8-1-2012

B.R. Wells Rice Research Studies 2011

R. J. Norman
University of Arkansas, Fayetteville

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

Recommended Citation

Norman, R. J. and Moldenhauer, K.A. K., "B.R. Wells Rice Research Studies 2011" (2012). *Research Series*. 53.
https://scholarworks.uark.edu/aaesser/53

B.R. Wells

RICE RESEARCH STUDIES 2011

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

U of A
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION
August 2012
Research Series 600

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

Cover Photo: The Rice Research and Extension Center facilities, Stuttgart, Ark., completed in 2010, include a 350-seat conference center, 16,616 sq ft of laboratory space, and 2,940 sq ft of new greenhouse space. Other facilities include multiple greenhouses, laboratories, a seed processing plant, a shop, equipment storage shed, chemical mixing facility, four residences for visiting students and scientists, and the original 1927 office building. Photo by Howell Medders.

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. MG400CS2/CS5.

ISSN:1941-2177 CODEN:AKAMA6

B.R. Wells

RICE

Research Studies

2011

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

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF

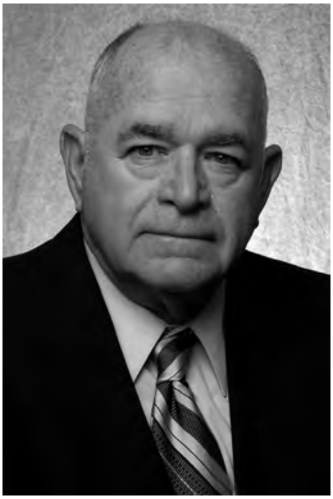
Bobby R. Wells

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.



FEATURED RICE COLLEAGUE

Fleet N. Lee

Fleet N. Lee was born in 1940 on a farm near Lonoke, Arkansas. He served four years in the U.S. Navy patrolling the South Pacific Islands, worked as a grunt on an Arkansas Power and Light line crew in Pine Bluff, Ark., and married Frances, who tolerated him all these years and basically raised three children while he was engrossed with research.

Lee enrolled at the University of Arkansas and received a B.S. degree in Agricultural Science in 1969 while studying plant pathology with George Templeton. He earned the M.S. in Plant Pathology from the University of Arkansas in 1972 working on soybean diseases with Jack Walters. The family then moved to Baton Rouge, La., to work with Norman Horn on soybean breeding for disease resistance. He earned the Ph.D. in plant pathology from Louisiana State University in 1974 and immediately accepted a position at the LSU Pecan Station, Shreveport, La. In 1977, Fleet elected to research rice diseases for the University of Arkansas and was stationed at the Rice Research and Extension Center in Stuttgart, Ark. Fleet's scientific education was immediately continued by the highly motivated and interactive scientists of the UA-RREC faculty including: Ted Johnston, USDA-ARS; Bob Wells, UA; Roy Smith, USDA-ARS; Frances Williams, UA-RREC Director; and Bobby Huey, UA-CES Rice Specialist. Other support came from George Templeton and D.A. Slack, Plant Pathology Department Head, UA Fayetteville. Charles Rush, LSU, and Toni Marchetti, USDA-ARS, provided insight and direction, about the primary diseases and their control. Fleet is forever thankful and respectful of these scientists and those who came later.

Research direction always seemed out of focus to Lee. The overall assignment was to develop efficacious rice disease control strategies; but, in reality, the immediate research direction was determined by the currently severe yield-limiting diseases of the day. Fleet initiated a germplasm evaluation program utilizing greenhouse assays and field nurseries with environmental conditions favorable for sheath blight and blast. After a slow start, he increased field testing efficiency by adapting a Hege plot planter to quickly plant replicated tests of entries in small hill plots and establishing an accurate assay for disease reactions. He also improved inoculum production techniques for sheath blight, blast and other diseases to facilitate the large field nurseries. Lee knew successful rice varieties must contain acceptable levels of disease resistance to survive the threat of disease and that control of disease by all other methods was secondary

One of the first diseases that Fleet worked with was sheath blight (SB). It had long appeared as small diseased 'holes' in rice fields until rice growers changed to shorter rotations growing susceptible semi-dwarf, high yield rice cultivars that required high nitrogen fertilizer rates. As soilborne inoculum accumulated in producer fields, SB became the major disease statewide with yield losses of up to 80% or higher. Fleet sifted through new and existing germplasm in inoculated field nurseries to identify individual breeding lines with useful genetic resistance for SB. Using rapidly generated field test data, UA-RREC scientists made significant progress in identifying, understanding and developing SB tolerant rice varieties. Plant lodging and yield loss due to SB in the new tolerant varieties was approximately 10% to 15% compared with the 80% loss in earlier years.

Scientists stationed at UA-RREC were well versed in disasters and epidemics caused by rice blast, the highly adaptable, widely distributed and most devastating disease in the rice world. Already involved in the cultivar improvement efforts to develop blast resistance varieties, Fleet was awestruck during 1986 and 1987 when the Newbonnet variety, planted to 65% of state rice acreage, was overwhelmed by the rice blast disease resulting in losses as high as 50% to 100%. Fleet and cooperators redoubled efforts to detect and define new sources of blast resistant germplasm using greenhouse and field assays for blast resistant genes. Improved genetic resistance to the many races of the rice blast pathogen were quickly detected in the Arkansas rice breeding program. In 1989, the blast resistant Katy variety was released to Arkansas growers. Katy carries the *Pita* resistance gene which confers resistance to common blast races known to occur before 1990.

Lee strongly supports breeding for disease resistant varieties. This requires a robust program dedicated to discovery, definition, and acquisition of resistance genes for all rice diseases, which is vital to developing rice varieties with improved disease resistance and desirable agronomic characteristics. Fleet was successful in establishing an APHIS-approved quarantine facility which processed over 2000 rice accessions for use in various rice research programs. Selected entries were assayed from rice germplasm collections in an ongoing effort to discover and define disease resistance. Although several accessions were flagged as having comparable or better blast resistance genes, the *Pita* blast resistance gene has proved the most valuable to date. Widely utilized in breeding programs since the early 1990s, the *Pita* gene continues to serve as an effective blast resistance gene. Only in the variety Banks, developed through backcrossing, was it defeated by a rare blast race acting in combination with severe drought stress and the absence of minor blast genes.

A unique strategic rice blast control system using resistance genes, field resistance, and effective cultural practices was developed by Lee and co-workers. Using the resources commonly available to rice growers, they discovered, described, tested, and demonstrated that a flood-induced blast resistance caused by a deeper consistent flood was very effective for impeding growth of the rice blast pathogen within diseased leaves, leaf nodes, and panicles. Plant hormones produced and accumulated within the continuously flooded plant root zone controlled rice blast disease development on responsive rice varieties. Flood induced blast field resistance appears to be a valuable, environmentally friendly rice blast control strategy. The UA-CES and other state rice specialists recommend growers utilize flood management to minimize rice blast. Growers rely on it to grow the new high-yielding, field tolerant blast susceptible varieties, such as Taggart.

Research on 'pecky' rice by Phillip Tugwell and Fleet showed that discolorations occurring on affected kernels resulted from fungi and yeast being vectored into the kernel during the stink bug feeding process. This emphasizes grower need to focus on stink bug control to reduce pecky rice incidence.

Fleet, in a unsuccessful effort to evaluate rice germplasm for kernel smut resistance, injected secondary sporidia of the kernel smut pathogen into the flag leaf whorl during the mid to late boot growth stage. When almost all of the grain on the panicles developed typical kernel smut symptoms, he concluded injection of sporidia directly into the plant overwhelmed any useful smut resistance. Surprisingly, separate roles in the disease were suggested when typical smutted grain developed in rice plants inoculated with secondary filamentous sporidia alone while few smutted grain developed in rice plants inoculated with secondary allantoid sporidia.

Besides his service to Arkansas rice growers, Fleet was active in his professional societies. He took an active role in the Rice Technical Working Group where he served on the rice germplasm committee for years and was a recipient of the RTWG Distinguished Rice Research Team Award and the RTWG Distinguished Service Award. He was a member of the American Phytopathological Society and the Arkansas Agricultural Pesticide Association where he served as President in 1987. He also was a member of the Rice Varietal Development and Management Team which won the John White Team Award for Research in 2004. He received the Distinguished Research Award at the 4th International Rice Blast Conference, Changsha, Hunan, China, 9 to 14 October, 2007, in recognition of outstanding life-long research on rice blast.

Fleet wonders about the future. The major yield-limiting diseases he worked with, as well new major diseases currently occurring in state production fields, are the unanticipated result of growing new varieties with increased yields. In reality, developing better varieties means changing their genetic backgrounds, often exposing hidden vulnerabilities to previously minor diseases. These changes often cannot be fully anticipated with a new rice variety until farmers grow them, perhaps for years, under the many field conditions or cultural practices not anticipated or duplicated experimentally.

Since starting during the early 1960s, Fleet has witnessed many changes. Science and agriculture now utilize molecular technology, computer sciences, disease monitoring, and other technical progresses which continue to increase exponentially. The days when a tractor is sent to plow, plant, and cultivate multiple fields without human supervision are here. Fleet now sits on the sideline trying to understand how they work and wonders if future scientists will still stand in awe of disease disasters such as those observed with the rice blast disease.

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

2011 Rice Research Verification Program

R.S. Mazzanti, S.K. Runsick, C.E. Wilson Jr., K.B Watkins, and T. Hristovska

ABSTRACT

The 2011 Rice Research Verification Program (RRVP) was conducted on 17 commercial rice fields across the state. Counties participating in the program included Arkansas, Clark, Clay, Cross, Desha (2 fields), Greene, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Prairie, Randolph, St. Francis and White for a total of 928 acres. Grain yield in the 2011 RRVP averaged 168 bu/acre ranging from 114 to 199 bu/acre. The 2011 RRVP average yield was 18 bu/acre greater than the estimated Arkansas state average of 150 bu/acre. The highest yielding field was in Desha 1 County with a grain yield of 199 bu/acre. The lowest yielding field was in Cross County and produced 114 bu/acre. Milling quality in the RRVP was comparable with milling from the Arkansas Rice Performance Trials and averaged 58/73 (i.e., head rice/total white rice).

INTRODUCTION

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service 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 Extension educational programs at the county and state level. Since

1983, the RRVP has been conducted on 358 commercial rice fields in 33 rice-producing counties in Arkansas. The program has typically averaged about 20 bu/acre better than the state average yield. This increase in yield over the state average can be attributed mainly to intensive cultural management and integrated pest management.

PROCEDURES

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement 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 by the coordinator and county agents were made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

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

Counties participating in the program during 2011 included Arkansas, Clark, Clay, Cross, Desha 1, Desha 2, Greene, Independence, Jackson, Jefferson, Lawrence, Lee, Lincoln, Prairie, Randolph, St. Francis and White. The 17 rice fields enrolled in the program totaled 928 acres. Seven varieties were seeded [Clearfield (CL) CL 142 AR, CL 151, CL XL 729, CL XL 745, Jupiter, Roy J, and Taggart] in the 17 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 is 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 for specific growth stages, grain yield, milling yield, and grain quality.

RESULTS

Yield

The average RRVP yield was 168 bu/acre with a range of 114 to 199 bu/acre (Table 1). The RRVP average yield was 18 bu/acre more than the estimated state yield of 150 bu/acre. This difference has been observed many times since the program began, and can be attributed in part to intensive management practices and utilization of Cooperative Extension Service recommendations. The highest yielding field of 199 bu/acre was seeded with Jupiter on 1 April in Arkansas County. In contrast, the lowest yielding field of 114 bu/acre was seeded with Jupiter on 11 May in Cross County. Of the three fields which exceeded 190 bu/acre, two were seeded with the hybrid CL XL 745.

Milling data was recorded on all of the RRVP fields. The average milling yield for the 17 fields was 58/73 (head rice/total white rice) with the highest milling yield of 68/76 occurring in Clark County (Table 1). The milling yield of 55/70 is considered the standard used by the rice milling industry. The lowest milling yield was 47/73 and occurred in the Desha 2 County field of CL XL 745 and the Jefferson County field of CL 142 AR.

Planting and Emergence

Planting began with Desha 1 County on 1 April and ended with Clay County planted 7 June (Table 1). The majority of the verification fields were planted in April. An average of 64.6 lb/acre of seed was sown in the RRVP fields (Table 1). Seeding rates were determined with the Cooperative Extension Service RICESEED program for all fields. An average of 15 days was required for emergence and stand density ranged from 5 to 25 plants/ft^2, with an average of 15 plants/ft^2. The seeding rates in some fields were higher than average due to planting method and soil texture. Broadcast seeding and clay soils require an elevated seeding rate.

Fertilization

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

Ammonium sulfate (21-0-24) was applied in some fields at the 2- to 3-lf stage as a management tool to speed height development and shorten the time required to get the rice to flood stage or to correct sulfur deficiencies (Table 2). Ammonium sulfate was applied at a rate of 100 lb/acre in Arkansas, Clark, Desha 2, Lee, and St. Francis 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, Clay, Cross, Desha 1, Desha 2, Greene, Jackson, Jefferson, Lawrence, Lee, Lincoln, Randolph, St. Francis, and White Counties. In five counties (Cross, Desha 1, Desha 2, Jefferson, and Lincoln), the P was 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 $144.63 (Table 3) which was $17.88 more than in 2010.

Weed Control

Command was utilized in 13 of the 17 fields for early-season grass control (Table 4). Facet was applied in 1 field (Arkansas County) preemergence and in 8 fields (Arkansas, Clark, Cross, Desha 1, Independence, Lawrence, Lee, and Randolph Counties) early postemergence. Five fields (Clay, Jefferson, Lawrence, Prairie, and St. Francis) did not utilize a herbicide for preemergence weed control. Nine fields, (Clark, Desha 2, Greene, Jefferson, Lee, Lincoln, Prairie, and Randolph) were seeded in Clearfield varieties and Newpath was applied for red rice and other weeds. All of the fields required a postemergence herbicide application for grass weed control.

Disease Control

Fungicides were applied to five of the fields in 2011 for control of sheath blight and/or blast (Table 5). The five fields treated were seeded in non-hybrid varieties. The field of Jupiter treated for blast with Stratego was in Independence County. Quilt Xcel was used to control sheath blight and blast in four fields; and rates were determined based on variety, growth stage, climate, disease incidence/severity, and disease history (Table 5).

Insect Control

Fourteen fields, (Arkansas, Clark, Clay, Cross, Desha 1, Desha 2, Independence, Jackson, Jefferson, Lee, Lincoln, Prairie, St. Francis, and White Counties) were treated for rice stink bug with Karate or Mustang Max (Table 5). Four of the fields (Arkansas, Clark, Desha 1, and Lincoln) required a second application for stinkbug control. Nine fields (Clark, Desha 1, Desha 2, Greene, Independence, Jefferson, Lawrence, Lee, and St. Francis Counties) had Cruiser seed treatment applied to the seed and one field (Arkansas County) had Nipsit Inside as the seed treatment.

Irrigation

Well water was used to irrigate 15 of the 17 fields in the 2011 RRVP (Table 6). Clark and Independence Counties were irrigated with surface water. Only the Desha 2 County field was zero grade. Three fields (Clay, Cross, and Lawrence Counties) used multiple inlet (MI) irrigation either by utilizing irrigation tubing or by having multiple risers or water sources. Flow meters were used in six of the fields to record water usage throughout the growing season. In fields where flow meters were not utilized, an average of 30 acre-inches was used.

