0.6	0.0
	Changes in net returns					
Commodity	2012	2013	2014	2015	2016	2017
	(%)					
Corn	53.2	19.4	1.2	-5.4	-5.6	-3.1
Wheat	83.7	54.3	13.5	-2.5	-5.6	-3.5
Soybeans	29.4	-0.7	-3.2	-1.2	-0.9	0.6

Table 2. Absolute changes on rice of selected countries and the world due to U.S. drought, by variable and by year, 2012-21.

Variable	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
World area harvested	1000 ha	6.0	-1332.3	-564.1	-63.4	240.4	311.2	219.8	51.0	14.9	43.4
World production	1000 mt	118.4	-6317.4	-2864.3	-589.3	801.8	1163.3	743.0	280.8	222.9	383.4
World consumption	1000 mt	1809.5	725.5	81.1	-176.9	31.1	680.4	639.1	177.5	-73.6	-53.1
World net trade	1000 mt	682.2	248.7	-48.4	-130.7	92.9	409.3	463.4	339.3	103.2	-8.0
Long-grain international reference price	US$/mt	28.8	14.4	1.0	-3.1	-7.1	-8.6	-6.4	-3.5	0.1	1.0
U.S. No.2 medium-grain price fob CA	US$/mt	28.4	91.8	81.1	42.6	43.0	-1.6	5.2	43.6	41.2	43.9
U.S. season ave. farm price	US$/cwt	0.1	0.0	0.9	1.1	1.5	0.3	0.6	-0.2	0.6	0.2
U.S. total harvested area	1000 ac	0.0	-169.3	-154.7	-83.5	-8.8	61.6	50.8	62.0	25.0	39.6
Ark. harvested area	1000 ac	0.0	-12.4	-6.3	1.9	9.5	16.4	9.3	10.3	1.3	4.7
La. harvested area	1000 ac	0.0	-43.8	-37.5	-21.2	2.8	30.4	26.0	35.8	18.1	25.5
Texas harvested area	1000 ac	0.0	-30.3	-38.1	-32.5	-18.8	-4.3	-2.0	2.8	-2.5	0.9
Mo. harvested area	1000 ac	0.0	-2.7	-3.2	-3.2	-2.5	-1.3	-1.8	-1.4	-2.7	-2.5
Miss. harvested area	1000 ac	0.0	-3.1	-3.4	-2.2	-0.1	1.8	1.4	1.8	0.3	0.8
Calif. harvested area	1000 ac	0.0	-77.1	-66.2	-26.2	0.3	18.6	17.8	12.8	10.5	10.1
U.S. production	1000 mt	0.0	-415.5	-383.0	-211.6	-35.8	129.2	106.1	130.8	45.6	79.6
U.S. consumption	1000 mt	-37.1	-27.3	-21.3	-7.5	-5.3	29.5	71.6	106.6	154.9	259.3
U.S. net trade	1000 mt	114.7	-123.5	-253.5	-235.8	-142.0	31.8	2.5	65.0	-73.6	-121.5
Bangladesh area harvested	1000 ha	0.0	45.5	36.4	14.5	0.4	-14.6	-26.5	-29.8	-27.8	-22.4
Bangladesh production	1000 mt	0.0	180.5	146.0	64.0	10.9	-46.6	-91.2	-105.3	-100.4	-81.9
Bangladesh consumption	1000 mt	-2.2	-1.2	-0.1	0.3	0.6	0.8	0.6	0.3	0.0	-0.1
Bangladesh net trade	1000 mt	-2.3	-181.6	-146.1	-63.8	-10.3	47.4	91.8	105.6	100.3	81.8
China area harvested	1000 ha	0.0	-1402.5	-749.8	-286.9	-20.0	68.3	22.3	-12.1	8.8	25.4
China production	1000 mt	0.0	-6669.6	-3554.1	-1321.2	-28.6	403.3	154.7	-17.5	103.6	193.5
China consumption	1000 mt	1426.9	368.8	-116.6	-220.7	-180.5	112.7	96.1	-116.0	-155.0	-171.2
China net trade	1000 mt	35.0	-42.1	-61.8	-64.4	-62.9	-66.1	-63.0	-55.6	-48.8	-45.0

continued

Table 2. Continued.

Variable	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
India area harvested	1000 ha	0.0	-91.5	-0.1	119.2	208.4	242.8	255.9	117.5	54.2	25.3
India production	1000 mt	0.0	-192.8	36.7	327.5	541.1	624.1	656.7	311.2	153.3	81.9
India consumption	1000 mt	203.3	139.7	45.0	-3.3	-14.1	-6.5	0.0	0.0	0.0	0.0
India net trade	1000 mt	1.2	-0.1	-3.0	-2.2	278.5	552.9	630.7	379.0	200.5	107.3
Indonesia area harvested	1000 ha	0.0	33.5	21.9	4.8	-2.4	-8.1	-11.1	-9.0	-5.2	-0.4
Indonesia production	1000 mt	0.0	134.6	100.9	40.2	13.1	-11.5	-27.2	-22.7	-10.7	7.4
Indonesia consumption	1000 mt	1492.0	1060.4	370.0	1.0	-49.9	32.0	65.6	35.6	-0.7	-10.1
Indonesia net trade	1000 mt	1492.0	925.9	269.1	-39.2	-63.0	43.5	92.8	58.3	10.0	-17.5
Philippines area harvested	1000 ha	0.0	11.0	16.0	15.2	12.8	8.8	4.3	1.1	-0.5	-0.3
Philippines production	1000 mt	0.0	47.2	61.3	56.2	48.3	34.6	19.0	8.8	4.2	5.9
Philippines consumption	1000 mt	-221.9	-118.0	-8.7	25.6	62.6	83.0	64.0	33.5	-0.7	-11.0
Philippines net trade	1000 mt	-221.9	-187.3	-64.0	-18.5	20.1	53.3	48.0	23.4	-8.2	-20.9
Thailand area harvested	1000 ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand production	1000 mt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand consumption	1000 mt	-16.7	-8.6	-0.6	1.9	4.4	5.5	4.2	2.2	0.0	-0.6
Thailand net trade	1000 mt	16.7	8.6	0.6	-1.8	-4.4	-5.5	-4.2	-2.2	0.0	0.6
Vietnam area harvested	1000 ha	0.0	3.0	2.6	1.0	0.1	-0.6	-1.0	-0.9	-0.6	-0.2
Vietnam production	1000 mt	0.0	73.3	63.8	40.5	29.4	16.9	7.9	7.0	9.5	15.4
Vietnam consumption	1000 mt	-299.5	-158.1	-11.5	33.7	82.5	108.9	83.6	44.5	-0.3	-4.5
Vietnam net trade	1000 mt	384.3	180.5	37.4	-1.9	-61.9	-93.9	-68.5	-30.2	17.9	21.5

Source: Computed and summarized from the Arkansas Global Rice Model (AGRM) simulation results.

Table 3. Percent changes on rice of selected countries and the world due to U.S. drought, by variable and by year, 2012-21.

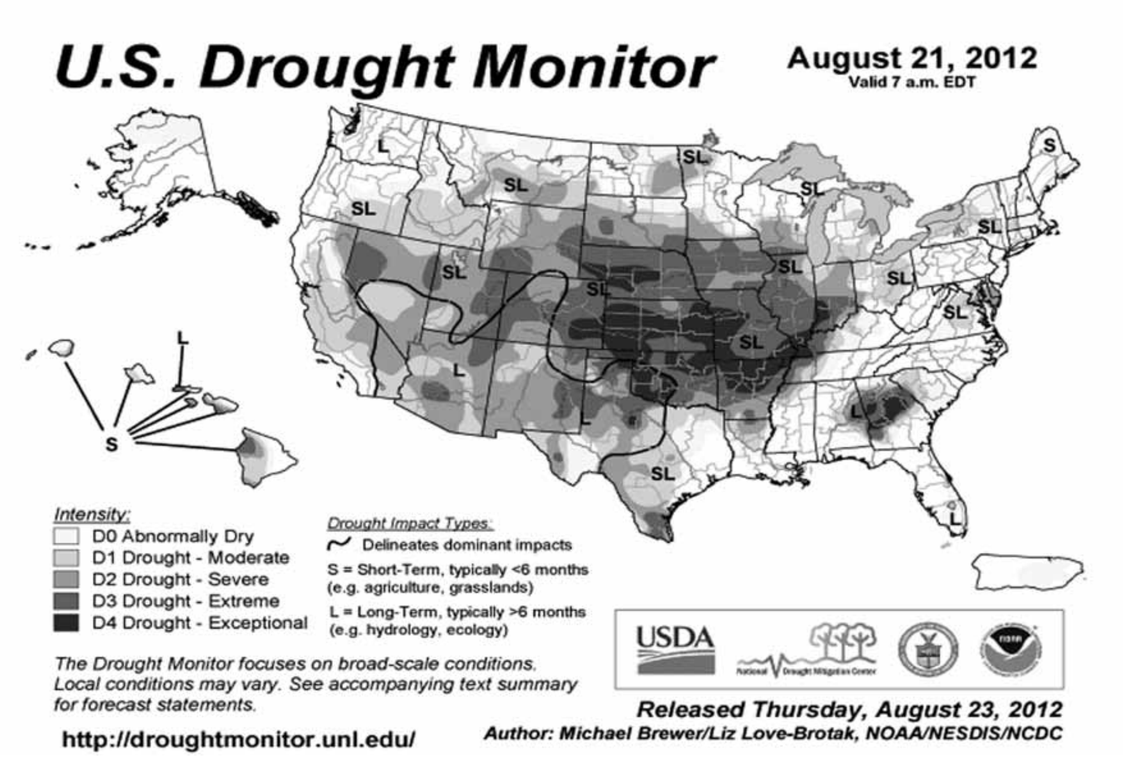
Variable	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		(% impact)									
World area harvested	1000 ha	0.0	-0.8	-0.4	0.0	0.2	0.2	0.1	0.0	0.0	0.0
World production	1000 mt	0.0	-1.3	-0.6	-0.1	0.2	0.2	0.2	0.1	0.0	0.1
World consumption	1000 mt	0.4	0.2	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
World net trade	1000 mt	2.2	0.7	-0.1	-0.4	0.3	1.1	1.3	0.9	0.3	0.0
Long-grain international reference price	US$/mt	6.2	3.2	0.2	-0.7	-1.6	-2.0	-1.5	-0.8	0.0	0.2
U.S. No.2 medium-grain price fob CA	US$/mt	3.1	9.4	8.3	4.2	4.1	-0.1	0.5	4.1	4.0	4.3
U.S. season ave. farm price	US$/cwt	1.0	0.2	6.1	8.1	11.6	1.9	4.6	-1.3	4.4	1.8
U.S. total harvested area	1000 ac	0.0	-6.1	-5.3	-2.8	-0.3	2.1	1.7	2.1	0.9	1.3
Ark. harvested area	1000 ac	0.0	-1.0	-0.5	0.1	0.7	1.2	0.7	0.8	0.1	0.4
La. harvested area	1000 ac	0.0	-10.1	-7.9	-4.3	0.6	6.5	5.6	7.9	3.9	5.6
Texas harvested area	1000 ac	0.0	-22.1	-23.6	-19.1	-11.6	-2.8	-1.2	1.8	-1.6	0.6
Mo. harvested area	1000 ac	0.0	-1.3	-1.5	-1.5	-1.2	-0.6	-0.9	-0.7	-1.3	-1.2
Miss. harvested area	1000 ac	0.0	-2.0	-2.1	-1.3	-0.1	1.0	0.8	1.0	0.2	0.5
Calif. harvested area	1000 ac	0.0	-13.9	-11.7	-4.6	0.0	3.3	3.1	2.2	1.8	1.7
U.S. production	1000 mt	0.0	-6.6	-5.8	-3.1	-0.5	1.9	1.5	1.9	0.6	1.1
U.S. consumption	1000 mt	-0.9	-0.6	-0.5	-0.2	-0.1	0.6	1.5	2.2	3.2	5.3
U.S. net trade	1000 mt	4.9	-5.8	-12.2	-10.0	-6.5	1.6	0.1	3.3	-3.6	-5.8
Bangladesh area harvested	1000 ha	0.0	0.4	0.3	0.1	0.0	-0.1	-0.2	-0.3	-0.2	-0.2
Bangladesh production	1000 mt	0.0	0.5	0.4	0.2	0.0	-0.1	-0.3	-0.3	-0.3	-0.2
Bangladesh consumption	1000 mt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bangladesh net trade	1000 mt	-0.4	-13.4	-10.1	-3.4	-0.6	2.7	4.9	5.1	5.1	3.9
China area harvested	1000 ha	0.0	-4.7	-2.6	-1.0	-0.1	0.2	0.1	0.0	0.0	0.1
China production	1000 mt	0.0	-4.7	-2.5	-0.9	0.0	0.3	0.1	0.0	0.1	0.1
China consumption	1000 mt	1.0	0.3	-0.1	-0.2	-0.1	0.1	0.1	-0.1	-0.1	-0.1
China net trade	1000 mt	-261.4	-39.5	-35.9	-27.2	-26.3	-23.9	-25.2	-20.6	-19.3	-24.0

continued

Table 3. Continued.

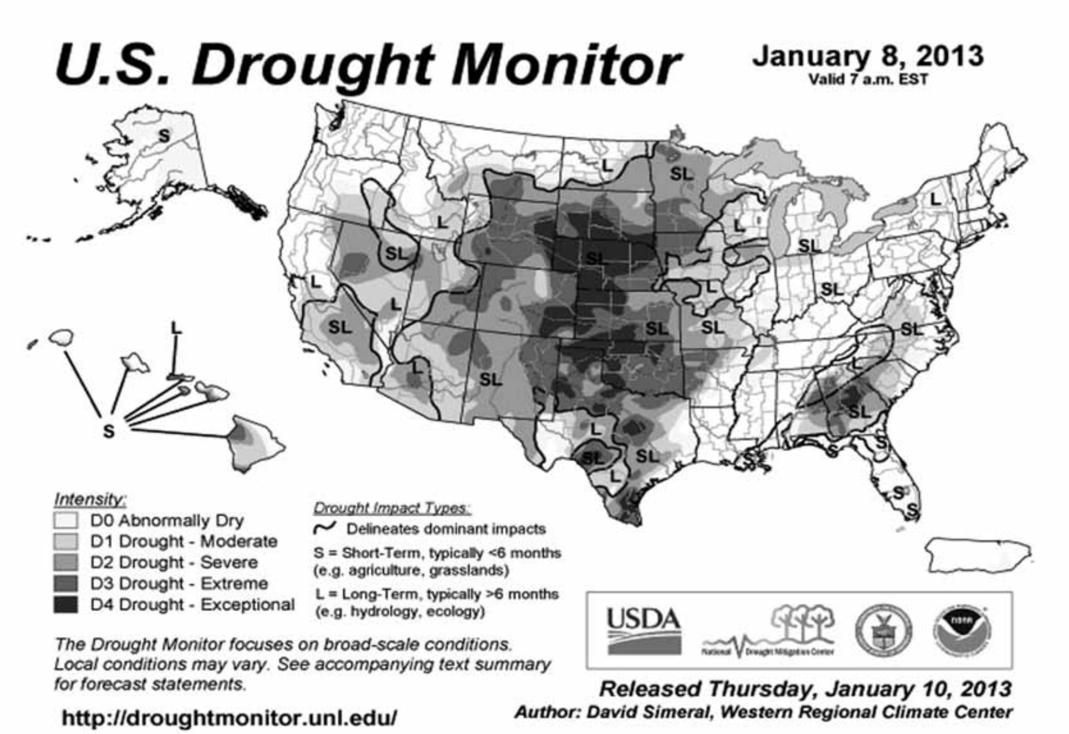
Variable	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		(% impact)									
India area harvested	1000 ha	0.0	-0.2	0.0	0.3	0.5	0.5	0.6	0.3	0.1	0.1
India production	1000 mt	0.0	-0.2	0.0	0.3	0.5	0.6	0.6	0.3	0.1	0.1
India consumption	1000 mt	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India net trade	1000 mt	0.0	0.0	0.0	0.0	4.0	6.9	7.4	4.4	2.3	1.2
Indonesia area harvested	1000 ha	0.0	0.3	0.2	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0
Indonesia production	1000 mt	0.0	0.4	0.3	0.1	0.0	0.0	-0.1	-0.1	0.0	0.0
Indonesia consumption	1000 mt	3.7	2.6	0.9	0.0	-0.1	0.1	0.2	0.1	0.0	0.0
Indonesia net trade	1000 mt	68.1	36.2	10.9	-1.8	-3.1	2.1	4.8	3.1	0.5	-0.9
Philippines area harvested	1000 ha	0.0	0.2	0.3	0.3	0.3	0.2	0.1	0.0	0.0	0.0
Philippines production	1000 mt	0.0	0.4	0.5	0.5	0.4	0.3	0.2	0.1	0.0	0.0
Philippines consumption	1000 mt	-1.7	-0.9	-0.1	0.2	0.5	0.6	0.4	0.2	0.0	-0.1
Philippines net trade	1000 mt	-10.9	-8.8	-3.1	-1.0	1.1	2.7	2.3	1.2	-0.4	-1.0
Thailand area harvested	1000 ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand production	1000 mt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thailand consumption	1000 mt	-0.2	-0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Thailand net trade	1000 mt	0.2	0.1	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
Vietnam area harvested	1000 ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vietnam production	1000 mt	0.0	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1
Vietnam consumption	1000 mt	-1.5	-0.8	-0.1	0.2	0.4	0.5	0.4	0.2	0.0	0.0
Vietnam net trade	1000 mt	5.9	2.5	0.5	0.0	-0.9	-1.3	-1.0	-0.4	0.2	0.3

Source: Computed and summarized from the Arkansas Global Rice Model (AGRM) simulation results.



The U.S. Drought Monitor is produced in partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.

Fig. 1. Map of the extent of U.S. Drought as of 21 August 2012.



The U.S. Drought Monitor is produced in partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.

Fig. 2. Map of the extent of U.S. Drought as of 8 January 2013.