An average of 28 acre-inches of water was used across all irrigation methods (Table 6). The zero grade fields averaged 28 acre-inches and the fields with MI irrigation averaged 25 acre-inches of water. Difference in water used was due in part to rainfall amounts which ranged from 7.50 to 25.80 inches. Typically a 25% reduction in water used is realized when using MI irrigation.

Economic Analysis

This section provides information on production costs and returns for the 2011 RRVP (Table 7). 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 17 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 costs' 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 2010 Crop Enterprise Budgets published by the 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 7. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs range from $480.43/acre for Independence County to $738.28/acre for Greene County, while operating costs per bushel range from $2.73/bu for Independence County to $4.99/bu for Greene County. Total costs per acre (operating plus fixed) range from $552.20/acre for Independence County to $811.87/acre for Greene County, and total costs per bushel range from $3.14/bu for Independence County to $5.49/bu for Greene County. Returns above operating costs range from $139.36/acre for Greene County to $834.29/acre for Independence County, and returns above total costs range from $65.77/acre for Greene County to $762.52/acre for Independence County.

A summary of yield, rice price, revenues, and expenses by type for each RRVP field is presented in Table 3. The average rice yield for the 2011 RRVP was 168 bu but ranged from 114 bu/acre for Cross County to 199 bu/acre for Desha 1 County. The Arkansas average long-grain cash price for the 2011 RRVP was estimated from August through 17 October daily price quotes to be $5.95/bu. The verification program had six fields planted in medium-grain varieties (Arkansas, Clay, Cross, Desha 1, Independence, and Lawrence). The average medium-grain price contracted in Arkansas was estimated to be $6.70/bu for the August through 17 October period. A premium or discount was given to each farm based upon the milling yield measured for each field. A standard milling of 55/70 would generate \$5.95/bu for long grain and \$6.70/bu for medium grain. Broken rice is 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 \$5.93/bu in Desha 2, Greene, and Jefferson to \$6.69/bu in Clark County. Medium-grain prices adjusted for milling yield varied from \$6.56/bu in Cross County to \$7.47/bu in Independence County (Table 3).

The average operating expense for the 17 RRVP fields was \$616.56/acre (Tables 3 and 7). Fertilizers and nutrients accounted for the largest share of operating expenses on average (23.5%) followed by seed (14.2%), chemicals (13.6%), and irrigation energy costs (12.3%; Table 3). Although seed's share of operating expenses was 14.2% across the 17 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid variety was used (\$141.33/acre; 22.1% of operating expenses), a Clearfield non-hybrid variety was used (\$116.04/acre; 17.3% of operating expenses), or a non-Clearfield, non-hybrid variety was used (\$39.13/acre; 6.8% of operating expenses). Greene County had to be seeded twice and 55% of the seed was donated in the second application. Still Greene County's seed costs (and operating expenses) were the highest due to this second seeding. Excluding Greene County from consideration would result in \$88.12/acre cost (13.6% of operating expenses) for fields with Clearfield varieties. The average return above operating expenses for the 17 fields was \$477.80/acre and ranged from \$139.36/acre for Greene County to \$834.29/acre for Independence County (Table 7). The average return above total specified expenses for the 17 fields was \$408.05/acre and ranged from \$65.77/acre for Greene County to \$762.52/acre for Independence County.

DISCUSSION

Field Summaries

The Arkansas County field was located just south of Almyra. The field was 74 acres, the previous crop was soybean, and the soil type was a Dewitt silt loam. The field was planted on 6 April in Jupiter, seeded at 72 lb/acre. The seed treatments used were zinc, Release, and Nipsit Inside. The rice emerged on 14 April with a stand density of 17 plants/ft^2. A preplant fertilizer rate of 21-54-108-0-24 was applied according to the soil test. Command and Facet were applied as preemergence herbicides and Dayflower was the persistent weed for this field. Permit, Superwham, and Londax were applied as postemergence herbicides. The herbicides gave good weed control. Urea was applied at 230 lb/acre preflood followed by 100 lb/acre at midseason. Quilt XL was applied for control of sheath blight. Mustang Max was applied twice for stink bug control. The field yielded 185 bu/acre. The average harvest moisture was 19%. The milling yield was 67/74.

Clark County was one of the later planted fields in the RRVP. The field was located northwest of Arkadelphia on the Ouachita River. Poultry litter was applied last fall at 1.5 ton/acre. The field was zero grade, no-till, with a previous crop of soybean. The field was 81 acres and the soil type was a Gurdon silt loam. The field was seeded on 13 May in CL XL 745 at a rate of 25 lb/acre. Cruiser Maxx was used as the seed treatment. Emergence and plant growth was extremely slow and the rice was thin in some places. The final stand counts indicated 9 plants/ft^2. Ammonium sulfate was applied at a rate of 100 lb/acre. The herbicides Newpath and Strata followed by Clearpath gave excellent weed control. Urea fertilizer was applied preflood at 270 lb/acre followed by 100 lb/acre at late boot. A fungicide treatment for disease control was not necessary, yet Karate insecticide was applied twice for stink bug control. The yield was a surprising 193 bu/acre with an excellent milling yield of 68/76. This verification field was the highest yielding field on the grower's farm.

The Clay County field was located west of Corning. The field was 35 acres and the previous crop was soybean. The soil type was a Kobel silty clay. A preplant fertilizer of 0-10-60 was applied as a result of the soil test. The field was supposed to be drill-seeded with Jupiter, however, frequent rains and flooding delayed planting in the spring. On 7 June, the field was seeded by mistake by an airplane that was planting other fields in the area. Jupiter was flown on dry, unprepared soil at a rate of 90 lb/acre. Levees were pulled and the field was flooded. A shallow flood was held on the field for seven days and then drained for peg down. An adequate stand was not achieved, as some areas of the field got too dry. Another 45 lb of seed/acre was flown on the field on 20 June and the field was flushed. A stand of over 20 plants/ft^2 was finally achieved on 1 July. No herbicides had been applied at that point. The field had a heavy aquatic weed population, mainly duck salad and some scattered large barnyardgrass. Duet and Command were applied and the field was flushed again. The plan was to follow this with Regiment prior to flooding, however, the applicator would not apply the herbicide because of adjacent soybean fields. Another application of Propanil with Storm was applied. Some of the barnyardgrass was missed and Clincher was used to treat about 15 acres. Urea was applied at 265 lb/acre. The higher N rate was used because of the clay soil. The rice grew rapidly during the hot days and nights in July and August but slowed way down in late September and early October as the temperatures dropped. The stink bug numbers exceeded treatment level late in the season and the field was treated with Karate. The field was finally harvested on 1 November and yielded 153 bu/acre.

The Cross County field was located in the southeast part of the county near the community of Coldwater. The field was 136 acres and the previous crop was rice. The soil was an Alligator clay, the kind of soil that sticks to your boots and you come out of the field 6 inches taller than you were when you went in. It was seeded in Jupiter on 11 May with a grain drill set on 10-inch rows, at a rate of 85 lb/acre. Command was applied and adequate rainfall was received to activate the herbicide and sprout the seed. The rice emerged to a stand of 11 plants/ft^2 on 24 May. The rain stopped falling and the wind started blowing causing the field to dry rapidly. Shallow rooted plants began to die and the field needed flushing immediately. The water was started one week later after the electricity was turned on and poly pipe laid out. It took two weeks to get the water on and off the field and some stand loss occurred. The field was sprayed with Ricestar and Facet, fertilized and flooded. The barnyardgrass turned yellow and appeared to be dying. Turns out, the 10-inch drill rows allowed for maximum sunlight to penetrate the canopy and a lot of the grass greened back up. Clincher was applied and did a good job finishing off the barnyardgrass. The wide rows also allowed for a lot of red rice to emerge late. Many areas of the field were taken down by the red rice. The combination of thin stand, red rice competition, and lodging resulted in a low yield of 114 bu/acre.

The Desha 1 County field was located between Dumas and Backgate. The field was 46 acres, the soil type was a Sharkey clay, and the previous crop was soybean. The field was seeded 1 April in Jupiter at a rate of 90 lb/acre. The seed was treated with CruiserMaxx and the rice emerged to a near picture perfect, uniform stand of 20 plants/ft^2. Command herbicide was applied preemergence. Facet and Permit followed by Rice Pro, Facet, and Permit herbicides were used postemergence. Preplant fertilizer was applied at a rate of 18-46-0 and urea was applied preflood at 225 lb/acre and at mid-season at 100 lb/acre. No fungicide was necessary for disease control. Mustang Max insecticide was applied twice for stink bug control. The field yielded 199 bu/acre with a milling yield of 50/72. This was the highest yielding of all the Jupiter fields on the grower's farm.

The Desha 2 County field was located between McGehee and Rohwer. The field was 49 acres, previously cropped to rice, and the soil type was Cahaba fine sand. The soil was heavy similar to clay and had been precision leveled three years ago. The field was seeded 31 April in CL XL 745 treated with Cruiser Maxx at a rate of 24 lb/acre. Command was used preemergence and the rate was higher than recommended for the particular soil type. Emergence was slow with stand counts indicating 5 plants/ft^2. Since the stand was thin, ammonium sulfate was applied at a rate of 100 lb/acre. Urea and DAP were applied three weeks later to quicken growth and satisfy the P needs indicated by the soil test results. The high Command rate seemed to affect the rice growth, but the field was weed free for several weeks. One application of Newpath followed by another and Permit were used postemergence. Urea fertilizer was applied at 180 lb/acre pre-flood with 75 lb/acre at the late boot stage. The field was treated with Karate insecticide for stink bugs. The yield in this field was 183 bu/acre and the milling was 47/73.

The Greene County field was located near the community of Fontaine. This was the second year on this farm. Last year's verification field was just down the road and was planted in CL 151. Last year's verification field yield of 151 bu/acre was similar to this year's yield. This year's verification field had a previous crop of CL 151. The verification field was planted the first time 20 March in an attempt to increase the yield with earlier planting. It was the only field in the area seeded and the black birds ate the majority of the seed. The field was planted again on 14 April in CL 142 AR at 90 lb/acre. The lower part of the field was under water for a week or so due to flooding in the area. When the water went down, the stand counts indicated 18 plants/ft^2. Weed control was fairly straightforward in this field. Command and Glyphosate were applied behind the drill, followed by two post emergence applications of Newpath. Strada was added on part of the field for control of northern jointvetch. Sheath blight exceeded treatment level in the field and Quilt Xcel was used for control. Rice stink bugs never exceeded treatment level in this field. The yield was about average with 148 bu/acre, but the rice appeared to be better than that. Fields nearby on the same farm also yielded around 150 bu/acre.

The Independence County field was located near Oil Trough. The field was 40 acres and precision leveled. The soil is classified as a silt loam, but it is actually very heavy and more like clay. The field was seeded in Jupiter on 12 May at a rate of 72 lb/acre. The rice came up to a very uniform stand with an average of 16 plants/ft^2. Command was applied behind the drill followed by Propanil and Facet preflood. The soil dried out rapidly in this field, as it did in the Cross County field, and the plants began to die. The field was flushed the same day as requested and the majority of the rice survived. There was some stand loss and a few coffee bean plants came up in the holes. Urea (200 lb/acre) plus ammonium sulfate (50 lb/acre) were applied preflood. The N rate was a little low as we had recommended 265 lb of urea alone. The rice began to yellow up two weeks after the application, about one week before panicle initiation. An additional 100 lb/acre of urea was applied into the flood at that time. A couple of weeks later, the rice was still short and the canopy was not closing in like it should. The rice appeared to still be deficient so another 100 lb/acre of urea was applied. The rice finally took off and started growing like it was supposed to. Sheath blight never was an issue in this field, however it was treated with Stratego at boot split for prevention of blast and smut. The seed was intended to be sold as seed rice to a local seed company. The field yielded 176 bu/acre which was around 20 bu/acre better than the other fields of Cheniere planted on the same farm. It was also the highest yielding field on the farm. We think the potential is better than this and hope to beat this yield next year with a little more preflood N. We will be interested to see what the N-St*r test recommends.

The Jackson County field was located on Hwy 18 between Newport and Grubbs. It was 40 acres and the previous crop was rice. The field was planted in CL XL 745 on 9 April at a rate of 28 lb/acre. The rice came up very uniformly with a stand of 8 plants/ft^2. Preplant fertilizer was applied according to soil test results with a rate of 0-50-60. Command and Glyphosate were applied behind the planter followed by Newpath at 2-lf rice. A lot of the barnyardgrass did not die following the first Newpath application. Frequent rainfall delayed the second herbicide application until preflood or 5-lf stage. Newpath, combined with Facet, was applied along with 260 lb of urea and the field was flooded. The grass turned yellow and began to die. No additional herbicides were required. We were very nervous, thinking the barnyardgrass may be resistant to Newpath, however, the County Extension Agent assured us the Facet ahead of the flood would take it out and it did. The rice looked excellent all season. When it came time for the boot N application, the rice was dark green, growing rapidly and did not appear to need any additional N. Stink bugs reached treatment level after heading and were treated. Sheath blight was present in the field but the disease never reached treatment level. The field yielded 191 bu/acre and was one of the highest yields in the program this year.

The Jefferson County field was located just off the Arkansas River between Pastoria and Altheimer. The field was 43 acres and the soil type was a Perry Clay. The previous year the field was fallow. The field had been leveled last fall, finished this spring, and was zero grade. Poultry litter was scheduled to be applied but the early season flooding prevented application. The field was flooded for 3 weeks due to 23 inches of rainfall. The rice was seeded with an airplane at a rate of 90 lb/acre on 9 April. The variety was CL 142 AR treated with Cruiser Maxx. After the water receded, the stand density was 10 plants/ft^2 and there were some areas of the field where the rice was thin. Applications of Newpath and Permit were used for weed control. Diammonium phosphate was applied at 150 lb/acre and supplied the P need indicated by the soil test. Urea was applied preflood at 300 lb/acre followed by 100 lb/acre at mid-season. Quilt XL fungicide was applied for sheath blight control. Karate insecticide was applied for stink bug control. The field yielded 173 bu/acre and the milling was 47/73.

The Lawrence County field was a Crowley silt loam and located south of Sedgwick. The field was 25 acres and had been recently leveled. Prior to leveling, the field had been fallow for some time. The heaviest cut area required additional P and K fertilizer than the rest of the field. We had hoped that poultry litter could have been applied, but it did not work out. The field was seeded in Jupiter at a rate of 75 lb/acre on 10 May. The rice emerged to an excellent stand of 20 plants/ft^2. Command was not used on this field because of the recent leveling. Propanil and Facet were applied shortly after emergence. Rainfall was not received following the application so the field was flushed. Complete grass control was not achieved, so Ricestar was applied preflood and cleaned up the field. The 150 total units of N was applied in the form of urea (240 lb/acre followed by 100 lb/acre). The rice was extremely thick, lush and dark green all year. The rice lodged right out in the middle where the top soil had been placed when leveling. No diseases or insects reached treatment level. The field yield was an impressive 184 bu/acre.