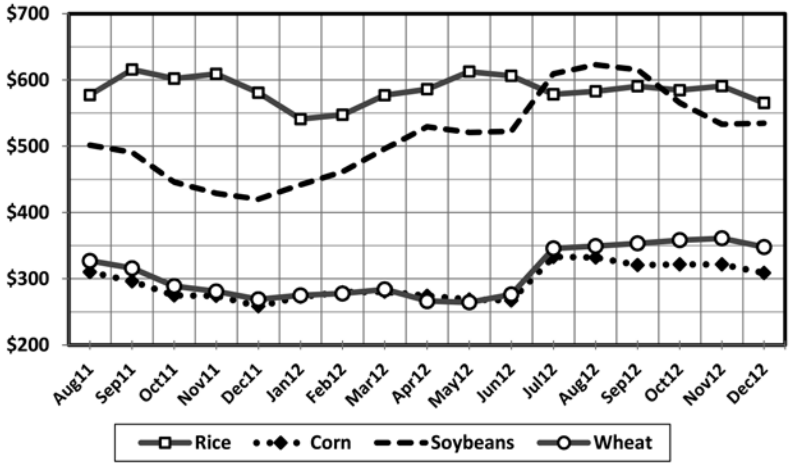


Fig. 3. Monthly commodity prices, $/MT, Aug. 2011-Dec. 2012.

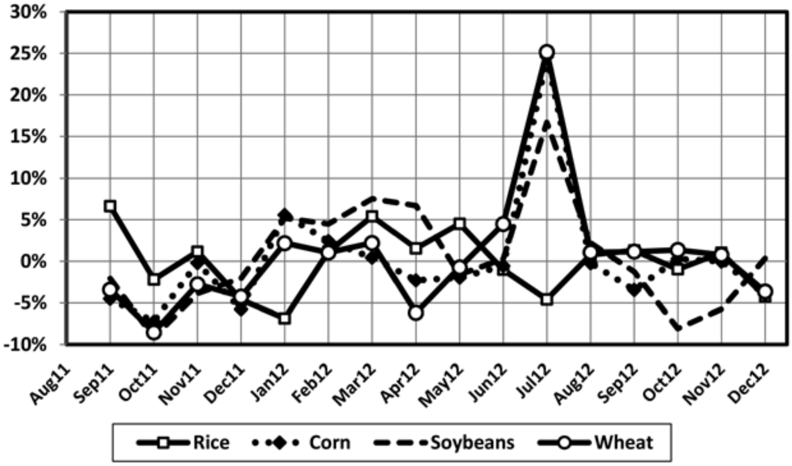


Fig. 4. Monthly commodity price changes, Aug. 2011-Dec. 2012.

World Rice Outlook: International Rice Baseline Projections, 2012-2022[1]

E.J. Wailes and E.C. Chavez

ABSTRACT

This study presents a set of deterministic baseline projections for international rice. The estimates assume continuation of existing policies; current macroeconomic variables; no new World Trade Organization (WTO) trade reforms; and average weather conditions. Over the 10-year baseline period, world rice output grows at 0.83%/year with 0.74% coming from yield improvement and 0.09% coming from slight growth in area harvested. Driven solely by an annual population growth of 1.03%, global rice consumption gains 0.77% annually as global average per capita rice use declines by 0.26%. Net trade continues to grow at 2.34%/year. A combination of relatively flat consumption and slight increase in output are expected to cause long-grain rice prices to stagnate over the baseline period. Medium-grain rice prices, on the other hand, increase slightly, as trade in medium-grain remains relatively thinner than that of long-grain.

INTRODUCTION

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population, accounting for more than 20% of daily caloric requirement (IRRI, 2013). The U.S. is one of the five top players in the international rice trade, exporting nearly half of its total rice output. Thus U.S. rice prices are heavily influenced by factors prevailing in the global rice economy. The international rice prices are determined by the supply, demand, trade, and stocks of rice as well as policies in the U.S. and other major rice exporting and importing countries. This study provides

---

[1] This material is based upon work supported in part with funding provided by the Arkansas Rice Research and Promotion Board.

a summary of 10-year baseline projections for the world rice markets. It is an assessment of the primary drivers of rice prices and supply and demand over the next decade.

The historical rice data is obtained from the Production, Supply, and Distribution (PS&D) report (USDA-FAS, 2013a) and Attache Reports (USDA-FAS, 2013b) and USDA-ERS Rice Outlook (Childs, 2013). This research benefitted from input information provided by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri which included projected costs and net returns for major U.S. commodity crops. However, all the results presented in this report remain the responsibility of the authors. The baseline numbers presented are average projections of what could happen if basic assumptions used in the analysis hold true.

PROCEDURES

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial, non-spatial multi-country statistical simulation and econometric framework developed and maintained by the University of Arkansas Global Rice Economics Program (AGREP) at the Department of Agricultural Economics and Agribusiness in Fayetteville, Ark. The global model is disaggregated into 45 of the major rice-producing, -consuming, and -trading countries; and the rest of the world into five regional aggregations: Africa, the Americas, Asia, Europe, and Oceania. Each country and regional model includes a supply sector, a demand sector, a trade sector, stocks, and price linkage equations. Other details and the theoretical structure and the general equations of the Arkansas Global Rice Model can be found in the online documentation by Wailes and Chavez (2011). The baseline assumes the following: continuation of existing policies; current macroeconomic variables; no new World Trade Organization (WTO) trade reforms; and average weather conditions.

RESULTS AND DISCUSSION[2]

Over the last couple of years, the international rice market has been dominated by twin events. The first is that of India's official lifting of its ban on non-basmati rice exports as of September 2011 due to mounting stocks—putting a downward pressure on rice prices which effectively neutralized the impact of recent weather-related calamities and production shortfalls in major economies in Asia (notably Thailand, Pakistan, and the Philippines). The second is Thailand's implementation of its paddy pledging scheme in October 2011, a price-floor support policy for Thai farmers which guarantees minimum prices for paddy rice that, at the time of its initial implementation, were 30% to 50% higher than world market prices.

While this intervention program is theoretically market-distorting because the producers are paid higher than normal prices, coupled with high minimum export prices, it has not affected the international rice trade as much as initially anticipated

---

[2] Although complete baseline projections for supply and demand variables are generated for all 50 countries/regions covered by AGRM, only selected variables are included in this report to save space.

due to abundant rice stocks and increased price competition from the other major rice exporting countries of India, Vietnam, and Pakistan. Consequently, Thailand's rice export volumes in 2011declined dramatically, i.e. by 44%, while export supplies from the three other major exporters dominated international trade. Thailand's share of global net exports declined to 19% in 2011 compared to a historical average of 34% during the period 2006-2010.

As the Thai government continues to purchase big paddy volumes from farmers in tandem with slow export shipments due to high quoted prices, the country's rice stockpile builds up rapidly. Another consequence of this situation is that the prevailing high Thai rice prices have diminished usefulness as the reference international rice prices. Currently, the equilibrium rice international reference prices generated by the AGRM are closer to the prevailing export prices of Vietnam and India; and substantially lower than the quoted Thai prices. This is supported by the fact that the global rice market is now dominated by India and Vietnam.

While criticisms and opposition to the pledging scheme abound, the government of Thailand has re-authorized the extension of the program for marketing year 2012/13. With Thailand's mounting rice stocks, storage concerns, and limited export shipments at high prices—coupled with abundant rice supplies of India—it is becoming more likely that Thailand will soon have very limited choices, and may be forced to subsidize exports of its huge stocks on the open international market at prevailing low prices. Combined with large rice stocks from India, the global rice market is expected to face an abundant supply of rice over the projection period, with a consequent dampening effect on international rice prices. This situation is beneficial for food-deficit rice-importing countries in the developing world but could have uncertain response from rice producers and exporters.

Detailed results of the analysis for the world and the U.S. showing 12 years of information (2011-2022) are presented in Tables 1 thru 5. Over the baseline projection period (2012-2022), world rice output grows at 0.83%/year with 0.74%/year coming from yield improvement and 0.09%/year coming from slight growth in area harvested. The detailed projected yields by country are presented in Table 5.

Driven solely by population growth (Shane, 2013), global rice consumption gains 0.77% annually, as population grows by 1.03% and average world rice per capita use declines by 0.26% (Tables 2 and 4).

Net trade continues to grow at 2.34%/year (Table 1). International long-grain rice prices are projected to be relatively flat or decline slightly as major consuming countries are expected to push towards self sufficiency in rice and the use of high-yielding hybrids and other improved production technologies. Medium-grain rice prices, however, are projected to increase slightly, as traded volumes remain small compared to long-grain. The international rice market is characterized by high volatility because it is thinly traded and highly concentrated, in addition to the price inelastic supply and demand of rice. In addition, the international rice market is subject to high levels of domestic and trade policy distortions in many countries. There is also a high concentration among leading rice exporters, with the top five (Thailand, Vietnam, India, Pakistan, and the U.S.) combined accounting for nearly 90% of global net trade (Table 1).

Despite its unpopular and controversial paddy pledging program, Thailand is expected to revive a stronger presence in the global rice market. Reports indicate that the country is increasing its efforts on attracting government-to-government rice deals with price discounts from government stocks to unload their increasing rice stockpile. While the Thai government is expected to incur substantial financial losses in the short-term as it ships high-priced rice in the global market at competitively lower prices, the country is expected to recoup its top global position as a rice exporter over the baseline period, given its good infrastructure resources and concerted focus on developing and maintaining a strong presence in the branded high quality rice markets.

India became the top exporter in 2011, with total shipments of 10.4 million metric tons (mmt), followed by Vietnam at 7.6 mmt (Table 1). In 8 out of 10 years over the projection period, India's rice exports are expected to exceed those of Vietnam's as the latter's shipments slow down due to area limitations. The U.S. rice exports decline slightly as consumption growth exceeds production—with producers expected to face increasing irrigation constraints and strong relative prices from competing crops in the future (Table 3). Cambodia and Myanmar are projected to increase rice exports steadily as production continues to exceed consumption. The export paths of both countries follow a similar shape, although that of Myanmar's is slightly higher.

Global net rice exports will grow by a total of 7.8 mmt over the baseline period (2012-2022)—43.5% of which is accounted for by Thailand; and a combined 35.2% will come from Vietnam, Myanmar, and Cambodia (Table 1). The bulk of the volume growth in world rice net imports will come from Bangladesh (34.0%); Nigeria and the Ivory Coast (16.4% combined); and Senegal, Malaysia, Iraq, and Saudi Arabia (14.7% combined).

While the global rice harvested area will grow, on a net basis, by 1.52 million hectares over the baseline period, some notable changes include a substantial decline of 2.78 million rice hectares in China due to a shift to substitute crops and irrigation constraints; and a combined contraction of 577 thousand rice hectares in Japan, Vietnam, and Bangladesh. Over the same period, India will gain 1.73 million hectares of rice; and the four countries of Myanmar, Pakistan, Brazil, and Tanzania combined will increase rice area by 1.51 million hectares. Other constraints to potential rice expansion include competing uses of limited land and water; farm demographics, with farmers getting older and labor moving from farm to cities; uncertain calamities due to climate change; changing consumer tastes towards healthy foods; and emerging environmental issues on rice carbon footprint.

The global milled rice output will grow by a total of 40.4 mmt over the period 2012-2022. India is expected to account for 37.6% of the total volume growth; with Indonesia, Bangladesh, and the Philippines accounting for 26.9% combined; and Thailand, Vietnam, Myanmar, Cambodia, and Brazil accounting for 22.5% combined. China's rice output, on the other hand, declines by 4.4 mmt.

Rice consumption is driven by income, population, and other demographics. Rising incomes dampen rice demand in some Asian countries where rice is considered an inferior food. Demographic trends also weaken rice demand as aging populations and increasing health consciousness shift preferences away from carbohydrates and towards protein-based diets. Over the projection period, the global rice consumption will grow by 37.0 mmt (net)—with nearly 31% coming from India; and 40% coming from the five countries of Bangladesh, Indonesia, Philippines, Nigeria, and Vietnam (Table 4). With rice per capita use on a continuing decline and population growing only slightly, China's total rice consumption will decline by 5.7 mmt over the same period. Likewise, the total rice consumption of Japan, South Korea, and Taiwan will contract by a combined total of 1.2 mmt.

SIGNIFICANCE OF FINDINGS

Arkansas is the top rice-producing state in the U.S. accounting for 46% of the country's rice output. Nearly half of Arkansas annual rice crop is exported to the foreign market hence it is beneficial for Arkansas rice stakeholders to have a better understanding of the market and policy forces that drive the global rice market. Market prices received by Arkansas rice producers are primarily determined by the factors that affect international trade. These include changes in rice production and consumption patterns, the economics of alternative crops, domestic, and international rice trade policies, as well as the general macroeconomic environment in which global rice trade is transacted. The baseline results presented in this report can be considered as a synthesis of the impacts of these factors, and serve to indicate what could happen over the next decade. The projections can also be used as a baseline for evaluating and comparing alternative macroeconomic, policy, weather, and technological scenarios.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board who provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model which was recently updated using the most recent USDA historical rice numbers; expanded by adding models for new countries; and enhanced with new information reflective of the current issues and developments in the global rice sector.

LITERATURE CITED

Childs, N. 2013. Rice outlook: February 2013. RCS-13B. USDA-Economic Research Service (ERS). http://www.ers.usda.gov/publications/rcs-rice-outlook/rcs-13b.aspx

(IRRI) International Rice Research Institute. 2013."Rice and Poverty." Published at: http://www.irri.org/index.php?option=com_k2&view=item&layout=item&id=9081&lang=en

Shane, M. 2013. Historical and Projected Population and Growth Rates in Population for Baseline Countries/Regions. 1969-2030. U.S. Census Bureau, International Data Base. http://www.census.gov/ipc/www/idb/

(USDA-FAS) USDA-Foreign Agricultural Service. 2013a. Production, Supply, and Distribution Online. http://www.fas.usda.gov/psdonline/psdquery.aspx

(USDA-FAS) USDA-Foreign Agricultural Service. 2013b. Various issues of Attache Reports. http://gain.fas.usda.gov/Lists/Advanced%20Search/AllItems.aspx

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. Published at http://ageconsearch.umn.edu/handle/102650.

This page left blank intentionally to facilitate the following tables.

Table 1. Projected rice trade and

	11/12	12/13	13/14	14/15	15/16
	------------------(thousand metric tons)------------------				
Net exporters					
Argentina	670	661	619	627	647
Australia	320	461	414	370	359
Cambodia	795	980	841	816	857
People's Republic of China	-1,349	-1,854	-958	-940	-857
Egypt	265	647	734	730	633
India	10,376	7,436	6,289	6,494	7,982
Myanmar (Burma)	700	625	575	813	952
Pakistan	3,440	3,631	3,795	3,798	3,822
Thailand	6,345	7,647	8,442	9,396	9,485
United States	2,607	2,683	2,650	2,559	2,502
Uruguay	750	855	999	1,009	999
Vietnam	7,617	6,192	7,359	6,816	6,538
Total net exports[a]	32,536	29,965	31,758	32,489	33,918
Net importers					
Bangladesh	563	251	1,400	1,268	1,563
Brazil	-250	173	217	88	45
Brunei Darussalam	40	42	44	45	46
Cameroon	375	413	427	442	480
Canada	351	354	369	389	424
China - Hong Kong	415	422	433	439	442
Colombia	155	179	189	185	191
Cote d'Ivoire	1,373	937	1,032	984	1,099
European Union-27	1,083	1,140	1,249	1,225	1,237
Ghana	610	679	691	711	727
Guinea	260	251	338	360	388
Indonesia	1,960	1,543	1,640	1,890	1,808
Iran	1,750	2,041	2,013	2,028	2,078
Iraq	1,240	1,401	1,346	1,340	1,369
Japan	435	500	482	482	482
Kenya	430	380	382	420	434
Lao PDR	13	60	21	9	5
Liberia	220	237	241	259	275
Malaysia	1,083	1,051	1,190	1,174	1,272
Mali	150	82	76	20	6
Mexico	644	717	774	788	793
Mozambique	375	410	438	456	501
Nigeria	3,200	2,463	2,474	2,554	2,673
Philippines	1,500	1,642	1,801	1,730	1,582
Saudi Arabia	1,130	1,211	1,207	1,232	1,258
Senegal	1,190	975	946	999	1,049
Sierra Leone	210	122	137	137	162
Singapore	350	355	366	367	373
South Africa	912	960	1,023	936	949
South Korea	377	601	400	409	409
Taiwan	140	128	128	128	128
Tanzania	100	129	59	59	87

prices over the next 10 years.

16/17	17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
---------------------	----------------	----------------	(thousand metric tons)	----------------	----------------	----------------	(%)	
654	654	672	695	699	705	716	0.81	55
366	385	399	405	391	409	399	-1.44	(62)
965	1,067	1,133	1,286	1,520	1,645	1,663	5.43	683
-855	-843	-850	-821	-819	-864	-810	-7.94	1,044
539	538	563	583	582	593	603	-0.70	(44)
8,198	8,286	8,131	8,016	7,695	7,813	7,867	0.57	431
1,134	1,255	1,345	1,427	1,510	1,582	1,594	9.81	968
3,885	3,737	3,835	3,721	3,791	3,911	3,875	0.65	243
9,519	9,749	9,907	10,158	10,403	10,815	11,042	3.74	3,394
2,407	2,358	2,432	2,466	2,438	2,465	2,469	-0.83	(214)
995	992	1,011	1,022	1,046	1,058	1,060	2.17	205
6,521	6,724	6,883	7,164	7,152	7,179	7,290	1.65	1,098
34,330	34,903	35,462	36,122	36,407	37,312	37,767	2.34	7,802
2,250	2,302	2,355	2,790	2,819	2,916	2,900	27.74	2,649
-116	-188	-205	-338	-393	-457	-385	--	(559)
47	47	48	49	50	50	51	1.86	9
488	511	518	525	548	545	558	3.05	145
436	452	466	471	480	486	494	3.40	140
443	449	451	450	452	451	453	0.71	31
172	165	159	159	154	158	162	-0.99	(17)
1,106	1,137	1,211	1,267	1,307	1,352	1,404	4.13	467
1,230	1,238	1,243	1,245	1,255	1,256	1,254	0.96	114
745	761	772	829	847	866	887	2.70	207
358	348	350	374	397	417	446	5.94	196
1,581	1,509	1,447	1,426	1,440	1,547	1,576	0.21	33
1,983	1,998	2,011	2,007	1,966	2,121	2,144	0.49	103
1,426	1,471	1,531	1,571	1,610	1,657	1,686	1.87	285
482	482	482	482	482	482	482	-0.37	(18)
442	435	444	480	503	527	534	3.46	154
-23	-69	-121	-164	-207	-256	-308	--	(368)
266	271	272	283	294	300	309	2.70	72
1,289	1,283	1,318	1,330	1,328	1,344	1,367	2.67	316
-20	-99	-105	-117	-143	-134	-156	--	(238)
789	794	806	834	860	873	879	2.06	162
487	530	544	564	572	597	617	4.17	207
2,737	2,801	2,858	2,961	3,066	3,177	3,274	2.89	811
1,567	1,591	1,625	1,517	1,543	1,625	1,595	-0.29	(46)
1,290	1,326	1,358	1,385	1,407	1,420	1,438	1.73	227
1,078	1,112	1,162	1,195	1,227	1,262	1,297	2.90	322
157	159	170	186	197	207	220	6.07	98
373	379	381	380	383	383	382	0.74	27
947	942	973	989	1,013	1,032	1,040	0.81	80
409	409	409	409	409	409	409	-3.78	(192)
128	128	128	128	128	128	128	0.00	-
20	8	29	27	34	27	8	-23.89	(121)

continued

Table 1. Continued.