The Lee County field was a Henry Silt Loam and located just south of Moro. The field was 49 acres with rice being the previous crop. The rice was seeded on 3 April at a rate of 72 lb/acre with the variety CL 142 AR treated with Cruiser Maxx insecticide. Command herbicide was used preemergence. The field received 19.5 inches of rainfall and 15 acres on the north end was lost due to flooding. This portion of the field was replanted. Numerous levees were washed out and had to be repaired. Newpath and Facet herbicides followed by Newpath were applied postemergence. The preplant fertilizer applied was 0-90-90. Urea N was applied at 240 lb/acre preflood and 100 lb/acre at midseason. Quilt XL fungicide was applied to control sheath blight. Bacterial panicle blight was prevalent on the south end of the field. Stink bugs were persistent and the field was treated twice: once with Karate and once with Mustang Max insecticide. The yield was a disappointing 133 bu/acre.

The Lincoln County field was a Perry clay located between Star City and Gould. The field was 38 acres and the previous crop was soybean. The variety CL XL 745 treated with Apron Maxx fungicide was seeded on 2 April at a rate of 25 lb/acre. Roundup and Command herbicides were applied preemergence. The early season flooding had this field submerged for 3 weeks. The stand counts averaged 6 plants/ft^2, but some areas of the field were thin. Diammonium phosphate was applied because of the thin stand to promote tillering. Post-emerence herbicides were Clearpath and Permit. Urea fertilizer was applied pre-flood at 225 lb/acre followed by 70 lb/acre at late boot stage. No fungicide treatment for disease was necessary. The stink bugs were persistent and were treated with two applications of Mustang Max. The field yielded 182 bu/acre with a milling yield of 60/74.

The Prairie County field was located just west of Des Arc. The field was 64 acres and the previous crop was soybean. Part of the field was a hillside with a lot of levees. The field was intended to be planted in Roy J, however, hybrid seed was used because it was already purchased and had to be planted. The field was planted 9 May in CL XL 729 at a rate of 25 lb/acre. The bottom couple of acres were replanted due to flooding. The rice emerged in 8 days and the stand density was 12 plants/ft^2. Command and Newpath were applied when the rice was at the 1- to 2-lf stage. The second Newpath application was applied preflood. The field was very clean of weeds with the exception of scattered coffeebean and indigo and a few pigweeds on the levees. The herbicide 2,4-D was applied at midseason to control them. Stinkbug pressure was heavy at beginning heading and the field was sprayed. All the other fields in the area were sprayed as well. The rice yielded very well in the patties; however, due to the large number of levees and poor stand in the borrow ditches, the whole field average was 166 bu/acre. The yield was similar to other fields in the area.

The Randolph County field was located in Okean. The field was actually in the city limits, making it a challenge to get sprayed. The field was planted in CL 151 the previous year. The field was 72 acres and the soil type was a Jackport silty clay loam. About one third of the field was seeded in CL 142 AR with the other two thirds in CL 151. The field was planted very late on 20 May due to heavy rain and flooding in the area. Command was applied by air after the levees were pulled. Glyphosate was supposed to be added to clean up some scattered big barnyardgrass and start off clean of weeds. However, due to windy conditions the glyphosate was left out of the mix. Facet was added in the first Newpath application to help out on the big grass and did a fair job. The field was flushed following the herbicide applications. The stand was a little thin and there were a few wet holes that were very thin so urea (50 lb/acre) and ammonium sulfate (50 lb/acre) were applied ahead of the flush in an effort to get the rice to grow and tiller rapidly. The second application of Newpath was applied preflood along with 250 lb/acre of urea. Grandstand and Propanil were used to clean up northern jointvetch at midseason. The rice looked good post flood and was disease free through heading. After heading, there was a lot of false smut present. This was one of only three verification fields (Randolph, Greene, and Lawrence Counties) that did not reach treatment level for rice stinkbug. The CL 142 AR yield was slightly better than the CL 151 yield, however, both were close to 150 bu/acre. We think the yield would have been 30% better if planted early, as the rice yields on this field are generally very good.

The St. Francis County field was located just west of Colt. The field was 58 acres, the soil type was a Jackport silty clay loam, and soybean was the previous crop. The field was seeded in Roy J treated with CruiserMaxx and Zn. Preplant fertilizer was applied according to the soil test results at a rate of 0-50-90 plus 10 lb/acre of Zn. The field was planted 2 May at a rate of 75 lb/acre and resulted in a stand density of 18 plants/ft^2. Ammonium sulfate was applied at a rate of 100 lb/acre in order to speed growth. Red rice was prevalent throughout the field and was more pronounced as the crop matured. Command and Superwham followed by Propanil and Permit were applied as postemergence herbicides. Urea fertilizer was applied preflood at 200 lb/acre followed by 100 lb/acre for mid-season. Karate insecticide was applied for stink bug control. The field yielded a disappointing 137 bu/acre and the milling was 53/74. There was severe blanking throughout the field and heavy competition from the red rice.

The White County field was located near Bald Knob in northern White County. The field was 30 acres, the previous crop was soybean,and the soil type was a Calloway silt loam. Preplant fertilizer was applied at a rate of 0-45-90. The field was planted on 10 May in Taggart at a rate of 80 lb/acre. The rice emerged in 9 days with a stand density of 24 plants/ft^2. Command was applied by air after the levees were pulled. Only one application of propanil was needed postemergence for weed control. Urea was applied preflood at the rate of 235 lb/acre followed by 100 lb/acre at midseason. There were a few isolated areas of sheath blight in the field, but the disease never reached treatment level. The field did reach treatment level for rice stink bugs and was treated with Karate. The field yielded 160 bu/acre which was an excellent yield for this field.

SIGNIFICANCE OF FINDINGS

Data collected from the 2011 RRVP reflect the general trend of increasing rice yields and above average returns in the 2011 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 Agriculture Experiment Station and Cooperative Extension Service and the district administration for their support.

Table 1. Agronomic information for the 2011 Rice Research Verification fields by county.

County	Variety	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield[a]	Harvest moisture
		(acre)		(lb/acre)	(plants/ft^2)				(bu/acre)		(%)
Arkansas	Jupiter	72	Soybean	72	17	6 April	14 April	8 Sept	185	67/74	19
Clark	CL XL 745	81	Soybean	25	9	13 May	25 May	10 Oct	193	68/76	15
Clay	Jupiter	35	Soybean	90	25	7 June	1 July	1 Nov	168	61/72	18
Cross	Jupiter	136	Rice	85	11	11 May	24 May	7 Oct	114	60/66	18
Desha 1	Jupiter	46	Soybean	90	20	1 April	18 April	15 Sept	199	50/72	13
Desha 2	CL XL 745	49	Rice	24	5	3 April	21 April	20 Sept	183	47/73	19
Greene	CL 142 AR	50	Rice	90	18	14 April	26 April	13 Sept	148	54/70	17
Independence	Jupiter	40	Soybean	72	16	12 May	24 May	17 Oct	176	64/77	18
Jackson	CL XL 745	40	Rice	28	8	9 April	22 April	9 Sept	191	66/72	18
Jefferson	CL 142 AR	43	Fallow	90	10	9 April	28 April	10 Sept	173	47/73	18
Lawrence	Jupiter	25	Fallow	75	20	10 May	21 May	8 Oct	184	66/73	16
Lee	CL 142 AR	49	Rice	72	13	3 April	12 April	28 Sept	145	57/76	18
Lincoln	CL XL 745	38	Soybean	25	6	2 April	17 April	15 Sept	182	60/74	18
Prairie	CL XL 729	64	Soybean	25	12	9 May	16 May	6 Sept	166	51/73	18
Randolph	CL 151	72	Rice	80	17	20 May	29 May	10 Oct	150	55/73	17
St. Francis	Roy J	58	Soybean	75	18	18 April	2 May	13 Sept	136	53/74	17
White	Taggart	30	Soybean	80	24	10 May	19 May	29 Sept	160	57/73	18
Average	-----	54.6	-----	64.6	15	25 April	8 May	25 Sept	168	58/73	17

[a] Head rice / total white rice.

Table 2. Soil test results, applied fertilizer, total fertilizer, and soil classification for the 2011 Rice Research Verification fields by county.

	Soil test				Applied Fertilizer N-P-K-Zn-S[a]			
County	pH	P	K	Zn	Preflood[b]	Split application rates of urea (45%)[c]	Total nitrogen rate	Soil classification
		--------------------	--------------------	--------------------	(lb/acre)	--------------------	--------------------	
Arkansas	6.5	32	174	6.6	21-54-108-0-24	230-100-0	170	Dewitt silt loam
Clark	5.5	26	100	4.0	21-0-0-0-24	270-0-100	188	Gurdon silt loam
Clay	6.7	77	261	10.1	0-10-60-0-0	265-100-0	164	Kobel silty clay
Cross	6.9	54	642	7.6	18-46-0-0-0	300-100-0	198	Alligator clay
Desha 1	6.5	50	362	5.4	18-46-60-0-0	225-100-0	164	Sharkey and Desha Clays
Desha 2	7.4	56	864	9.0	84-46-0-0-24	180-0-75	199	Cahaba Fine Sandy
Greene	6.3	43	174	3.6	0-54-78-10-0	250-100-0	158	Foley-Bonn complex
Independence	6.7	78	318	15.2	10-0-0-0-12	200-100-70	177	Egam silt loam
Jackson	5.5	25	243	3.4	0-50-60-0-0	260-0-70	149	Amagon silt loam
Jefferson	7.0	46	808	10	18-46-0-0-0	300-100-0	198	Perry clay
Lawrence	5.3	55	197	13.5	0-17-31-2-3	240-100-0	153	Crowley silt loam
Lee	7.8	22	152	4.4	21-90-90-10-24	240-100-0	174	Henry Silt Loam
Lincoln	7.0	88	568	7.4	18-46-0-0-0	300-0-75	187	Perry Clay
Prairie	7.4	87	221	7	0-0-60-0-0	200-0-70	122	Loring silt lam
Randolph	7.1	48	447	3.9	51-46-0-5.7-12	250-100-0	209	Jackport silty clay loam
St. Francis	7.5	82	196	6.4	21-50-90-10-24	200-100-0	159	Calhoun silt loam
White	5.8	50	194	3.4	0-45-90-0-0	235-100-0	150	Calloway silt loam

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

[b] N-P_2O_5-K_2O-Zn-S.

[c] Preflood-midseason-boot.

Table 3. Summary of revenue and expenses per acre in 2011 for the Rice Research Verification Program fields by county.

Receipts	Arkansas	Clark	Clay	Cross	Desha 1	Desha 2	Greene	Independence	Jackson
	(bu/acre)								
Yield	185	193	168	114	199	183	148	176	191
	($)								
Price	7.35	6.69	7.02	6.56	6.69	5.93	5.93	7.47	6.38
Total crop revenue	**1,359.75**	**1,291.17**	**1,179.36**	**747.84**	**1,331.31**	**1,085.19**	**877.64**	**1,314.72**	**1,218.58**
Operating expenses									
Seed (and treatment, if applicable)	30.74	146.83	39.15	38.85	47.43	141.27	199.80	40.54	155.84
Fertilizers and nutrients	179.65	105.90	120.41	140.30	157.16	137.58	162.16	93.96	142.68
Chemicals	135.34	73.96	85.90	105.16	110.77	70.21	78.64	71.44	87.39
Custom applications	72.10	74.90	72.05	70.00	70.50	68.60	45.50	39.50	65.95
Fuel and lube	25.24	16.50	27.63	22.41	24.77	16.08	21.12	24.16	27.18
Repairs and maintenance	15.71	13.74	22.96	14.59	14.67	16.79	21.69	17.78	19.21
Irrigation energy costs	52.16	47.42	103.11	45.52	37.94	96.24	92.80	68.74	92.80
Labor, field activities	7.89	6.19	9.15	7.38	7.77	4.72	9.09	6.86	7.68
Other inputs and fees, preharvest	18.44	17.16	23.16	18.18	17.31	13.10	21.10	14.74	21.85
Postharvest expenses	107.95	112.62	98.03	66.52	116.12	106.78	86.36	102.70	111.45
Total operating expenses	**645.22**	**615.21**	**601.55**	**528.90**	**604.43**	**671.37**	**738.28**	**480.43**	**732.03**
Returns to operating expenses	**714.53**	**675.96**	**577.81**	**218.94**	**726.88**	**413.82**	**139.36**	**834.29**	**486.55**
Capital recovery and fixed costs	73.74	60.00	83.34	67.79	71.34	58.24	73.60	71.77	77.07
Total specified expenses[a]	**718.96**	**675.21**	**684.89**	**596.70**	**675.77**	**729.61**	**811.87**	**552.20**	**809.10**
Returns to specified expenses	**640.79**	**615.96**	**494.47**	**151.14**	**655.54**	**355.58**	**65.77**	**762.52**	**409.48**
Operating expenses/yield unit	3.49	3.19	3.58	4.64	3.04	3.67	4.99	2.73	3.83
Total expenses/yield unit	**3.89**	**3.50**	**4.08**	**5.23**	**3.40**	**3.99**	**5.49**	**3.14**	**4.24**

continued

Table 3. Continued.

Receipts	Jefferson	Lawrence	Lee	Lincoln	Prairie	Randolph	St. Francis	White	Average
	--	----------------	----------------	----------------	(bu/acre)	----------------	----------------	----------------	--
Yield	173	184	145	182	166	150	137	160	168
	--	----------------	----------------	----------------	($)	----------------	----------------	----------------	--
Price	5.93	7.25	6.39	6.34	6.04	6.14	6.15	6.20	6.50
Total crop revenue	**1,025.89**	**1,334.00**	**926.55**	**1,153.88**	**1,002.64**	**921.00**	**842.55**	**992.00**	**1,094.36**
Operating expenses									
Seed (and treatment, if applicable)	104.67	45.15	83.74	143.20	119.52	75.95	41.33	29.84	87.28
Fertilizers and nutrients	159.01	159.19	198.61	134.32	96.38	153.95	163.68	153.72	144.63
Chemicals	87.20	75.58	101.22	74.39	48.82	83.82	95.59	38.66	83.77
Custom applications	80.50	32.50	78.55	49.00	47.75	65.25	54.75	50.20	61.04
Fuel and lube	11.57	19.67	23.29	23.61	22.62	19.71	29.88	29.87	22.67
Repairs and maintenance	11.35	16.38	14.27	18.39	15.13	18.75	20.70	22.75	17.35
Irrigation energy costs	68.74	68.74	56.90	82.49	47.42	103.11	130.61	92.80	75.74
Labor, field activities	2.44	6.54	7.08	7.06	7.96	7.23	8.18	11.42	7.33
Other inputs and fees, preharvest	20.11	21.82	19.51	18.77	17.26	18.66	20.56	17.82	18.80
Post-harvest expenses	100.95	107.36	84.61	106.20	96.86	87.53	79.94	93.36	97.96
Total operating expenses	**646.53**	**552.94**	**667.78**	**657.43**	**519.73**	**633.96**	**645.21**	**540.45**	**616.56**
Returns to operating expenses	**379.36**	**781.06**	**58.77**	**496.45**	**482.91**	**287.04**	**197.34**	**451.55**	**477.80**
Capital recovery and fixed costs	46.40	64.59	65.71	71.11	69.58	67.05	77.03	87.49	69.76
Total specified expenses[a]	**692.93**	**617.53**	**733.49**	**728.53**	**589.31**	**701.01**	**722.24**	**627.94**	**686.31**
Returns to specified expenses	**332.96**	**716.47**	**193.06**	**425.35**	**413.33**	**219.99**	**120.31**	**364.06**	**408.05**
Operating expenses/yield unit	3.74	3.01	4.61	3.61	3.13	4.23	4.71	3.38	3.74
Total expenses/yield unit	**4.01**	**3.36**	**5.06**	**4.00**	**3.55**	**4.67**	**5.27**	**3.92**	**4.16**

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

Table 4. Herbicide rates and timings for 2011 Rice Research Verification Program fields by county.