	11/12	12/13	13/14	14/15	15/16
	------------------(thousand metric tons)-------------------				
Net importers (continued)					
Turkey	226	185	274	279	287
Other Africa	3,594	3,556	3,578	3,858	4,090
Other Americas	1,612	2,180	1,749	1,771	1,905
Other Asia	2,395	2,218	2,276	2,672	2,952
Other Europe	816	-5	320	278	260
Other Oceania	244	306	301	299	297
Residual	1,264	-324	-275	-223	-207
Total net imports	32,536	29,965	31,758	32,489	33,918
	-----------------(U.S. dollars/metric ton)------------------				
Rice prices					
International long-grain reference price	477	440	450	412	411
U.S. export price, FOB Gulf	575	588	577	541	511
U.S. No. 2 medium-grain price, FOB Calif.	809	814	815	808	814

[a] Total net exports are the sum of all positive net exports and negative net imports.

16/17	17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
----------------------------------(thousand metric tons)-------------------------------							(%)	
295	301	305	310	314	329	332	6.03	147
4,212	4,358	4,404	4,413	4,363	4,476	4,567	2.53	1,010
1,863	1,933	1,948	1,885	1,850	1,756	1,671	-2.62	(509)
3,063	3,282	3,375	3,493	3,506	3,656	3,710	5.28	1,492
245	282	290	279	282	274	277	--	282
296	295	295	296	297	298	299	-0.22	(7)
-210	-231	-246	-250	-233	-247	-236	-3.11	88
34,330	34,903	35,462	36,122	36,407	37,312	37,767	2.34	7,802
----------------------------------(U.S. dollars/metric ton)------------------------------							(%)	
418	399	399	417	413	421	436	-0.08	-4
518	523	519	537	527	527	533	-0.97	-55
836	849	853	853	833	836	851	0.45	37

Table 2. Projected world rice supply

	11/12	12/13	13/14	14/15	15/16	16/17
	(thousand hectares)					
Area harvested	159,153	158,884	159,967	160,127	160,363	160,583
	(metric tons/hectare)					
Yield	2.93	2.94	2.97	3.00	3.03	3.04
Production	465,882	467,136	475,441	481,048	485,570	488,841
Beginning stocks	98,821	106,067	106,001	110,733	116,627	121,466
Domestic supply	564,702	573,204	581,442	591,781	602,197	610,308
Consumption	457,049	467,533	470,985	475,377	480,937	482,916
Ending stocks	106,067	106,001	110,733	116,627	121,466	127,602
Domestic use	563,117	573,534	581,718	592,003	602,404	610,518
Total trade	39,366	35,267	36,306	37,213	38,528	38,973
	(%)					
Stocks-to-use ratio	23.21	22.67	23.51	24.53	25.26	26.42

Table 3. U.S. rice supply and

	11/12	12/13	13/14	14/15	15/16	16/17
	(thousand hectares)					
Area harvested	1,059	1,084	1,118	1,132	1,163	1,178
	(metric tons/hectare)					
Yield	5.54	5.87	5.78	5.79	5.80	5.81
	(thousand metric tons)					
Production	5,866	6,357	6,460	6,555	6,743	6,851
Beginning stocks	1,514	1,303	1,014	778	571	484
Domestic supply	7,380	7,660	7,474	7,334	7,314	7,335
Consumption	3,470	3,969	4,046	4,204	4,328	4,413
Ending stocks	1,303	1,014	778	571	484	515
Domestic use	4,773	4,983	4,824	4,775	4,812	4,928
Net trade	2,607	2,683	2,650	2,559	2,502	2,407
	(U.S. dollars/cwt[a])					
U.S. rice farm prices						
Season average	14.30	14.73	14.92	14.94	14.44	14.63
Long-grain average	13.40	14.01	14.20	14.09	13.47	13.87
Medium-grain average	16.50	16.62	16.61	16.86	16.62	16.32

[a] cwt = per hundred-weight.

and utilization over the next 10 years.

17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
(thousand hectares)						(%)	
160,517	160,568	160,563	160,548	160,501	160,399	0.09	1,515
(metric tons/hectare)						(%)	
3.06	3.08	3.10	3.12	3.15	3.16	0.74	0.22
491,311	494,302	497,635	501,161	504,806	507,562	0.83	40,425
127,602	132,904	137,619	141,642	145,929	149,740	3.51	43,673
618,912	627,206	635,254	642,803	650,735	657,302	1.38	84,098
486,239	489,833	493,863	497,107	501,242	504,506	0.76	36,973
132,904	137,619	141,642	145,929	149,740	153,032	3.74	47,030
619,144	627,452	635,505	643,035	650,982	657,538	1.38	84,004
39,587	40,159	40,843	41,196	42,115	42,557	1.90	7,289
(%)							
27.33	28.10	28.68	29.36	29.87	30.33	2.95	8

utilization over the next 10 years.

17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
(thousand hectares)						(%)	
1,197	1,221	1,224	1,232	1,237	1,239	1.35	155
(metric tons/hectare)						(%)	
5.83	5.85	5.86	5.89	5.91	5.94	0.12	0
(thousand metric tons)						(%)	
6,976	7,135	7,180	7,251	7,309	7,357	1.47	1000
515	687	848	954	1,109	1,221	-0.65	-82
7,491	7,821	8,028	8,205	8,419	8,577	1.14	917
4,446	4,541	4,608	4,658	4,733	4,814	1.95	845
687	848	954	1,109	1,221	1,294	2.46	279
5,133	5,389	5,562	5,768	5,954	6,108	2.06	1124
2,358	2,432	2,466	2,438	2,465	2,469	-0.83	-214
(U.S. dollars/cwt)						(%)	
15.11	14.75	15.19	15.12	14.77	14.75	0.01	0.02
14.15	13.59	13.97	14.18	13.79	13.69	-0.23	-0.32
17.24	17.38	17.93	17.24	16.97	17.12	0.30	0.50

Table 4. Projected per capita rice consumption

	11/12	12/13	13/14	14/15	15/16	16/17
	(kilograms)					
Argentina	8.9	8.8	8.8	8.8	8.8	8.8
Australia	14.9	15.6	15.9	16.9	17.7	17.8
Bangladesh	216.3	214.2	214.8	215.6	214.6	214.9
Brazil	39.6	39.2	40.3	40.5	41.1	41.2
Brunei Darussalam	102.0	106.4	108.7	109.8	110.0	109.6
Cambodia	234.7	239.9	241.0	242.4	243.8	244.1
Cameroon	22.3	22.8	24.1	24.6	25.9	25.8
Canada	10.3	10.3	10.7	11.2	12.1	12.3
People’s Republic of China	95.8	97.3	96.3	95.2	94.8	93.4
Colombia	35.8	35.4	37.3	38.0	38.8	38.5
Cote d’Ivoire	71.1	68.6	70.1	68.9	70.3	68.7
Egypt	44.1	45.6	47.3	47.7	47.7	46.6
European Union-27	6.5	6.5	6.6	6.6	6.6	6.6
Ghana	36.3	38.5	38.6	38.6	38.6	38.7
Guinea	128.0	127.3	132.7	134.2	136.7	133.8
China - Hong Kong	58.3	59.0	60.3	60.8	61.0	61.0
India	77.7	79.0	78.9	78.9	78.9	79.0
Indonesia	160.7	160.8	159.9	159.8	160.0	160.3
Iran	42.4	45.3	44.9	45.1	45.4	44.1
Iraq	45.2	45.0	44.3	44.4	44.9	45.7
Japan	63.2	64.0	62.6	62.1	62.0	61.7
Kenya	10.7	10.8	10.4	10.9	11.0	11.1
Lao PDR	222.3	230.9	232.7	229.9	230.7	228.6
Liberia	108.0	106.0	108.8	111.5	113.5	110.2
Malaysia	94.3	96.6	96.7	97.1	99.7	99.5
Mali	94.5	100.1	100.4	101.6	103.2	102.5
Mexico	7.3	7.4	7.7	8.0	8.1	8.1
Mozambique	24.0	24.5	25.7	26.4	27.6	26.7
Myanmar (Burma)	188.7	189.7	190.2	190.1	190.0	188.6
Nigeria	31.4	32.1	31.7	31.8	31.9	31.9
Pakistan	13.7	14.2	14.5	14.9	15.2	15.0
Philippines	126.2	125.0	124.9	124.6	124.7	124.5
Saudi Arabia	44.0	44.5	44.7	45.0	45.3	45.7
Senegal	102.8	104.1	103.5	104.2	104.8	105.3
Sierra Leone	178.2	146.6	150.7	149.1	151.7	149.5
Singapore	66.7	66.3	67.0	65.9	65.7	64.5
South Africa	18.0	20.0	20.0	19.5	19.6	19.6
South Korea	102.1	96.9	94.3	94.4	94.8	94.5
Taiwan	55.2	55.8	54.5	53.7	53.1	52.1
Tanzania	23.9	23.6	24.3	24.9	25.9	25.2
Thailand	155.9	157.2	156.7	156.2	156.1	156.0
Turkey	9.5	9.6	9.7	9.7	9.7	9.7
United States	11.1	12.6	12.8	13.2	13.5	13.6
Uruguay	19.6	21.4	21.7	21.4	21.5	21.1
Vietnam	217.0	219.3	217.3	220.3	224.2	221.2
Rest of world	21.3	22.0	22.0	22.3	22.5	22.5
World	65.8	66.6	66.3	66.2	66.3	65.9

of selected countries over the next 10 years.

17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
(kilograms)						(%)	
8.9	9.0	9.1	9.1	9.2	9.3	0.54	0.49
17.4	17.7	18.1	18.4	18.3	18.2	1.58	2.64
213.4	212.8	213.2	213.6	213.9	213.0	-0.06	-1.18
41.6	41.9	41.7	41.8	41.8	41.8	0.65	2.62
109.2	109.6	108.9	109.6	108.9	109.0	0.24	2.56
244.7	245.6	246.5	247.5	249.1	249.6	0.40	9.77
26.4	26.3	26.2	26.7	26.2	26.3	1.46	3.56
12.7	13.0	13.0	13.2	13.3	13.4	2.65	3.09
92.5	91.9	91.9	91.0	90.7	90.2	-0.76	-7.11
38.2	38.2	38.4	38.7	38.8	38.9	0.95	3.52
68.6	69.2	69.7	70.3	70.6	71.0	0.36	2.48
46.6	46.3	46.2	46.1	45.9	45.8	0.04	0.18
6.6	6.6	6.6	6.7	6.7	6.7	0.39	0.26
38.7	38.6	39.8	39.9	39.9	39.9	0.36	1.39
132.3	132.4	133.9	135.1	135.6	136.3	0.69	9.00
61.6	61.8	61.6	61.6	61.5	61.7	0.44	2.68
78.9	78.9	78.9	78.8	78.8	78.7	-0.04	-0.30
160.2	160.2	159.9	159.8	160.0	159.8	-0.06	-0.99
43.9	43.7	43.4	42.7	44.0	44.1	-0.27	-1.22
46.1	46.9	47.2	47.5	47.9	47.8	0.59	2.72
61.6	61.0	60.4	59.3	59.3	59.2	-0.78	-4.82
10.9	10.9	11.4	11.8	12.1	12.2	1.17	1.34
227.6	226.3	225.4	225.3	224.6	223.9	-0.31	-6.97
109.8	109.0	110.4	112.0	112.5	113.8	0.71	7.78
99.3	99.8	99.5	99.1	98.9	99.0	0.24	2.38
101.0	101.2	101.7	101.4	102.3	102.5	0.24	2.45
8.1	8.2	8.3	8.5	8.5	8.5	1.36	1.07
27.7	27.7	27.9	27.6	27.9	28.0	1.38	3.59
187.7	187.1	186.3	186.1	185.2	184.3	-0.29	-5.40
32.0	32.0	32.2	32.4	32.7	32.9	0.24	0.77
14.9	14.9	14.8	14.9	15.1	15.1	0.65	0.95
124.9	124.9	124.3	124.7	125.3	125.1	0.01	0.12
46.3	46.7	47.0	47.1	46.9	46.9	0.52	2.36
105.7	106.1	106.4	106.7	106.9	107.1	0.29	3.07
148.3	148.8	150.1	150.6	150.9	151.4	0.32	4.80
64.4	63.6	62.2	61.6	60.7	59.5	-1.07	-6.78
19.5	20.0	20.3	20.8	21.2	21.4	0.65	1.33
94.4	93.4	92.1	90.7	89.8	89.7	-0.78	-7.26
51.5	50.9	50.7	50.5	50.2	49.9	-1.10	-5.85
25.2	25.8	25.9	26.0	25.9	25.6	0.83	2.03
155.8	155.6	155.5	155.4	155.3	155.2	-0.13	-1.97
9.7	9.8	9.8	9.8	9.9	9.9	0.29	0.29
13.7	13.8	14.0	14.0	14.1	14.3	1.24	1.66
20.9	20.8	20.7	20.7	20.6	20.4	-0.49	-1.03
218.8	218.0	216.4	216.1	216.0	215.8	-0.16	-3.54
22.7	22.7	22.6	22.6	22.5	37.8	5.57	15.83
65.6	65.5	65.3	65.1	65.1	64.9	-0.26	-1.71

Table 5. Projected yield per hectare of selected

	11/12	12/13	13/14	14/15	15/16	16/17
	---------------------------- (metric tons/hectare)					------------------------------
Argentina	4.34	4.36	4.39	4.43	4.47	4.51
Australia	6.28	6.59	6.72	6.80	6.88	6.93
Bangladesh	2.88	2.92	2.93	3.01	3.04	3.06
Brazil	3.25	3.23	3.23	3.25	3.29	3.33
Brunei Darussalam	0.21	0.21	0.21	0.21	0.21	0.21
Cambodia	1.54	1.58	1.61	1.66	1.71	1.77
Cameroon	0.98	0.97	1.09	1.18	1.20	1.21
Canada	0.00	0.00	0.00	0.00	0.00	0.00
People’s Republic of China	4.68	4.72	4.75	4.78	4.82	4.84
Colombia	3.04	3.50	3.54	3.55	3.57	3.59
Egypt	6.07	6.35	6.48	6.69	6.77	6.80
European Union-27	4.32	4.35	4.36	4.38	4.41	4.43
Ghana	1.62	1.64	1.66	1.67	1.71	1.76
Guinea	1.32	1.34	1.35	1.36	1.37	1.39
China - Hong Kong	0.00	0.00	0.00	0.00	0.00	0.00
India	2.37	2.30	2.37	2.41	2.44	2.45
Indonesia	3.00	3.05	3.11	3.17	3.23	3.28
Iran	2.77	2.80	2.84	2.90	2.92	2.95
Iraq	2.13	2.15	2.15	2.16	2.16	2.18
Cote d’Ivoire	1.41	1.42	1.47	1.48	1.49	1.49
Japan	4.85	4.89	4.86	4.87	4.88	4.89
Kenya	1.92	2.02	2.09	2.16	2.19	2.22
Lao PDR	1.71	1.75	1.77	1.80	1.83	1.87
Liberia	0.95	0.96	0.97	0.98	0.98	0.99
Malaysia	2.50	2.51	2.52	2.53	2.56	2.59
Mali	2.26	2.25	2.31	2.36	2.42	2.47
Mexico	3.58	3.46	3.56	3.61	3.60	3.64
Mozambique	0.80	0.83	0.85	0.87	0.88	0.89
Myanmar (Burma)	1.51	1.65	1.66	1.67	1.67	1.70
Nigeria	1.25	1.27	1.31	1.35	1.39	1.42
Pakistan	2.36	2.42	2.42	2.43	2.43	2.42
Philippines	2.41	2.45	2.51	2.56	2.60	2.65
Saudi Arabia	0.00	0.00	0.00	0.00	0.00	0.00
Senegal	2.72	2.78	2.77	2.78	2.83	2.87
Sierra Leone	1.11	1.03	1.05	1.06	1.07	1.08
Singapore	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	0.00	0.00	0.00	0.00	0.00	0.00
South Korea	4.95	4.96	5.10	5.12	5.13	5.15
Taiwan	4.20	4.12	4.13	4.14	4.13	4.13
Tanzania	1.10	1.04	1.14	1.15	1.17	1.18
Thailand	1.86	1.88	1.91	1.93	1.94	1.96
Turkey	4.78	4.80	4.89	4.93	4.99	5.05
United States	5.54	5.87	5.78	5.79	5.80	5.81
Uruguay	5.51	5.60	5.73	5.78	5.82	5.87
Vietnam	3.50	3.53	3.55	3.58	3.62	3.64
Rest of world	2.23	2.25	2.27	2.29	2.31	2.32
World	2.93	2.94	2.97	3.00	3.03	3.04

countries over the next 10 years.