	Herbicide[a]	
County	Preemergence	Postemergence
Arkansas	Command (8 oz); Facet (0.25 lb)	Permit (.5 oz); Facet (0.33 lb) fb Propanil (4 qt); Londax (1 oz); Permit (0.75 oz)
Clark	Glyphosate (32 oz)	Newpath (4 oz); Strada (2 oz) fb Clearpath (0.5 lb)
Clay	------	Duet (3 qt); Command (10 oz) fb Propanil (3 qt); Storm (24 oz)
Cross	Command (16 oz)	Ricestar HT (21 oz); Facet (0.5 lb) fb Clincher (15 oz)
Desha 1	Command (16 oz)	Facet (0.33 lb); Permit (0.5 oz) fb Propanil (3 qt); Facet (.25 lb); Permit (.75 oz)
Desha 2	Command (21 oz)	Newpath (4 oz) fb Newpath (4 oz); Permit (.75 oz)
Greene	Command (16 oz); Glyphosate (32 oz)	Newpath (4 oz) fb Newpath (4 oz)
Independence	Command (12.8 oz); Glyphosate (24 oz)	Propanil (3 qt); Facet (0.375 lb)
Jackson	Command (14 oz); Glyphosate (32 oz)	Newpath (4 oz) fb Newpath (4 oz); Facet (0.5 lb)
Jefferson	------	Newpath (4 oz); Permit (1 oz) fb Newpath (4 oz)
Lawrence	------	Propanil (3 qt); Facet (0.5 lb) fb Ricestar (19 oz)
Lee	Command (11 oz)	Newpath (4 oz); Facet (0.33 lb) fb Newpath (5 oz)
Lincoln	Command (19 oz); Glyphosate (26 oz)	Clearpath (0.5 lb); Permit (0.67 oz)
Prairie	------	Command (8.25 oz); Newpath (4 oz) fb Newpath (4 oz) fb 2,4-D (2 pt/acre)
Randolph	Command (12 oz)	Newpath (4 oz); Facet (0.5 lb) fb Newpath (4 oz) fb Grandstand (8 oz); Propanil (32 oz)
St. Francis	------	Command (12.8 oz); Propanil (4 qt) fb Propanil (4 qt); Permit (1 oz)
White	Command (10 oz)	Propanil (4 qt)

[a] See field reviews for explanation.

Table 5. Fungicide and insecticide applications in 2011 Rice Research Verification fields by county.

County	Sheath blight	Blast	Grape colaspis/ rice water weevil	Rice stink bug
Arkansas	Quilt Xcel (20 oz)	------	Nipsit INSIDE	Mustang Max (4 oz) fb Mustang Max (4 oz)
Clark	------	------	Cruiser Maxx	Karate (1.8 oz) fb Karate (1.8 oz)
Clay	------	-----	------	Karate (1.8 oz)
Cross	------	------	------	Karate (1.8 oz)
Desha 1	------	------	CruiserMaxx	Mustang Max (4 oz) fb Mustang Max(4 oz)
Desha 2	------	------	CruiserMaxx	Karate (1.6 oz)
Greene	Quilt Xcel (15 oz)	------	CruiserMaxx	------
Independence	------	Stratego (16 oz)	CruiserMaxx	Karate (1.8 oz)
Jackson	------	------	------	Karate (1.8 oz)
Jefferson	Quilt Xcel (16 oz)	------	CruiserMaxx	Karate (1.8 oz)
Lawrence	------	------	CruiserMaxx	------
Lee	Quilt Xcel (20 oz)	------	CruiserMaxx	Karate (1.6 oz)
Lincoln	------	------	------	Mustang Max (4 oz) fb Mustang Max (4 oz)
Prairie	------	------	------	Karate (1.8 oz)
Randolph	------	------	------	------
St. Francis	------	------	CruiserMaxx	Karate (1.8 oz)
White	------	------	------	Karate (1.8 oz)

Table 6. Irrigation information and rainfall for the 2011 Rice Research Verification fields by county.

County	Rainfall	Irrigation[a]	Rainfall + irrigation
	(inches)	(acre inches)	(inches)
Arkansas	19.0	33.0	52.0
Clark	7.5	30.0	37.5
Clay	8.6	30.0	38.6
Cross	12.2	28.8	41.0
Desha 1	22.4	24.0	46.4
Desha 2	11.3	28.0	39.3
Greene	23.6	27.0	50.6
Independence	12.5	20.0	32.5
Jackson	21.0	27.0	48.0
Jefferson	22.8	20.0	42.8
Lawrence	9.2	20.0	29.2
Lee	25.8	36.0	61.8
Lincoln	18.4	24.0	42.4
Prairie	9.4	30.0	39.4
Randolph	14.2	30.0	44.2
St. Francis	18.4	38.0	56.4
White	13.7	27.0	40.7
Average	16.0	28.0	43.7

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

Table 7. Operating costs, total costs, and returns in 2011 for the Rice Research Verification Program fields by county.

	Rice						
County	Operating costs	Operating costs	Returns to operating costs	Fixed costs	Total costs	Returns to total costs	Total costs per bushel
	($/acre)	($/bu)	---------------- ($/acre) ----------------				($/bu)
Arkansas	645.22	3.49	714.53	73.74	718.96	640.79	3.89
Clark	615.21	3.19	675.96	60.00	675.21	615.96	3.50
Clay	601.55	3.58	577.81	83.34	684.89	494.47	4.08
Cross	528.90	4.64	218.94	67.79	596.70	151.14	5.23
Desha#1	604.43	3.04	726.88	71.34	675.77	655.54	3.40
Desha#2	671.37	3.67	413.82	58.24	729.61	355.58	3.99
Greene	738.28	4.99	139.36	73.60	811.87	65.77	5.49
Independence	480.43	2.73	834.29	71.77	552.20	762.52	3.14
Jackson	732.03	3.83	486.55	77.07	809.10	409.48	4.24
Jefferson	646.53	3.74	379.36	46.40	692.93	332.96	4.01
Lawrence	552.94	3.01	781.06	64.59	617.53	716.47	3.36
Lee	667.78	4.61	258.77	65.71	733.49	193.06	5.06
Lincoln	657.43	3.61	496.45	71.11	728.53	425.35	4.00
Prairie	519.73	3.13	482.91	69.58	589.31	413.33	3.55
Randolph	633.96	4.23	287.04	67.05	701.01	219.99	4.67
St. Francis	645.21	4.71	197.34	77.03	722.24	120.31	5.27
White	540.45	3.38	451.55	87.49	627.94	364.06	3.92
Average	616.56	3.74	477.80	69.76	686.31	408.05	4.16

Development of Aromatic Rice Varieties

D.K. Ahrent, K.A.K. Moldenhauer,
J.A Bulloch, V.A. Boyett, V. Booth, and V. Thompson

ABSTRACT

The University of Arkansas System Division of Agriculture has implemented an aromatic rice breeding program at the Rice Research and Extension Center (RREC), Stuttgart, Ark., to develop cultivars for the U.S. to meet the market demand for aromatic rice. Rice imports have doubled in the last ten years and are composed mainly of aromatic rice. The aromatic rice breeding program has made cross-pollinations to incorporate genes for aroma, yield, improved plant type, superior quality, and broad-based disease resistance. Marker-Assisted Selection is used to screen for aroma, cooking quality, and blast resistance. In 2010, an experiment was established to determine the effect of different nitrogen fertilizer rates on the aroma and yield of aromatic rice varieties. Results of the yield trials in 2010 and 2011 showed mixed varietal response to increased nitrogen fertilizer. Some varieties increased in yield while others remained unchanged or decreased with increased nitrogen fertilization. Total rice percentages in the two-year study varied significantly across varieties.

INTRODUCTION

Approximately 13.3 million cwt of milled rice was imported to the U.S. in the fiscal year 2009/2010. This is an increase of 22% in the last eight years years (USA Rice Federation, 2008 and 2010). 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. Research is needed to determine what type of Arkansas soils will produce the best aromatic rice and 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 genes 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 2012.

DNA analyses were run on the parents and F_2 populations (Boyett et al., 2011). In 2011, approximately 2,550 F_4 panicle rows were planted in the RREC nursery from 2010 selections. Approximately 1,575 of the panicle rows were heterozygous lines from two of the F_4 populations and they were screened through Marker-Assisted Selection for aroma and amylose content. Leaf tissue was collected from five plants in each row for analysis.

An Aromatic Rice by Nitrogen Rate study was conducted in 2010 and 2011 to determine the effect of different rates of nitrogen fertilizer on the aroma and yield of aromatic rice varieties. Eight rice lines: Dellrose, Jasmine 85, Jazzman, Jazzman II, JES, Sierra, Wells, and STG03-085, which is a University of Arkansas experimental line, were treated with six nitrogen rates: 0, 30, 60, 90, 120, and 150 lb/acre. In 2010, another University of Arkansas experimental line, STG06-126, was determined to be non-aromatic and was dropped from the experiment the following year. Agronomic and yield data were collected. Hulled and milled seed samples from each plot were tested for the concentration of the aroma compound 2-acetyl-1-pyrroline (2A-P). This analysis is being conducted at the USDA-ARS Southern Regional Research Center, New Orleans, La.

RESULTS AND DISCUSSION

In 2011, 63 cross-pollinations were made to produce aromatic lines for screening. The F_1 plants from these crosses are growing in the greenhouse this winter to produce F_2 seed. The F_2 populations will be planted in 2012 at RREC for observation and selection.

Panicles were selected from 21 F_2 populations in 2011. All of the parents in these crosses were aromatic. Approximately 625 F_3 lines were planted in the winter nursery at Puerto Rico to advance a generation. The harvested seed from Puerto Rico will be planted at the RREC for further observation and selections in 2012. Marker analysis will be conducted to detect or determine the characteristics of aroma, cooking quality, and blast resistance.

Results of the Marker-Assisted Selection for the 1,573 heterozygous lines screened in 2011 for aroma and amylose content helped eliminate lines which did not meet quality requirements. Using the microsatellite marker RM190, 16% of the entries were heterozygous for amylose content. "Approximately 45% of the entries were homozygous long-grain class and 37% were homozygous Jasmine-type quality" (Boyett et al., 2012). Only 1% of the lines were discarded due to non-parental alleles.

Results of the 2010 Aromatic Rice by Nitrogen Rate study showed that grain yield responses to increased nitrogen 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 that grain yield response to nitrogen rates varied among the varieties. Dellrose, Jasmine 85, and STG03-085 grain yields decreased with increased nitrogen. STG03-085 had the lowest yields across all varieties. Jazzman and Wells responded with increasing yields to the additional nitrogen. Jazzman II, JES, and Sierra had no significant yield changes across the nitrogen 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 nitrogen fertilizer treatments. STG03-085 had the lowest and Sierra had the highest overall percentage of total rice.

SIGNIFICANCE OF FINDINGS

The Aromatic Rice by Nitrogen Rate experiments were planted in two different areas of the RREC and will be continued a third year in a new area. The yields were noticeably higher in 2011. Perhaps the experiment was planted in a high fertility area in 2011. The planting dates for the tests were 12 May 2010 and 18 May 2011. The weather in 2010 was abnormally hot and high nighttime temperatures may have affected kernel fill. The analysis for 2A-P is not complete at this time but will be included in all further reports.

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 Charles Wilson Jr., Donna Frizzell, and Jamie Branson for planting and fertilizing the experiment. We thank Merle Anders for statistical assistance.

LITERATURE CITED

Boyett, V.A., D. K. Ahrent, and K.A.K. Moldenhauer. 2011. Molecular characterization of elite aromatic breeding lines. *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 591:40-48. Fayetteville.

Boyett, V.A., D.K. Ahrent, V.L. Booth, V.I. Thompson, J.W. Gibbons, and K.A.K. Moldenhauer. 2012. Molecular analysis in an aromatic breeding program. Poster.

"U. S. Rice Domestic Usage Report For the Milling Year August 1, 2007 - July 31, 2008." USA Rice Federation. 2008.

"U. S. Rice Domestic Usage Report For the Milling Year August 1, 2009 - July 31, 2010." USA Rice Federation. 2010.

BREEDING, GENETICS, AND PHYSIOLOGY

DNA Marker-Assisted Selection of *Oryza rufipogon/*Wells Backcross Populations

V.A. Boyett, K.A.K. Moldenhauer, V. Booth, and V. Thompson

ABSTRACT

Backcross populations of *Oryza rufipogon/*Wells//Wells were analyzed with molecular markers linked to Quantitative Trait Loci (QTLs) known to enhance yield. Eight segregating populations totaling 1,752 individual genomic DNA samples were evaluated with peak markers for the yield QTLs *yld1.1*, *yld3.2*, *yld6.1*, *yld8.1*, and *yld9.1* on chromosomes 1, 3, 6, 8, and 9, respectively. Two populations resulting from crosses between an *O. rufipogon* improved Jefferson line and *O. rufipogon*/Wells//Wells backcross lines were screened with a marker for *yld2.1* on chromosome 2 in addition to the other yield QTLs. Selections of progeny for additional analysis were based on both genotypic data and phenotypic assessment. Selected plants were screened with markers flanking the QTL to determine if the entire region of the QTL was introgressed. Plants in which alleles derived from *O. rufipogon* were amplified at the flanking marker loci and showed potential for containing the yield QTLs were retained for further development with the goal of producing a high-yielding cultivar.

INTRODUCTION

Rice researchers worldwide have identified the potential of *O. rufipogon* as a source of trait-enhancing alleles for cultivated rice, *Oryza sativa* (McCouch et al., 2007). Many of these trait-enhancing alleles are of Quantitative Trait Loci (QTLs) linked to yield and yield components including loci for yield, grains per panicle, panicle length, and grain weight (Thomson et al., 2003). Many are stable across different environments and genetic backgrounds and could be useful in a backcross scheme to develop improved germplasm (Moncada et al., 2001; Septiningsih et al., 2003).

O. rufipogon is a wild relative and probable progenitor of cultivated rice with a red pericarp encoded by the dominant *Rc* gene. It shares the AA genome with cultivated rice and can be hybridized through crossing. It is genetically very close to cultivated rice and gives fertile F_1 offspring when crossed with both *Indica* and *Japonica* cultivars. It is phenotypically inferior to cultivated rice for many important agronomic traits, however, QTLs derived from *O. rufipogon* can contribute positively to the performance of elite cultivars of domesticated rice (Xiao et al., 1998; McCouch et al., 2007).

The objectives of this study are to use DNA markers linked to yield QTLs derived from *O. rufipogon* to (i) identify the progeny of *O. rufipogon*/Wells//Wells that are homozygous for the *O. rufipogon* allele at the peak marker for the yield QTLs, (ii) identify the resulting selections that are homozygous for the *O. rufipogon* allele at the flanking markers for the yield QTLs, and (iii) identify the selections to use as parents in a marker-assisted backcross program.