17/18	18/19	19/20	20/21	21/22	22/23	Annual growth 2012-22	Total change 2012-22
----------------------------------(metric tons/hectare)					-------------------------------	(%)	
4.55	4.59	4.64	4.68	4.73	4.74	0.83	0.38
6.99	7.05	7.11	7.16	7.20	7.21	0.90	0.61
3.09	3.12	3.14	3.20	3.24	3.28	1.18	0.36
3.38	3.40	3.43	3.46	3.48	3.46	0.72	0.24
0.21	0.21	0.21	0.21	0.21	0.21	0.00	0.00
1.82	1.87	1.95	2.03	2.09	2.12	2.99	0.54
1.23	1.24	1.26	1.28	1.29	1.31	3.06	0.34
0.00	0.00	0.00	0.00	0.00	0.00	--	0.00
4.88	4.91	4.94	4.97	5.00	5.03	0.65	0.32
3.61	3.62	3.64	3.66	3.67	3.69	0.52	0.19
6.83	6.86	6.88	6.94	7.00	7.06	1.07	0.71
4.45	4.47	4.49	4.52	4.54	4.56	0.47	0.21
1.80	1.84	1.89	1.91	1.94	1.98	1.90	0.34
1.40	1.41	1.42	1.43	1.43	1.44	0.74	0.10
0.00	0.00	0.00	0.00	0.00	0.00	--	0.00
2.46	2.46	2.48	2.51	2.54	2.55	1.04	0.25
3.32	3.35	3.36	3.38	3.40	3.42	1.15	0.37
2.97	3.00	3.02	3.05	3.07	3.10	1.01	0.30
2.19	2.20	2.21	2.23	2.24	2.25	0.43	0.09
1.50	1.50	1.51	1.51	1.52	1.52	0.68	0.10
4.89	4.88	4.87	4.85	4.84	4.84	-0.12	-0.06
2.25	2.27	2.30	2.33	2.36	2.38	1.68	0.37
1.93	1.98	2.02	2.07	2.11	2.15	2.08	0.40
1.00	1.01	1.02	1.03	1.04	1.05	0.98	0.10
2.63	2.66	2.69	2.73	2.75	2.79	1.06	0.28
2.53	2.58	2.63	2.66	2.71	2.75	2.06	0.51
3.66	3.66	3.69	3.66	3.67	3.71	0.68	0.24
0.90	0.91	0.91	0.92	0.93	0.94	1.26	0.11
1.72	1.74	1.76	1.77	1.79	1.79	0.81	0.14
1.46	1.49	1.52	1.56	1.59	1.63	2.53	0.36
2.43	2.44	2.45	2.46	2.47	2.47	0.20	0.05
2.70	2.74	2.79	2.84	2.89	2.93	1.82	0.48
0.00	0.00	0.00	0.00	0.00	0.00	--	0.00
2.91	2.93	2.97	3.00	3.03	3.07	0.98	0.28
1.10	1.11	1.12	1.13	1.14	1.16	1.19	0.13
0.00	0.00	0.00	0.00	0.00	0.00	--	0.00
0.00	0.00	0.00	0.00	0.00	0.00	--	0.00
5.16	5.17	5.18	5.19	5.20	5.21	0.49	0.25
4.12	4.12	4.13	4.13	4.15	4.18	0.13	0.05
1.20	1.21	1.23	1.24	1.26	1.27	2.02	0.23
1.96	1.97	2.00	2.01	2.03	2.05	0.88	0.17
5.11	5.17	5.23	5.29	5.34	5.40	1.19	0.60
5.83	5.85	5.86	5.89	5.91	5.94	0.12	0.07
5.91	5.96	6.00	6.05	6.09	6.17	0.98	0.58
3.68	3.71	3.75	3.79	3.81	3.85	0.85	0.31
2.34	2.36	2.38	2.41	2.43	2.46	0.87	0.20
3.06	3.08	3.10	3.12	3.15	3.16	0.74	0.22

Measuring Cost Efficiency in Rice Production Using Data from the Rice Research Verification Program

K.B. Watkins, T. Hristovska, R. Mazzanti, and C.E. Wilson Jr.

ABSTRACT

Large expenses associated with rice production and dependence on energy related inputs, like fuel and fertilizer in particular, compel rice producers to use management practices that are input efficient and result in least cost. This study uses data envelopment analysis (DEA) to calculate cost efficiency (CE) for rice production in Arkansas using data from 137 fields enrolled in the University of Arkansas, Rice Research Verification Program (RRVP) from 2005 to 2011. Cost efficiency scores are compared across RRVP fields and across alternative management practices. The average CE score across the 137 RRVP fields was 0.625, implying that on average, fields enrolled in the RRVP are 38% cost inefficient (1-0.625). In other words, RRVP fields could reduce total input costs on average by approximately 38% to achieve the same level of output. Alternative management practices have an impact on CE scores. Fields planted to hybrid, Clearfield-hybrid combinations, and medium-grain (MG) varieties along with fields with a zero-grade and fields using multiple inlet (MI) irrigation produced higher CE scores relative to other RRVP fields.

INTRODUCTION

Rice is the most expensive crop produced in Arkansas. Variable expenses range from $666/acre for conventional rice (rice using non-hybrid, non-Clearfield varieties) to $744/acre for Clearfield-hybrid rice (Flanders et al., 2011). Fertilizer and fuel expenses are the primary reason for the high cost of rice production in the state. Fertilizer expenses range from $151 to $171/acre depending on the variety. Nitrogen accounts for the largest share of fertilizer expenses (56% to 61% of total fertilizer expenses). Rice fuel expenses are the largest of any crop grown in Arkansas and average around $155/acre. Irrigation energy costs are the primary reason for high fuel expenses in rice production and account for 79% of total fuel expenses. Expenses associated with both fuel and fertilizer account for 41% to 49% of total variable expenses. Other expenses of note include seed and pesticide costs. These expenses are largely dependent on the variety planted. Seed expenses range from $26/acre for conventional varieties to $162/acre for Clearfield-hybrid varieties. Pesticide expenses (herbicide, insecticide, and fungicide) range from $63/acre for fields planted with Clearfield-hybrids to $113/acre for fields planted with conventional varieties.

Because of the large expenses associated with rice production and the considerable dependence on energy related inputs like fuel and fertilizer in particular, rice producers are compelled to use management practices that are both efficient and result in least cost. This study uses data envelopment analysis (DEA) to calculate cost efficiency scores for rice production in Arkansas at the field level. Data envelopment analysis is a linear programming approach for measuring relative efficiency among a set of decision making units (rice fields in this case). Data for the study are obtained from 137 fields enrolled in the University of Arkansas, Rice Research Verification Program (RRVP) for the period 2005 to 2011.

PROCEDURES

Data envelopment analysis is used in this study to calculate the minimum total cost for each RRVP field. The DEA model chooses economically optimal input quantities that minimize the total costs for each RRVP field based on the input prices faced by the producer. The minimum total cost obtained by DEA is then divided by the actual total cost observed for the field to construct a cost efficiency (CE) score. The CE score takes on a value less than or equal to 1. A CE score equal to 1 means the field is fully cost efficient (e.g., rice is produced at the minimum feasible cost for the field). A CE score less than 1 implies cost inefficiency (the field does not use inputs in cost minimizing quantities given input prices). For a more detailed explanation about how CE scores are calculated, see Watkins et al. (2013).

Cost efficiency scores are calculated using data from fields enrolled in the University of Arkansas, RRVP. The RRVP was originally established in 1983 as a means of public demonstration of research-based University of Arkansas Cooperative Extension Service recommendations in actual farming environments using on-farm field trials. The goals of the RRVP are to: 1) educate producers on the benefits of utilizing their recommendations, 2) verify these recommendations on farm-field settings, 3) identify research areas needing additional study, 4) improve or refine these existing recommendations, 5) incorporate RRVP data into state and local education programs, and 6) provide in-field training for county agents. From 1983 to 2011, the RRVP has been conducted on 358 commercial rice fields in 33 rice-producing counties in Arkansas.

Inputs quantities, inputs costs, prices, and output data for the DEA analysis were obtained from 137 rice fields enrolled in the RRVP during 2005 to 2011 and are summarized in Table 1. Inputs for the DEA analysis include field size (acres); irrigation water (acre-inches); nitrogen, phosphorus, and potassium (lb); seed (lb); costs of other soil amendments ($); herbicide, insecticide, and fungicide costs ($); custom charges ($); and machine fuel expenses ($). Output for the DEA analysis is measured as the value of rice production (rice yield × milling yield adjusted rice price × field size). Input prices for irrigation water, nitrogen, phosphorus, potassium, and seed are also obtained from the RRVP. A land charge of 25% of rice value was assumed for the value of land. A 25% crop share is a typical rental payment for rented cropland in eastern Arkansas. All economic data (prices and costs) are converted to 2011 dollars using the Producer Price Index.

RESULTS AND DISCUSSION

Cost efficiency score summary statistics for the 137 RRVP fields are presented in Table 2. The mean CE score across RRVP fields is 0.625 and ranges from a minimum of 0.316 to a maximum of 1.000. These results indicate rice fields enrolled in the RRVP are cost inefficient on average and that the total cost of rice production for each field could be reduced on average by approximately 38% (1-0.625) to achieve the same level of output. Rice producers face a variety of management decisions when growing rice in Arkansas, and the types of decisions made directly impact the cost of rice production. In the following paragraphs, cost efficiency scores are compared across RRVP fields for some of the more common management decisions made by rice producers: 1) which type of variety to grow; 2) the shape of the field (topography) desired for efficient water delivery, and 3) whether or not to use multiple inlet (MI) irrigation.

Cost efficiency score summary statistics by variety type across RRVP fields are presented in Table 3. Mean and median CE scores are greatest for fields with hybrids, medium-grain varieties, and Clearfield-hybrids. Fields planted with these three variety types have higher average rice yields (190, 184, and 175 bu/acre for hybrids, Clearfield-hybrids, and conventional medium-grain (MG) varieties, respectively) than fields planted with either conventional long-grain (LG) or Clearfield varieties (166 and 149 bu/acre for conventional LG and Clearfield varieties, respectively). Hybrid and Clearfield-hybrid rice fields also have negligible fungicide expenses ($1/acre) relative to fields with other variety types ($11, $12, and $19/acre for conventional LG, conventional MG, and Clearfield varieties, respectively).

Cost efficiency score summary statistics by field typography across RRVP fields are presented in Table 4. Mean CE scores for both contour and straight levee rice fields are nearly equal. The median CE score for straight levee fields is slightly larger than that for contour levee fields (median CE = 0.634 for straight levee fields; median CE = 0.568 for contour levees), implying fields with straight levees may be slightly more cost efficient than contour levee fields, although the advantage is not significant. Zero-grade fields have the largest mean and median CE scores (mean CE = 0.723; median CE = 0.731). Zero-grade fields in the RRVP use significantly less irrigation water on average (24 acre-inches) than either straight or contour levee fields (31 and 32 acre-inches for straight and contour levee fields, respectively). Zero-grade fields also have significantly lower average fungicide expenses ($2/acre) than either straight or contour levee fields ($9/acre each) and significantly lower average custom costs and machinery fuel expenses than contour levee fields ($39/acre custom costs and $21/acre machinery fuel costs for zero-grade; $50/acre custom costs and $28/acre fuel costs for contour levee fields). Average rice yields for zero-grade fields are not significantly different from those observed for straight and contour levee fields (177 bu/acre zero-grade; 173 bu/acre straight levees; 171 bu/acre contour levees). Thus the higher cost efficiency scores for zero-grade fields are related to cost savings in fuel, irrigation, and fungicide expenses rather than higher yields. Furrow-irrigated fields had the smallest mean and median CE scores (mean CE = 0.575; median CE = 0.538), but only four furrow-irrigated fields are included in the analysis.

Cost efficiency score summary statistics for RRVP fields with and without MI are presented in Table 5. Zero-grade fields do not require MI because they have no levees, but zero-grade fields are also presented in Table 5 to be inclusive of all 137 fields. Mean and median CE scores for fields with MI are larger than those for fields without MI. Although smaller, CE scores for MI fields are comparable to CE scores for zero-grade fields. There is little difference in mean input usage between MI and non-MI fields in the RRVP. However, MI fields in the RRVP had significantly larger rice yields than non-MI fields (187 bu/acre for MI fields; 167 bu/acre for non-MI fields). This observation implies that for the same level of input usage, MI fields produce more rice than non-MI fields. Thus, MI fields are more cost efficient than non-MI fields based on this study.

SIGNIFICANCE OF FINDINGS

Variety selection appears to have an impact on cost efficiency. Fields planting hybrids, Clearfield-hybrid combinations, and medium-grain varieties have higher CE scores relative to fields planted with conventional and Clearfield (non hybrid) varieties. These variety types tend to be higher yielding than conventional long-grain and non-hybrid Clearfield varieties. The hybrids also have negligible fungicide expenses due to greater disease resistance.

Irrigation management also impacts the cost efficiency of rice production. Our results indicate zero-grade fields and fields using MI irrigation have higher cost efficiency scores than other RRVP fields. Zero-grade fields are precision leveled to a zero slope. These fields have greater water control than contour or straight levee fields and use significantly less irrigation water, fuel, and fungicide. However, zero-grade fields are not conducive to rotation of other crops with rice and require a high capital investment for field shaping and soil removal. Producers wishing to remain flexible at planting other crops like soybeans or corn according to market signals may not wish to sink such investment into fields where only rice may be grown.

Multiple inlet irrigation is significantly less costly to implement than zero-grade management. Our analysis found RRVP fields using MI have CE scores approaching those obtained for zero-grade fields. Although input usage appears to be the same for both MI and non-MI fields, rice yields from MI fields are significantly greater than rice yields from non-MI fields. The reason for the higher rice yields on MI fields is presently unknown, but a likely reason may be more efficient utilization of nitrogen fertilizer resulting from flooding up the field faster. This represents a good future research topic.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Flanders, A., C. Dunn, S. Stiles, C. Grimes, S. Kelley, K. Lawson, R. Mazzanti, B. McClelland, and S. Runsick. 2011. Crop enterprise budgets for Arkansas field crops planted in 2012. University of Arkansas Division of Agriculture, Research and Extension, AG-1272, December, 2011. http://www.uaex.edu/depts/ag_economics/budgets/2012/Budgets2012.pdf

Watkins, K.B., T. Hristovska, R. Mazzanti, and C.E. Wilson Jr. 2013. Measuring technical, allocative, and economic efficiency of rice production in Arkansas using Data Envelopment Analysis. Selected paper presented at the 2013 Southern Agricultural Economics Association Annual Meeting, 3-5 February 2013, Orlando, Fla. http://ageconsearch.umn.edu/bitstream/142962/2/Watkins%202013.pdf

Table 1. Output, inputs, and input prices summary statistics used in the data envelopment analysis.

Variable	Mean[a]	SD[b]	CV[c]	Minimum	Median	Maximum
Output[d]						
Rice production value ($)[e]	61,831	40,355	65	7,577	51,827	226,768
Inputs						
Field size (acres)	61	32	53	9	50	183
Irrigation water (acre-inches)	31	10	31	10	30	74
Nitrogen (lb)[f]	10,104	5,488	54	1,183	8,758	33,672
Phosphorus (lb)[f]	1,978	2,012	102	0	1,656	8,100
Potassium (lb)[f]	2,537	3,266	129	0	1,260	15,012
Seed (lb)	4,546	3,565	78	216	3,375	19,980
Other soil amendments ($)[g]	699	1,472	211	0	230	9,364
Herbicides ($)	3,914	2,435	62	394	3,325	13,253
Insecticides ($)	205	366	178	0	0	2,370
Fungicides ($)	535	869	162	0	0	4,036
Custom charges ($)	2,957	2,002	68	139	2,493	11,501
Machinery fuel ($)	1,564	1,106	71	146	1,199	6,171
Input prices						
Land charge ($/acre)[h]	254	76	30	118	248	471
Irrigation price ($/acre-inch)	2.68	0.93	35	1.15	2.59	4.51
Nitrogen price ($/lb)	0.50	0.11	21	0.32	0.49	0.75
Phosphorus price ($/lb)	0.52	0.21	40	0.26	0.52	1.01
Potassium price ($/lb)	0.44	0.20	45	0.10	0.45	0.81
Seed price ($/lb)	1.95	2.17	111	0.10	0.60	6.97

[a] Summary statistics calculated from 137 fields enrolled in the University of Arkansas Rice Research Verification Program for the period 2005 to 2011.

[b] SD = standard deviation.

[c] CV = coefficient of variation. The CV is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the SD divided by the mean.

[d] Rice values, input costs, and input prices are adjusted to 2011 dollars using the Producer Price Index.

[e] Rice production value = field yield (bu/acre) × rice price adjusted for milling quality ($/bu) × field size (acres).

[f] Input levels for nitrogen, phosphorus, and potassium are in elemental levels.

[g] Other soil amendments include chicken litter, zinc, and/or Agrotain, a urease inhibitor.

[h] Land charge = 25% rice production value.

Table 2. Cost efficiency (CE) score summary statistics of 137 University of Arkansas Rice Research Verification Program fields.

	Mean	SD[a]	CV[b]	Minimum	Median	Maximum
CE	0.625	0.187	30	0.316	0.614	1.000

[a] SD = standard deviation

[b] CV = coefficient of variation. The CV is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the SD divided by the mean.

Table 3. Cost efficiency score summary statistics by variety type for 137 University of Arkansas Rice Research Verification Program fields.

Variety type	Mean	Fields	SD[a]	CV[b]	Minimum	Median	Maximum
Clearfield	0.481	13	0.101	21	0.321	0.448	0.680
Conventional LG[c]	0.530	62	0.157	30	0.316	0.482	1.000
Conventional MG	0.751	12	0.153	20	0.405	0.771	1.000
Hybrid	0.778	13	0.151	19	0.533	0.783	1.000
Clearfield-hybrid	0.741	37	0.147	20	0.414	0.753	1.000
All fields	0.625	137	0.187	30	0.316	0.614	1.000

[a] SD = standard deviation.

[b] CV = coefficient of variation. The CV is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the SD divided by the mean.

[c] LG = long-grain; MG = medium-grain.

Table 4. Cost efficiency score summary statistics by field typography for 137 University of Arkansas Rice Research Verification Program fields.

Field typography	Mean	Fields	SD[a]	CV[b]	Minimum	Median	Maximum
Contour levee	0.600	55	0.195	32	0.321	0.568	1.000
Straight levee	0.626	62	0.178	28	0.316	0.634	1.000
Zero-grade	0.723	16	0.184	25	0.380	0.731	1.000
Furrow	0.575	4	0.138	24	0.398	0.599	0.701
All fields	0.625	137	0.187	30	0.316	0.614	1.000

[a] SD = standard deviation.

[b] CV = coefficient of variation. The CV is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the SD divided by the mean.

Table 5. Cost efficiency score summary statistics with and without multiple inlet irrigation for 137 University of Arkansas Rice Research Verification Program fields.

Irrigation method	Mean	Fields	SD[a]	CV[b]	Minimum	Median	Maximum
Without multiple inlet	0.571	79	0.168	29	0.316	0.538	1.000
With multiple inlet	0.691	42	0.189	27	0.390	0.688	1.000
Zero-grade	0.723	16	0.184	25	0.380	0.731	1.000
All fields	0.625	137	0.187	30	0.316	0.614	1.000

[a] SD = standard deviation.

[b] CV = coefficient of variation. The CV is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the SD divided by the mean.

U of A
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

B.R. Wells Rice Research Studies 2012

Norman and Moldenhauer

AAES