PROCEDURES

Leaf tissue from individually tagged field plants was harvested into manila coin envelopes and stored at -80 °C until sampled. Sampling was performed with a single hole-punch, and total genomic DNA was extracted using Sodium hydroxide/Tween 20 and neutralized with 100mM Tris-HCl, 2 mM EDTA (Xin et al., 2003). Each sample was arrayed in a 96-well format and 2 µl of template used for each 25µl Polymerase Chain Reaction (PCR) analysis.

To save on processing and analysis costs, PCR was performed using only the peak markers first, and then material selected from the peak marker analysis was further screened with flanking markers. Polymerase Chain Reaction was performed on all DNA samples with the simple sequence repeat (SSR) peak markers RM5, RM1373, RM3, RM210, and RM215 for QTLs yld1.1, yld3.2, yld6.1, yld8.1, and yld9.1, respectively. Since work on earlier generations of these populations revealed a homogeneous null allele with the RM6165 marker for yld2.1 (Boyett et al., 2009), this marker was not used. RM341, a replacement marker for RM6165, was used only on the progeny resulting from crosses between a Jefferson line improved with introgression of the yld2.1 QTL from O. rufipogon (McClung et al., 2008). Plants that amplified homozygous O. rufipogon alleles at several peak loci were selected and further screened with the flanking markers to the QTLs.

Polymerase Chain Reaction was 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 were grouped according to allele sizes and dye colors and diluted together with a 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

Of the 1,752 plants flagged in the field, successful amplification was achieved with the peak markers on 1,735 of the genomic DNA samples. RM341 was found to be monomorphic between Wells and *O. rufipogon* and therefore not informative with these populations.

Since it is currently possible to screen for only five of the yield QTLs in these populations, plants were selected on the basis of the data for the five peak markers for *yld1.1*, *yld3.2*, *yld6.1*, *yld8.1*, and *yld9.1*. Homozygous *O. rufipogon* alleles amplified in a range from only 26% of the samples for only one QTL (Pass 26-2) to amplification at all five loci with 99% of the samples homozygous *O. rufipogon* at four of the five QTLs (Pass 28-1). The DNA samples in most of the passes amplified homozygous *O. rufipogon* alleles at most of the loci in the 20% range, but 99% of the samples in Pass 28-1 and 28-2 amplified homozygous *O. rufipogon* alleles at *yld1.1*, *yld3.2*, *yld6.1*, and *yld8.1* (Table 1).

An analysis of the allele distribution across all populations for all QTLs revealed that the majority of amplifications were homozygous with the number of samples amplifying homozygous Wells alleles only slightly higher than those that were homozygous *O. rufipogon*. About one quarter of the amplifications were heterozygous and the low number of non-parental alleles were amplified only with RM1373 (Table 2).

With the goal of introgressing all the QTLs with positive effects on yield, plants were selected to be used in further crossing that had the homozygous *O. rufipogon* allele at three or more loci and had a desirable plant type. In most of the passes, the vast majority of the samples amplified homozygous Wells alleles or amplified homozygous *O. rufipogon* alleles at only one locus (Table 3). Based on this analysis, a core group of 25 plants were advanced to the flanking marker analysis to determine if the entire region of the QTL or only part of it was introgressed.

Total genomic DNA from this selected group of plants was analyzed using SSR markers flanking both sides of all six yield QTLs. If the sample amplified homozygous *O. rufipogon* alleles with the peak marker for a particular locus it was more likely to look like *O. rufipogon* with the flanking markers as well, indicating complete introgression of the yield QTL. For *yld1.1*, 56% of the samples amplified homozygous *O. rufipogon* alleles with all three markers. For *yld3.2* and *yld6.1*, 80% of the samples looked like *O. rufipogon* across the QTL. It was impossible to perform this analysis for *yld2.1*, *yld8.1*, and *yld9.1* as there is a problem with at least one of the markers for each QTL and suitable replacement markers have not yet been found (Table 4).

SIGNIFICANCE OF FINDINGS

Using DNA marker-assisted selection enabled the breeder to choose material containing the yield QTLs from *O. rufipogon* while retaining other good agronomic traits from Wells. This selected material will be used in backcrosses and as parents of new crosses for further development into high-yielding commercial varieties. Any plants with non-parental alleles or other undesirable genetics were able to be eliminated before those alleles were passed on to the next generation.

Informative markers need to be found not only to fill in the regions where currently there is no marker data, but also to characterize other parts of the genome as well. This work will be necessary to determine exactly what regions of the genome are responsible for yield and what molecular markers are associated with the yield trait.

ACKNOWLEDGMENTS

The authors thank the rice growers of Arkansas for the check-off monies administered by 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 J. Bulloch, M. Blocker, H. Ellenburg, J. Griffith, and A. Glover for their excellent technical assistance.

LITERATURE CITED

Boyett, V.A., J. You, and K.A.K. Moldenhauer. 2009. Challenges of marker-assisted selection of quantitative trait loci introgression from *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.

McClung, A.M., S. Moon, G. Eizenga, and S. McCouch. 2008. Enhancement of Yield Using Chromosomal Introgressions from Oryza rufipogon. In: Proceedings of the 32nd Rice Technical Working Group Meetings, February 18-21, 2008, San Diego, CA.

McCouch, S.R., M. Sweeney, J. Li, H. Jiang, M. Thomson, E. Septiningsih, J. Edwards, P. Moncada, J. Xiao, A. Garris, T. Tai, C. Martinez, J. Tohme, M. Sugiono, A. McClung, L.P. Yuan, and S-N. Ahn. 2007. Through the genetic bottleneck: *O. rufipogon* as a source of trait-enhancing alleles for *O. sativa*. Euphytica 154:317-339.

Moncada, P., C.P. Martinez, J. Borrero, M. Chattel, H. Gauch Jr., E. Guimaraes, J. Tohme, and S.R. McCouch. 2001. Quantitative trait loci for yield and yield components in an *Oryza sativa* X *Oryza rufipogon* BC_2F_2 population evaluated in an upland environment. Theor Appl Genet 102:41-52.

Septiningsih, E.M., J. Prasetiyono, E. Lubis, T.H. Tai, T Tjubaryat, S. Moeljopawiro, and S.R. McCouch. 2003. Identification of quantitative trait loci for yield and yield components in an advanced backcross population derived from the *Oryza sativa* variety IR64 and the wild relative *O. rufipogon*. Theor Appl Genet 107:1419-1432.

Thomson, M.J., T.H. Tai, A.M. McClung, X-H. Lai, M.E. Hinga, K.B. Lobos, Y. Xu, C.P. Martinez, and S.R. McCouch. 2003. Mapping quantitative trait loci for yield, yield components and morphological traits in an advanced backcross population between *Oryza rufipogon* and the *Oryza sativa* cultivar Jefferson. Theor Appl Genet 107:479-493.

Xiao, J., J. Li, S. Grandillo, S.N. Ahn, L. Yan, S.D. Tanksley, and S.R. McCouch. 1998. Identification of trait-improving quantitative trait loci alleles from a wild rice relative, *Oryza rufipogon*. Genetics 150:899-909.

Xin, Z., J.P. Velten, M.J. Oliver, and J.J. Burke. 2003. High-throughput DNA extraction method suitable for PCR. BioTech. 34:4:820-825.

Table 1. Results from analysis of the DNA samples with the peak markers linked to the yield Quantitative Trait Loci showing percent of samples amplifying homozygous *O. rufipogon* alleles. Totals reflect the number of successful amplifications with a given marker.

	yld1.1	*yld2.1*	*yld3.2*	*yld6.1*	*yld8.1*	*yld9.1*	
Pass	RM5	RM341[a]	RM1373	RM3	RM210	RM215	Total
26-2	0	M	0	0	0	20 26%	78
26-3	54 14%	M	41 10%	35 9%	41 10%	88 22%	394
26-4	79 39%	NA	40 20%	14 7%	46 23%	49 24%	203
27-1	74 43%	NA	46 26%	44 25%	45 26%	52 30%	174
27-3	65 32%	NA	55 27%	1 0.5%	0	57 28%	201
27-4	60 27%	NA	55 25%	0	52 24%	48 22%	219
28-1	236 99%	NA	236 99%	237 99%	236 99%	85 36%	239
28-2	226 99%	NA	225 99%	225 99%	226 99%	0	227

[a] RM341 was a replacement marker for the null RM6165 peak marker. It was found to be monomorphic between Wells and *O. rufipogon* and not informative.

Table 2. Allele distribution across all populations with the peak markers linked to the yield Quantitative Trait Loci.

QTL	Peak marker	Homozygous *O. rufipogon*	Homozygous WLLS/ JEFF	Heterozygotes	Non-parental	Test no.
yld1.1	RM5	46%	27%	27%	0%	1,733
yld3.2	RM1373	40%	24%	29%	7%	1,731
yld6.1	RM3	32%	57%	11%	0%	1,728
yld8.1	RM210	37%	40%	22%	0%	1,731
yld9.1	RM215	23%	36%	40%	0%	1,729

Table 3. Distribution of homozygous *O. rufipogon* alleles amplified with yield Quantitative Trait Loci peak markers, percentages by number of loci.

Pass	5 Loci	4 Loci	3 Loci	2 Loci	1 Locus	0	Total
26-2	0	0	0	0	20 26%	58 74%	78
26-3	0	7 2%	18 5%	36 9%	110 28%	223 57%	394
26-4	1 0.5%	1 0.5%	18 9%	43 21%	79 39%	61 30%	203
27-1	0	2 1%	20 12%	71 41%	51 29%	30 17%	174
27-3	0	0	8 4%	39 19%	77 38%	77 38%	201
27-4	0	0	8 4%	45 21%	101 46%	65 30%	219
28-1	84 35%	151 63%	1 0.4%	0	3 1%	0	239
28-2	0	223 98%	2 1%	2 1%	0	0	227

Table 4. Allele distribution of a selected core group of 25 plants with all the peak and flanking markers linked to the yield Quantitative Trait Loci.

QTL	Position	Marker	Homozygous *O. rufipogon*	Homozygous WLLS/JEFF	Hetero-zygotes	Non-parental
yld1.1	Left flank	RM1196	64%	16%	16%	4%
	Peak	RM5	68%	12%	20%	0
	Right flank	RM306	60%	16%	12%	0
		All 3	56%			
yld2.1	Left flank	RM3284	72%	16%	8%	0
	Peak	RM6165	Null	Null	Null	Null
	Right flank	RM13452	Monomorphic	Monomorphic	Mono	Mono
yld3.2	Left flank	RM130	80%	12%	8%	0
	Peak	RM1373	80%	8%	4%	8%
	Right flank	RM85	84%	8%	8%	0
		All 3	80%			
yld6.1	Left flank	RM3183	80%	16%	4%	0
	Peak	RM3	80%	16%	4%	0
	Right flank	RM20071	80%	16%	4%	0
		All 3	80%			
yld8.1	Left flank	RM6193	Monomorphic	Monomorphic	Mono	Mono
	Peak	RM210	80%	12%	4%	4%
	Right flank	RM149	76%	12%	12%	0
yld9.1	Left flank	RM107	68%	16%	16%	0
	Peak	RM215	76%	8%	12%	4%
	Right flank	RM6643	Monomorphic	Monomorphic	Mono	Mono

BREEDING, GENETICS, AND PHYSIOLOGY

2011 Rice Blast Pathogenicity Test of Uniform Rice Regional Nursery Lines

C. Feng and J.C. Correll

ABSTRACT

In 2011, 192 rice breeding lines were tested with 12 *Magnaporthe oryzae* reference isolates and one isolate from hybrid rice. Race IG-1 isolate #24, race IB54, and race ID13 were weak in virulence; over 75% of the cultivars were resistant to these isolates. Only 12.5% of the lines were resistant to IB33, and less than 20% of the lines were resistant to 49D, one of the 3 race IB-49 isolates used in this study. A119 was also a race IB-49 isolate, but about 3 quarters of the lines were resistant to it. About 40% to 60% of the lines were resistant to the third race IB-49 isolate, A598, and the other 5 isolates, including one isolate obtained from hybrid rice. There were 14 cultivars resistant to all 13 rice blast isolates, 16 lines resistant to 12 isolates, and 46 lines resistant to 11 isolates. However, 8 lines were susceptible to all isolates, 16 lines were resistant to only one of the 13 isolates, and 12 were resistant to two of the 13 isolates. These publically available results could help rice breeders in their selection of parental lines for improving blast resistant germplasm.

INTRODUCTION

Rice is a major staple crop worldwide. Half of the world's population, mainly from developing countries in Asia and Africa, depend on rice as a staple food crop. Rice blast disease, caused by the fungus *Magnaporthe oryzea* (anamorph: *Pyricularia oryzae*), is a common disease of rice that can be found in all countries where rice is produced, and is one of the most destructive diseases which could cause severe yield loss under favorable conditions. Modern high-yielding rice cultivars demand high nitrogen fertilizer rates, which promote rice blast disease. The most economic and effective way to manage rice blast disease is to plant resistant cultivars. It is necessary to know the resistance or susceptibility of newly developed lines to the current rice blast pathogen population. In the last a few years, hybrid rice acreage has increased dramatically in the U.S. It is easier to combine resistance genes in a hybrid, and some hybrids have good resistance. With the development of new hybrid rice cultivars, we are continuing to survey these lines for blast to determine if there is any virulence difference among isolates from hybrid rice lines. The objective of this research was to test the Uniform Rice Regional Nursery (URRN) lines, including newly develop rice cultivars and breeding lines with 12 rice blast reference isolates and one reference strain isolated from hybrid rice.

PROCEDURES

A total of 192 rice breeding lines developed by the rice breeders from Arkansas, Louisiana, Mississippi, and Texas have been tested with 12 rice blast reference isolates as well as one isolate (30H) isolated from a rice hybrid. The susceptible control M204 was included in each test. Rice seed were planted in plastic trays filled with river sand mixed with potting soil in the greenhouse at the University of Arkansas, Fayetteville. Each tray was planted with 38 rows of URRN entrees and 2 rows of susceptible control M204. Plants were fertilized (Miracle Gro All-Purpose Plant Food 20-20-20) once a week during each test. Plants were inoculated approximately 14 to 20 days after planting.

Twelve isolates of the rice blast pathogen representing 10 races and one isolate from hybrid rice were used in the study (Table 1). Inoculum was produced by incubating each isolate on Rice Bran Agar plate (Correll et al., 2000) for approximately 7 days, collecting the spores in cool water, and adjusting the inoculum concentration to 200,000 spores/ml per isolate. Approximately 50 ml of inoculum was applied to each tray with an air compressor sprayer. After inoculation, the plants were incubated at 100% relative humidity at approximately 22 °C for 24 hr, allowed to dry for 2 to 3 hr, then moved to the greenhouse and incubated for 6 days. On the seventh day after inoculation, the plants were scored according to a standard 0 to 9 disease rating scale (Correll et al., 1998). Lines rated 0 to 3 were considered resistant whereas those rated 4 to 9 were considered susceptible.

RESULTS AND DISCUSSION

Among the rice blast reference isolates used in this study, Isolate #24 (race IG-1), ID13 (race ID-13), and IB54 (race IB-54) were the least virulent ones and there were 140 to 160 (about 75% to 83%) lines resistant to these isolates. Isolate IB33 (race IB-33), originally recovered from rice under greenhouse conditions (F.N. Lee, pers. comm.), was the most virulent isolate and only 24 lines (12% of total) were resistant to this isolate. Isolates A119, A598, and 49D were classified as race IB-49 previously. There were only 35 lines (less than 20% of total) that were resistant to 49D, but 141 lines (73% of total) were resistant to isolate A119 and 98 lines (51% of total) were resistant to isolate A598. Isolate 49D (race IB-49) was highly virulent to most lines as compared to the other two race IB-49 isolates. There were about 40% to 50% of the lines resistant or susceptible to the other 5 isolates, including A264(IC-17), ZN7 (IE-1), ZN15 (IB-1), ZN46 (IC-1), and TM2 (race K) (Table 2). Isolate 30H was isolated from a rice hybrid; it could infect about half (97) of the lines. The frequencies of the lines with a given disease rating for each isolate are shown in Fig. 1.

The most resistant and susceptible lines are listed in Table 3. Fourteen lines, including RU1001099, RU1001124, RU1001130, JES, RU1102071, RU1101084, RU1101102, RU1001111, RU1101136, RU1101151, RU1001164, RU1101170, RU1101179, and RNDO, were resistant to all 13 isolates, 16 lines were resistant to 12 of the 13 isolates, and 46 lines were resistant to 11 out of the 13 isolates. Eight lines, including RU0801167, Francis, RU1004053, RU0801176, RU0801182, RU1104186, RU1104191, and RU1104193, were susceptible to all 13 isolates. Sixteen lines were only resistant to 1 of the 13 isolates. Twelve lines were resistant to 2 of the 13 isolates (Fig. 2). A complete examination of the entry by isolate interactions is available online at http://www.uark.edu/ua/jcorrell/data/2011URRNfinal.xls.

SIGNIFICANCE OF FINDING

Planting resistant cultivars is the most effective and economical way for managing rice blast disease. This study provides useful information for farmers to select rice cultivars based on the spectrum of disease resistance to control rice blast disease, and for breeders to determine what lines should be released and what lines can be chosen as parental lines for their future breeding programs.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board for their financial support of the research reported.

LITERATURE CITED

Correll, J.C., T.L. Harp, and F.N. Lee. 1998. Large-scale screening of USDA rice germplasm for qualitative and quantitative resistance to two common races (IC-17 and IB-49) of the rice blast pathogen, *Pyricularia grisea*. *In:* R.J. Norman and T.H. Johnson (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:169-194. Fayetteville.

Correll, J.C., T.L. Harp, J.C. Guerber, R.S. Zeigler, B. Liu, R.D. Cartwright, and F.N. Lee. 2000. Characterization of a population of *Pyricularia grisea* from rice in the United States using independent genetic and molecular markers. Phytopathology 90:1396-1404.

Table 1. Background information on the 10 isolates of *Magnaporthe oryzae* used in this study[a].

Isolate	Vegetative compatibility group (VCG)	MGR586 group	RACE	Year	Location
A119	US-03	C	IB49	1992	Ark.
A264	US-02	B	IC17	1993	Ark.
A598	US-01	A	IB49	1992	Ark.
ZN7	US-02	B	IE-1	1995	Texas
Zn15	US-01	A	IB-1	1996	Texas
ZN46	US-01	A	IC-1	1996	Fla.
IB33			IB33		Ark.
IB54			IB54		
ID13			ID13		
#24	US-02	B	IG-1	1992	Ark.
49D	US-03	E	IB49	1985	Ark.
TM2	US-02	B	Race K		Texas
30H					Ark.

[a] More complete background on most of these isolates is available in Correll et al., 2000.

Table 2. Summary of disease ratings of the total number of lines tested to each isolate.

		Resistant		Susceptible	
Isolate	Race	Lines	%	Lines	%
A119	IB49	141	73.4	51	26.6
A264	IC17	112	58.3	80	41.7
A598	IB49	98	51.0	94	49.0
ZN7	IE-1	108	56.3	84	43.8
ZN15	IB-1	100	52.1	92	47.9
ZN46	IC-1	107	55.7	85	44.3
IB33	IB33	24	12.5	168	87.5
IB54	IB54	160	83.3	32	16.7
ID13	ID13	141	75.0	47	25.0[a]
24	IG-1	149	77.6	43	22.4
49D	IB49	35	19.8	142	80.2[a]
TM2	race K	91	47.4	101	52.6
30H		97	50.5	95	49.5

[a] When tested with ID13 and 49D, 4 and 15 lines had died from a seedling disease, respectively.

Table 3. Disease reactions of the most resistant (14) and susceptible (8) lines tested.

		A119	A264	A598	ZN7	ZN15	ZN46	IB33	IB54	TM2	24	ID13	49D	
Entry	Variety	IB-49	IC-17	IB-49	IE-1	IB-1	IC-1	IB33	IB54	Race K	IG-1	ID13	IB-49	30H
21	RU1001099	0	0	0	0	0	0	0	0	0	0	0	0	0
44	RU1001124	0	0	0	3	3	3	0	0	0	0	0	3	0
47	RU1001130	0	0	0	3	3	3	3	3	0	0	0	0	3
64	JES	0	0	0	0	1	0	0	3	0	0	0	3	0
71	RU1102071	0	0	0	0	0	0	0	0	0	0	0	0	0
84	RU1101084	0	0	0	0	0	0	3	0	0	0	0	3	0
102	RU1101102	0	0	0	2	0	0	3	0	3	0	0	0	0
111	RU1001111	0	0	0	0	0	0	3	0	0	0	0	0	0
136	RU1101136	0	0	0	0	3	3	3	0	0	0	3	3	0
151	RU1101151	0	0	0	0	0	0	3	0	0	0	0	0	0
164	RU1001164	0	0	0	3	3	3	3	0	0	0	0	3	0
170	RU1101170	0	0	0	0	0	0	3	0	0	0	0	3	3
179	RU1101179	0	0	0	0	0	0	0	0	0	0	0	0	0
199	RNDO	0	0	0	0	0	0	3	0	0	0	0	3	0
27	RU0801167	4	7	7	6	6	6	6	5	7	5	6	8	7
40	FRNS	4	4	6	7	7	6	6	8	8	5	4	7	6
53	RU1004053	4	6	6	6	6	6	6	7	7	5	6	7	6
176	RU0801176	5	7	6	6	7	6	6	7	7	4	6	8	6
182	RU0801182	6	7	6	6	6	6	7	6	6	4	6	7	7
186	RU1104186	5	7	6	6	6	4	4	5	4	4	6	6	6
191	RU1104191	6	7	6	6	6	6	6	4	6	4	5	7	6
193	RU1104193	5	7	7	6	6	6	6	5	7	4	6	7	6`

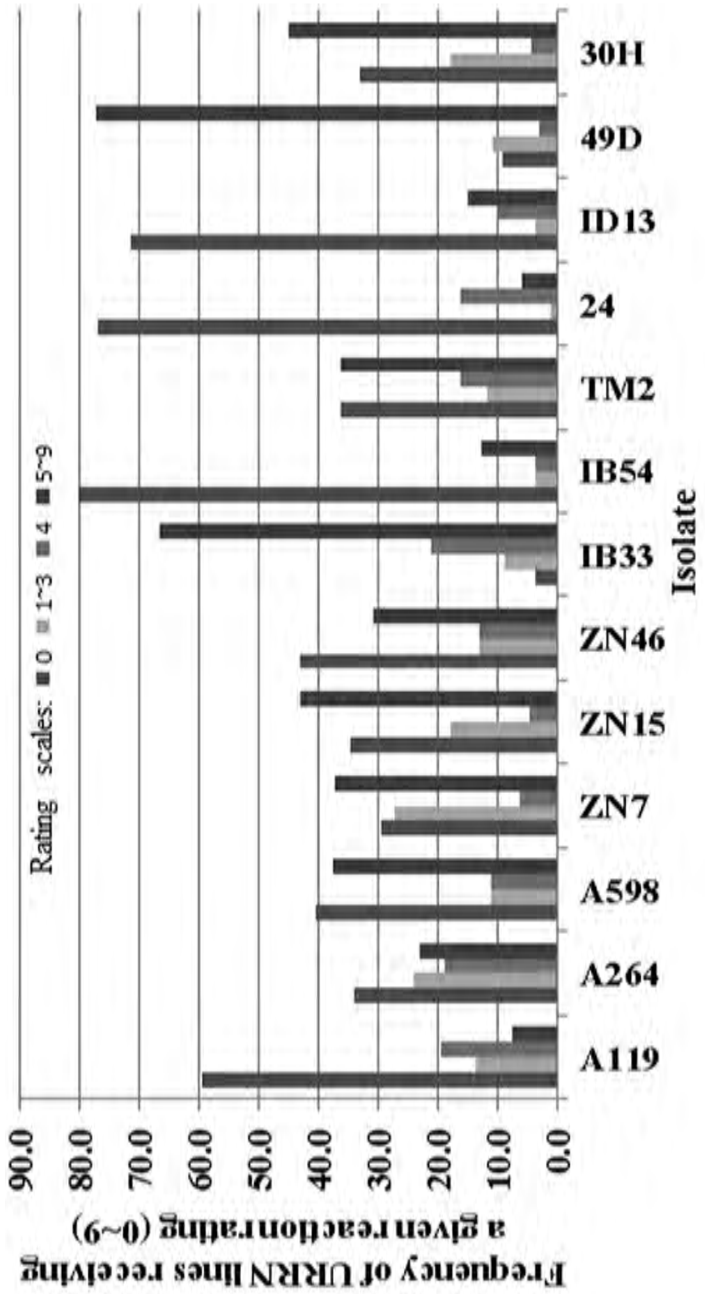


Fig. 1. Distribution of the number of lines receiving a disease reaction rating of 0 (most resistant) to 9 (most susceptible) for each isolate.

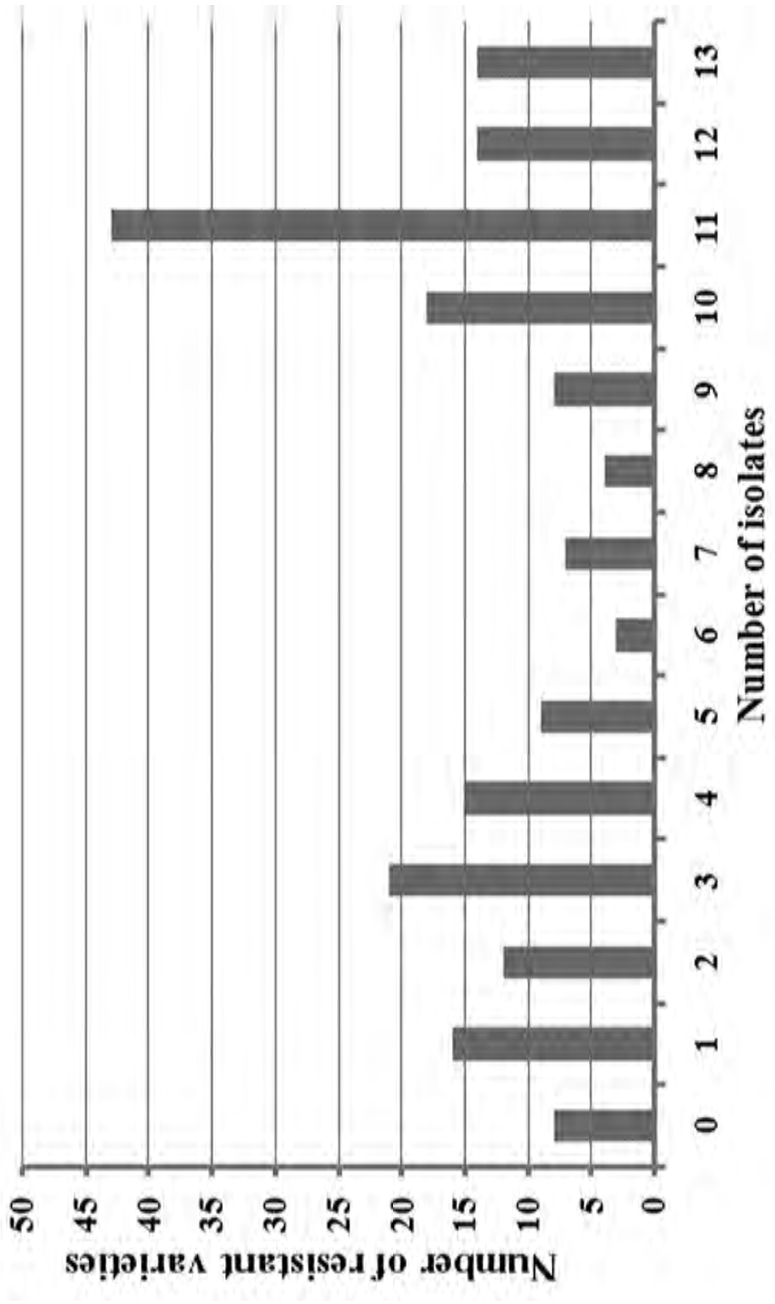


Fig. 2. Distribution of the number of lines rated as resistant to 0 isolate, 1 isolate, 2 isolates, etc.

Pathological and Molecular Characterization of Rice Blast Pathogenicity Factor *AVR-Pita1* in Field Isolates

Y. Jia, J.C. Correll, and F.N. Lee

ABSTRACT

The rice blast resistance gene *Pi-ta* has been effective in managing rice blast disease in Arkansas and the southern U.S. The *AVR-Pita1* gene in the pathogen, *Maganporthe oryzae,* encodes a metalloprotease that determines the efficacy of *Pi-ta* mediated blast resistance. Analysis of genetic variation of *AVR-Pita1* in field isolates of the pathogen has led to a better understanding of the stability of rice blast resistance. In the present study, race identity in 126 field blast isolates was determined, the *AVR-Pita1* alleles were sequenced, and pathogenicity toward cultivars containing *Pi-ta* and lacking *Pi-ta* was determined. It was found that most of sequence variation in *AVR-Pita1* results in altered metalloproteases in avirulent isolates. However, in isolates that attack *Pi-ta* resistance gene, *AVR-Pita1* metalloproteases were found to be "destroyed" through various genetic mechanisms. For the first time, we provided evidence to demonstrate molecular mechanisms of the instability of rice blast resistance and the evolution of virulence in the pathogen.

INTRODUCTION

Blast disease of rice, caused by the fungal pathogen *Magnaporthe oryzae,* has been a serious threat for rice production in the Arkansas, the southern U.S., and worldwide. However, it is well established that the major blast resistance (*R*) genes in rice can provide complete resistance to *M. oryzae* isolates/races that contain the corresponding avirulence genes. This gene-for-gene relationship is highly similar to a "Key and Lock" relation where a key must match with a particular lock to be effective. These major blast *R* genes have been effectively incorporated into newly developed rice cultivars in classical rice breeding programs. In Arkansas and the southern U.S., the *Pi-ta* resistance gene is the most widely and effectively deployed major blast *R* gene for preventing infections by some of the most commonly found races of the rice blast pathogen that contain the corresponding avriulence gene *AVR-Pita1*. *Pi-ta* was characterized and shown to have a predicted product, a cytoplasmic receptor. Subsequently, DNA markers for *Pi-ta* have been developed from the cloned gene for marker assisted breeding (Jia et al., 2002; Jia et al., 2004). The presence of *AVR-Pita1* is known to be critical for *Pi-ta* mediated blast resistance. *AVR-Pita1* is known to encode a predicted metalloprotease (Orbach et al., 2000) and is thought to be involved in pathgoenicity; however, such direct evidence for *AVR-Pita1* is still lacking. Since blast epidemics in the 1980s in the southern U.S., *Pi-ta* was introduced into Katy from a landrace variety Tetep in 1990. Subsequently, Katy has been used as the *Pi-ta* donor for a series of rice cultivars, such as Drew, Madison, Kaybonnet, Cybonnet, Ahrent, Springs, Banks, and Templeton (Dai et al., 2008; Moldenhauer, pers. comm.). DNA markers for *Pi-ta* developed with partial funding from the Arkansas Rice Research and Promotion Board and have been used for some of the newly developed cultivars (Moldenhuaer and Gibbons, pers. comm.). Severe blast disease has been found in cultivar Banks that carry *Pi-ta* in commercial fields in numerous counties in Arkansas since 2004 (Correll et al., 2009; Lee et al., 2009). These findings raised a serious concern of continued *Pi-ta* deployment in Arkansas. Therefore, continued monitoring of genetic changes of *AVR-Pita1* allele in field blast isolates has significant impact for Arkansas rice breeding programs.

One of the overall goals of molecular plant pathology programs in the University of Arkansas System Division of Agriculture and USDA-ARS Dale Bumpers National Rice Research Center (DB NRRC) is to monitor genetic changes of the rice blast fungus to provide critical guidance for blast *R* gene deployment. The present study addresses genetic variation of *AVR-Pita1* in 126 field isolates collected from 1970 to 2009 from Arkansas, the southern U.S., and worldwide.

PROCEDURES

The fungal isolates collected from Arkansas and the southern U.S. were purified from diseased leaves, stem nodes, and panicles using a standard method as described in Jia, 2009. The fungal DNA and pathogenicity data from foreign countries were collected in the respective countries. The local fungus isolates were cultured on oatmeal to produce spores for inoculation using the method described in Jia (2009). Fungal DNA was extracted using a Qiagen Kit following the manufacturer's instructions (Qiagen, Germantown, Md.). DNA was amplified by *AVR-Pita1* specific primers following a method previously described in Zhou et al. (2007) and Dai et al. (2008). Products of the polymerase chain reaction (PCR) were purified using Qiagen gel extraction kit and DNA and was sequenced by the USDA Mid South Area Genomics Laboratory (MSAGL) in Stoneville, Miss. Sequences were assembled using Vector NTI software (Invitrogen, Carlsbad, Calif., and analyzed using MEGA 4 and DnaSP 4.5.

RESULTS AND DISCUSSION

A total of 24 races of *M. oryzae* were identified among the 126 U.S. isolates (Table 1). Among them, 33 isolates were identified as race IC17, 19 as race IB49, 16 as race IE1, and 13 as race IB1. These data suggest that IC17, IB49, IE1, and IB1 were the most prevalent in the rice-production areas where the samples were collected (Table 1). Next, we determined that 151 out of the 187 isolates examined were avirulent and unable to cause disease on the *Pi-ta*-containing rice cultivars (Fig. 1b). The other 36 isolates were virulent (Table 1). The avirulent isolates were shown to contain functional *AVR-Pita1* alleles with minor DNA sequence variation; in contrast, major structural variation of *AVR-Pita1* was detected among all the virulent isolates (Dai et al., 2010b).

We then sequenced the *AVR-Pita1* gene from 151 avirulent isolates (Table 1). A total of 38 *AVR-Pita1* haplotypes, including the original *AVR-Pita1,* were identified (Table 2). Among them, 23 haplotypes were identified only in single isolates and the remaining 15 haplotypes were identified in multiple isolates (Table 1). The original *AVR-Pita1* allele was found in two Chinese isolates including O-137, and three Columbian isolates (Table 1). These data suggest that the *AVR-Pita1* gene in field isolates of *M. oryzae* likely assists in the pathogen's adaptation (Dai et al., 2010a, 2010b; Zhou et al., 2007).

AVR-Pita1 is known to possess three introns and four exons in the open reading frame (Orbach et al., 2000). The *AVR-Pita1* sequences in 151 avirulent isolates were predicted to produce 38 functional *AVR-Pita1* alleles, and these alleles could be translated into 27 highly similar *AVR-Pita1* proteins. Among the 27 AVR-Pita1 proteins, amino acid variations were observed to occur at 23 positions including a deletion/insertion. All variations occurred throughout the entire protein, including the one at position 173 of the putative protease motif (Table 2). The protease motif in 27 putative proteins was identical except for the 173rd amino acid "V173I" in the metalloprotease motif that is consistent with the report by Orbach et al. (2000).

We also identified two additional nucleotides in the first exon of the *AVR-Pita1* alleles in four virulent isolates. Insertion of two nucleotides in the first exon was predicted to form a premature stop codon after the 123rd nucleotide. As a result, these *AVR-Pita1* alleles are predicted to produce truncated non-functional metalloproteases (Fig. 2e). These observations suggest that frame-shift mutation at the *AVR-Pita1* alleles is one mechanism that the fungus uses to defeat the *Pi-ta* gene.

Through repeated efforts, using different combinations of *AVR-Pita1* primers (primer location is indicated in Fig. 1c), we failed to amplify the *AVR-Pita1* alleles in 32 virulent isolates. The failure of amplification of *AVR-Pita1* suggests that DNA sequences at some of these primer sets may have been significantly altered. This possibility was borne out when we performed Southern blot analysis with the genomic DNA of the 10 virulent isolates digested with *Eco*RI and *Bam*HI, respectively (Fig. 2b and Fig. 2c). When hybridizing with a fragment of the *AVR-Pita1* coding region, a 5 kb band was detected in the ten virulent isolates except isolate B2, which had an additional 4 kb band. However, two hybridization bands between 5 kb and 9 kb were detected in the two avirulent isolates 60 and 60/1, respectively (Fig. 2b). Similar hybridization patterns were observed when the restriction endonuclease *Bam*HI was used (Fig. 2b). When the PCR product of *AVR-Pita1* was amplified from 5' UTR, including a 5' portion of the gene, by primers YL169 and YL165 used as the probe, no hybridization signal was observed among the 9 virulent isolates except for B2. There was a hybridization signal in B2, suggesting that B2 has a different *AVR-Pita1* allele. In contrast, two bands of the same size were observed in an avirulent check isolate 60 and 60/1 as predicted (Fig. 2c). Using R23 (with newly introduced *AVR-Pita1*) as a control, further study of the remaining 22 virulent isolates by southern blot analysis using the genomic DNA digested with *Bam*HI revealed both similar and novel results: A single fragment was revealed in 19 of the 22 virulent isolates when using the *AVR-Pita1* coding region as a probe while the other 3 isolates showed no hybridization signal indicating a complete deletion of *AVR-Pita1* in these 3 isolates (Fig. 2d). When the 5' portion of *AVR-Pita1* was used as a probe to hybridize the stripped membrane, none of the 22 virulent isolates had any hybridization signal (Fig. 2d). These results demonstrate that *AVR-Pita1* was either partially or completely deleted in these virulent isolates (Zhou et al., 2007; Dai et al., 2010b).

In summary, our observations and findings by Orbach et al. (2000), Kang et al. (2001), and Zhou et al. (2007) together demonstrated that genetic changes had occurred in *AVR-Pita1* alleles in field isolates by point mutations, partial and complete delections, frameshift mutations, and transposon insertion (Fig.2e).

SIGNIFICANCE OF FINDINGS

We present evidence to support a hypothesis that major variation at the *AVR-Pita1* locus is responsible for "defeating" *Pi-ta*-mediated resistance in commercial rice cultivars. These findings illustrate the fact that these *AVR-Pita1* variants are both ecologically fit and capable of avoiding host recognition to trigger host resistance. Although the *Pi-ta* gene has evolved to detect the *AVR-Pita1* variants with minor diversification, it is possible that these *AVR-Pita1* variants may evolve to be new pathogenicity factors for future blast epidemic. This new knowledge should guide blast *R* gene deployment in Arkansas, the southern U.S., and worldwide.

ACKNOWLEDGMENTS

We thank the University of Arkansas Rice Research and Promotion Board for financial support of the Jia and Correll laboratories and for the support of the graduate student Yuntao Dai. We also thank Toni Marchetti (ARS-RET) for providing archived isolates and Yanli Wang of Zhejiang Academy of Agricultural Sciences for DNA and pathogenicity data of Chinese isolates and Fernando Correa-Victoria for Colombian isolates. The Molecular Plant Pathology program of DB NRRC is funded by National Programs 301 and 303 of USDA-ARS.

LITERATURE CITED

Correll, J.C., E.J. Boza, E. Seyran, R.D. Cartwright, Y. Jia, and F.N. Lee. 2009. G. Wang, ed. Examination of the rice blast pathogen population diversity in Arkansas, USA – stable or unstable? Advances in the genetics genomics, and control of rice blast disease. Pgs 217-228. Springer.

Dai, Y., J.C. Correll, and Y. Jia. 2010a. Understanding the molecular mechanism of instability of the avivrulence gen *AVR-Pita1* in field isolates of *Magnaporthe oryzae*. Page 52 *In:* Proc. 5th International Rice Blast Conference, Little Rock, Ark.

Dai, Y., Y. Jia, J. Correll, X. Wang, and Y. Wang. 2010b. Diversification and evolution of the avirulence gene *AVR-Pita1* in field isolates of *Magnaporthe oryzae*. Fungal Genetics and Biology 47:973-980.

Dai, Y., Y. Jia, X. Wang, F.N. Lee, Y. Wang, and J.C. Correll. 2008. Structural and functional analysis of the rice blast fungus avirulence gene *AVR-Pita*. Phytopathology 98:S44.

Jia, Y. 2009. A user friendly method to isolate and single spore the fungi *Magnaporthe oryzae* and *Magnaporthe grisea* obtained from diseased field samples. Plant Health Progress. Page 1-4. doi:10.1094/PHP-2009-1215-01-BR, Online.

Jia, Y., McAdams, S. A., Bryan, G. T., Hershey, H. P., and Valent, B. 2000. Direct interaction of resistance gene and avirulence gene products confers rice blast resistance. The EMBO J. 19:4004-4014.

Jia, Y., M. 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.

Jia, Y., Z. Wang, and P. Singh. 2002. Development of dominant rice blast resistance *Pi-ta* gene markers. Crop Sci. 42: 2145-2149.

Kang, S., M.H. Lebrun, L. Farrall, and B. Valent. 2001. Gain of virulence caused by insertion of a Pot3 transposon in a *Magnaporthe grisea* avirulence gene. Mol. Plant Microbe Interact. 14:671–674.

Lee, F.N., R.D. Cartwright, Y. Jia, and J.C. Correll. 2009. Field resistance expressed when the Pi-ta gene is compromised by *Magnaporthe oryzae*. Pp. 281-289. *In:* G.-L. Wang and B. Valent (eds.). Advances in Genetics, Genomics and control of rice blast disease, Springer.

Orbach, M.J., L. Farrall, J.A. Sweigard, F.G. Chumley, and B. Valent. 2000. A telomeric avirulence gene determines efficacy for the rice blast resistance gene *Pi-ta*. Plant Cell 12:2019-2032.

Valent, B., Farrall, L., and Chumley, F. G. 1991. Magnaporthe grisea genes for pathogenicity and virulence identified through a series of backcrosses. Genetics 127: 87–101.

Zhou, E., Y. Jia, J. Correll, and F.N. Lee. 2007. Instability of the *Magnaporthe oryzae* avirulence gene *AVR-Pita* alters virulence. Fungal Genetics and Biology 44: 1024-1034.

Table 1. A summary of the fungal

Isolate	Race[a]	Origin country	Year	Collector	Host
O-137	—	China	1985	B. Valent and Y. Shen	Rice
China 9	A49	China	1993	Y. Wang	Rice
China 20	F1	China	1993	Y. Wang	Rice
China 47	A49	China	1993	Y. Wang	Rice
China 117	E3	China	1993	Y. Wang	Rice
China 154	E1	China	1993	Y. Wang	Rice
China 170	G1	China	1993	Y. Wang	Rice
CH11	—	China	2001	J. Correll	Rice
C11	—	Columbia	2002	F. Victoria	Rice
C12	—	Columbia	2002	F. Victoria	Rice
C13	—	Columbia	2002	F. Victoria	Rice
C14	—	Columbia	2002	F. Victoria	Rice
C17	—	Columbia	2002	F. Victoria	Rice
C19	—	Columbia	2002	F. Victoria	Rice
C20	—	Columbia	2002	F. Victoria	Rice
C21	—	Columbia	2002	F. Victoria	Rice
C22	—	Columbia	2002	F. Victoria	Rice
FC12	—	Columbia	2002	J. Correll	Rice
FC23	—	Columbia	2002	J. Correll	Rice
EG85	—	Egypt	1997	J. Correll	Rice
EG174	—	Egypt	1997	J. Correll	Rice
IN24	—	India	1999	J. Correll	Rice
IN46	—	India	1999	J. Correll	Rice
RP9	—	The Philippines	1997	J. Correll	Rice
RP44	—	The Philippines	1997	J. Correll	Rice
75A1	IB-1	U.S.	1975	T. Marchetti	Rice
75A13	IG-1	U.S.	1975	T. Marchetti	Rice
75A19	IH-1	U.S.	1975	T. Marchetti	Rice
75A41	IH-1	U.S.	1975	T. Marchetti	Rice
75A43	IG-1	U.S.	1975	T. Marchetti	Rice
75A49	IG-1	U.S.	1975	T. Marchetti	Rice
75A53	ID-13	U.S.	1975	T. Marchetti	Rice
75L2	IH-1	U.S.	1975	T. Marchetti	Rice
75L26	IB-1	U.S.	1975	T. Marchetti	Rice
75L42	IG-1	U.S.	1975	T. Marchetti	Rice
75T51	ID-13	U.S.	1975	T. Marchetti	Rice
75T56	IC-17	U.S.	1975	T. Marchetti	Rice
76T51	IC-17	U.S.	1976	T. Marchetti	Rice
79A2	IE-1	U.S.	1979	T. Marchetti	Rice
79A4	IE-1	U.S.	1979	T. Marchetti	Rice
80F1	IC-17	U.S.	1980	T. Marchetti	Rice
81F1	IC-17	U.S.	1981	T. Marchetti	Rice
81F2	IC-17	U.S.	1981	T. Marchetti	Rice
81F3	IB-49	U.S.	1981	T. Marchetti	Rice
81L14	IB-1	U.S.	1981	T. Marchetti	Rice
81L19	IB-1	U.S.	1981	T. Marchetti	Rice
81T4	N/A	U.S.	1981	T. Marchetti	Crabgrass
82T14	IB-45	U.S.	1982	T. Marchetti	Rice
85A12	IG-1	U.S.	1985	T. Marchetti	Rice

isolates used in this study.

Disease reactions[b]					*AVR-Pita1* amplicon[c]	Haplotype number[d]
M202	Katy	Drew	K1	Tetep		
—	R	R	—	—	+	38
—	—	—	—	S	+	N/A
—	—	—	—	R	+	5
—	—	—	—	S	+	N/A
—	—	—	—	S	+	N/A
—	—	—	—	S	+	N/A
—	—	—	—	R	+	1
S	R	R	—	—	+	38
—	—	—	R	—	+	9
—	—	—	R	—	+	9
—	—	—	R	—	+	9
—	—	—	R	—	+	9
—	—	—	R	—	+	9
—	—	—	R	—	+	9
—	—	—	R	—	+	38
—	—	—	R	—	+	38
—	—	—	R	—	+	9
S	R	R	—	—	+	38
S	R	R	—	—	+	30
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	32
S	R	R	—	—	+	33
S	R	R	—	—	+	31
S	R	R	—	—	+	29
S	R	R	—	—	+	1
S	R	R	—	—	+	11
S	R	R	—	—	+	14
S	R	R	—	—	+	5
S	R	R	—	—	+	2
S	R	R	—	—	+	11
S	R	R	—	—	+	5
S	R	R	—	—	+	5
S	R	R	—	—	+	1
S	R	R	—	—	+	5
S	R	R	—	—	+	5
S	R	R	—	—	+	5
S	R	R	—	—	+	14
S	R	R	—	—	+	14
S	R	R	—	—	+	11
S	R	R	—	—	+	2
S	R	R	—	—	+	2
S	R	R	—	—	+	1
S	R	R	—	—	+	24
S	R	R	—	—	+	1
S	R	R	—	—	+	1
R	R	R	—	—	+	18
S	S	S	—	—	-	N/A
S	R	R	—	—	+	11

continued

Table 1. Continued.

Isolate	Race[a]	Origin country	Year	Collector	Host
85F1	IB-49	U.S.	1985	T. Marchetti	Rice
85F15	IC-17	U.S.	1985	T. Marchetti	Rice
85L2	IB-1	U.S.	1985	T. Marchetti	Rice
85M5	IE-1	U.S.	1985	T. Marchetti	Rice
91A37	IB-17	U.S.	1991	T. Marchetti	Rice
91A38	IB-1	U.S.	1991	T. Marchetti	Rice
91A51	IE-1	U.S.	1991	T. Marchetti	Rice
91A55	IE-1	U.S.	1991	T. Marchetti	Rice
91T34	IG-1	U.S.	1991	T. Marchetti	Rice
91T36	IC-17	U.S.	1991	T. Marchetti	Rice
91T59	IC-17	U.S.	1991	T. Marchetti	Rice
92A8	IB-49	U.S.	1992	T. Marchetti	Rice
92M3	IC-17	U.S.	1992	T. Marchetti	Rice
92M6	IC-17	U.S.	1992	T. Marchetti	Rice
92M7	IC-17	U.S.	1992	T. Marchetti	Rice
92M11	IC-17	U.S.	1992	T. Marchetti	Rice
92T5	IC-17	U.S.	1992	T. Marchetti	Rice
93A17	IE-1	U.S.	1993	T. Marchetti	Rice
93A27	IE-1	U.S.	1993	T. Marchetti	Rice
93A29	IC-17	U.S.	1993	T. Marchetti	Rice
93L6	IB-1	U.S.	1993	T. Marchetti	Rice
93L7	IB-1	U.S.	1993	T. Marchetti	Rice
93L29	IB-1	U.S.	1993	T. Marchetti	Rice
93M1	IE-1	U.S.	1993	T. Marchetti	Rice
93M2	IB-49	U.S.	1993	T. Marchetti	Rice
93M4	IB-49	U.S.	1993	T. Marchetti	Rice
93M5	IB-49	U.S.	1993	T. Marchetti	Rice
ZN04	IE-1	U.S.	1995	J. Correll	Rice
ZN07	IE-1	U.S.	1995	J. Correll	Rice
ZN11	IE-1	U.S.	1996	J. Correll	Rice
ZN14	IB-49	U.S.	1996	J. Correll	Rice
ZN19	K	U.S.	1993	J. Correll	Rice
ZN22	ID-1	U.S.	1994	J. Correll	Rice
ZN25	IB-49	U.S.	1995	J. Correll	Rice
ZN26	IE-1	U.S.	1996	J. Correll	Rice
ZN27	IC-17	U.S.	1996	J. Correll	Rice
ZN28	ID-1	U.S.	1996	J. Correll	Rice
ZN30	IB-49	U.S.	1994	J. Correll	Rice
ZN32	IA-17	U.S.	1994	J. Correll	Rice
ZN34	IB-1	U.S.	1994	J. Correll	Rice
ZN35	IB-17	U.S.	1996	J. Correll	Rice
ZN36	IE-1	U.S.	1996	J. Correll	Rice
ZN39	IG-1	U.S.	1996	J. Correll	Rice
ZN41	IE-1	U.S.	1995	J. Correll	Rice
ZN42	ID-1	U.S.	1995	J. Correll	Rice
ZN44	IC-1	U.S.	1995	J. Correll	Rice
ZN49	IE-1	U.S.	1995	J. Correll	Rice
ZN57	IC-17	U.S.	1992	J. Correll	Rice
ZN61	IB-49	U.S.	1992	J. Correll	Rice

Disease reactions[b]					*AVR-Pita1* amplicon[c]	Haplotype number[d]
M202	Katy	Drew	K1	Tetep		
S	R	R	—	—	+	20
S	R	R	—	—	+	2
S	R	R	—	—	+	1
S	R	R	—	—	+	7
S	R	R	—	—	+	1
S	R	R	—	—	+	1
S	R	R	—	—	+	11
S	R	R	—	—	+	21
S	R	R	—	—	+	24
S	R	R	—	—	+	20
S	R	R	—	—	+	13
S	R	R	—	—	+	23
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	2
S	R	R	—	—	+	22
S	R	R	—	—	+	2
S	R	R	—	—	+	2
S	R	R	—	—	+	27
S	R	R	—	—	+	1
S	R	R	—	—	+	36
S	R	R	—	—	+	11
S	R	R	—	—	+	22
S	R	R	—	—	+	22
S	R	R	—	—	+	22
S	R	R	—	—	+	20
S	R	R	—	—	+	11
S	R	R	—	—	+	12
S	R	R	—	—	+	14
S	S	S	—	—	-	N/A
S	R	R	—	—	+	1
S	R	R	—	—	+	26
S	R	R	—	—	+	5
S	R	R	—	—	+	16
S	R	R	—	—	+	1
S	R	R	—	—	+	5
S	R	R	—	—	+	5
S	R	R	—	—	+	1
S	R	R	—	—	+	5
S	R	R	—	—	+	5
S	R	R	—	—	+	10
S	R	R	—	—	+	3
S	R	R	—	—	+	5
S	R	R	—	—	+	1
S	R	R	—	—	+	4
S	R	R	—	—	+	11
S	R	R	—	—	+	20

continued

Table 1. Continued.

Isolate	Race[a]	Origin country	Year	Collector	Host
ZN62	IB-49	U.S.	1992	J. Correll	Rice
ZN70	IC-17	U.S.	1992	J. Correll	Rice
MGS03	—	U.S.	1992	T. Marchetti	Rice
MGS16	—	U.S.	1992	T. Marchetti	Rice
MGS19	—	U.S.	1992	T. Marchetti	Rice
MGS23	—	U.S.	1992	T. Marchetti	Rice
MGS24	—	U.S.	1992	T. Marchetti	Rice
MGS26	—	U.S.	1992	T. Marchetti	Rice
MGS27	—	U.S.	1992	T. Marchetti	Rice
MGS28	—	U.S.	1992	T. Marchetti	Rice
MGS29	—	U.S.	1992	T. Marchetti	Rice
MGS30	—	U.S.	1992	T. Marchetti	Rice
MGS31	—	U.S.	1992	T. Marchetti	Rice
MGS32	—	U.S.	1992	T. Marchetti	Rice
A119	IB-49	U.S.	1992	J. Correll	Rice
A264	IC-17	U.S.	1993	J. Correll	Rice
A347	IC-17	U.S.	1992	J. Correll	Rice
A598	IB-49	U.S.	1992	J. Correll	Rice
24/1-2	K	U.S.	1992	J. Correll	Rice
K60	IG-1	U.S.	—	J. Correll	Rice
18/IN-13	K	U.S.	1992	J. Correll	Rice
1188S	—	U.S.	2004	J. Correll	Rice
9407/A	—	U.S.	1994	J. Correll	Rice
IE1K	K	U.S.	—	J. Correll	Rice
IB45	IB45	U.S.	—	J. Correll	Rice
18/1-2	K	U.S.	1992	J. Correll	Rice
S-1	K	U.S.	1994	J. Correll	Rice
75A49/3	IG-1	U.S.	1975	J. Correll	Rice
18	IC-17	U.S.	1992	J. Correll	Rice
18/1	IC-17	U.S.	1992	J. Correll	Rice
24/1	IG-1	U.S.	1992	J. Correll	Rice
25	IC-17	U.S.	1992	J. Correll	Rice
25/104	IC-17	U.S.	1992	J. Correll	Rice
60	IC-17	U.S.	1992	J. Correll	Rice
60/1	IC-17	U.S.	1992	J. Correll	Rice
1188R	IG-1	U.S.	2004	J. Correll	Rice
TM2	K	U.S.	2004	J. Correll	Rice
IB1	IB-1	U.S.	2001	J. Correll	Rice
IE1	IE-1	U.S.	2001	J. Correll	Rice
IB54	IB-54	U.S.	2001	J. Correll	Rice
IH1	IH-1	U.S.	2001	J. Correll	Rice
RUR2	—	U.S.	2000	J. Correll	Rice
NE5	—	U.S.	2001	J. Correll	Rice
MF10	—	U.S.	2002	J. Correll	Rice
RH1	—	U.S.	2003	J. Correll	Rice
DP53	—	U.S.	2003	J. Correll	Rice
49D	IB-49	U.S.	1985	J. Correll	Rice
LeR2	—	U.S.	2000	J. Correll	Rice
31V-02	N/A	U.S.	2001	J. Correll	Crabgrass

Disease reactions[b]					*AVR-Pita1* amplicon[c]	Haplotype number[d]
M202	Katy	Drew	K1	Tetep		
S	R	R	—	—	+	28
S	R	R	—	—	+	20
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	R	R	—	—	+	15
S	R	R	—	—	+	11
S	R	R	—	—	+	1
S	R	R	—	—	+	1
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	9
S	R	R	—	—	+	9
S	R	R	—	—	+	1
S	S	S	—	—	-	N/A
S	R	R	—	—	+	1
S	R	R	—	—	+	27
S	R	R	—	—	+	8
S	R	R	—	—	+	1
S	R	R	—	—	+	14
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	8
S	R	R	—	—	+	14
R	R	R	—	—	+	18

continued

Table 1. Continued.

Isolate	Race[a]	Origin country	Year	Collector	Host
X25	N/A	U.S.	2000	J. Correll	Crabgrass
X54	N/A	U.S.	2000	J. Correll	Crabgrass
B1	K	U.S.	2004	F.N. Lee	Rice
B2	K	U.S.	2004	F.N. Lee	Rice
B3	K	U.S.	2004	F.N. Lee	Rice
B4	K	U.S.	2004	F.N. Lee	Rice
B5	K	U.S.	2004	F.N. Lee	Rice
B6	K	U.S.	2004	F.N. Lee	Rice
B7	K	U.S.	2004	F.N. Lee	Rice
B8	K	U.S.	2004	F.N. Lee	Rice
PTr11	ID-1	U.S.	2007	Y. Jia	Rice
PTr14	IC-11	U.S.	2007	Y. Jia	Rice
PTr16	IA-27	U.S.	2007	Y. Jia	Rice
PTr19	IC-13	U.S.	2007	Y. Jia	Rice
PTr24	IA-1	U.S.	2007	Y. Jia	Rice
PTr25	IC-17	U.S.	2007	Y. Jia	Rice
Stuttgart 2	ID-13	U.S.	2007	Y. Jia	Rice
Stuttgart 4	IC-17	U.S.	2007	Y. Jia	Rice
Stuttgart 7	IC-17	U.S.	2007	Y. Jia	Rice
Stuttgart 8	IB-45	U.S.	2007	Y. Jia	Rice
Stuttgart 9	IC-17	U.S.	2007	Y. Jia	Rice
Stuttgart10	IA-1	U.S.	2007	Y. Jia	Rice
CG1	N/A	U.S.	2008	Y. Jia	Crabgrass
CG2	N/A	U.S.	2008	Y. Jia	Crabgrass
CG3	N/A	U.S.	2008	Y. Jia	Crabgrass
CG4	N/A	U.S.	2008	Y. Jia	Crabgrass
EF3	IC-17	U.S.	2008	Y. Jia	Rice
SCF1	IC-17	U.S.	2008	Y. Jia	Rice
SCF3	IC-17	U.S.	2008	Y. Jia	Rice
SCF4	IC-18	U.S.	2008	Y. Jia	Rice
SEF1	IB-18	U.S.	2008	Y. Jia	Rice
SEF2	IB-22	U.S.	2008	Y. Jia	Rice
SEF3	IB-1	U.S.	2008	Y. Jia	Rice
SEF4	IB-18	U.S.	2008	Y. Jia	Rice
SEF5	IA-1	U.S.	2008	Y. Jia	Rice
SEF6	IB-22	U.S.	2008	Y. Jia	Rice
SEF8	IB-18	U.S.	2008	Y. Jia	Rice
SEF9	IB-2	U.S.	2008	Y. Jia	Rice
SEF10	IB-2	U.S.	2008	Y. Jia	Rice
SEF11	IB-1	U.S.	2008	Y. Jia	Rice

[a] The race was determined either in the current study or part of previous studies. Race K designates virulence on *Pi-ta*-containing cultivars Katy and Drew. Information on race identity of some foreign isolates was determined by the cooperators using their systems and others are unavailable.

[b] Cultivars Katy, Drew, Tetep, and K1 have the resistant *Pi-ta* allele, M202 has the susceptible *pi-ta* allele. Disease reactions were rated using a rating scale described by Valent et al. (1991). “R” indicates resistance and “S” indicates susceptible. “--” indicates data not available. N/A indicates not applicable.

Disease reactions[b]					*AVR-Pita1* amplicon[c]	Haplotype number[d]
M202	Katy	Drew	K1	Tetep		
R	R	R	—	—	+	19
R	R	R	—	—	+	18
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	S	S	—	—	-	N/A
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	6
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
S	R	R	—	—	+	37
R	R	R	—	—	+	18
R	R	R	—	—	+	18
R	R	R	—	—	+	18
R	R	R	—	—	+	18
S	R	R	—	—	+	14
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	11
S	R	R	—	—	+	14
S	R	R	—	—	+	14
S	R	R	—	—	+	14
S	R	R	—	—	+	7
S	R	R	—	—	+	14
S	R	R	—	—	+	17
S	R	R	—	—	+	5
S	R	R	—	—	+	25
S	R	R	—	—	+	34
S	R	R	—	—	+	35

[c] The presence (+) or absence (-) of a PCR amplicon with *AVR-Pita1* specific primers.

[d] The haplotype group in Fig.1 was determined using the software DnaSP for all avirulent isolates. N/A indicates not applicable.

Table 2. Protein variation among 38 *AVR-Pita1*

Protein[b]	Allele[c]	3	4	[d]	12	59	81	82	87	98	103	118
AVR-Pita1	N/A	F	Y	-	V	S	N	D	R	Q	K	E
A	1	F	Y	L	V	S	S	N	K	Q	N	E
B	2	F	Y	L	V	S	S	D	K	Q	N	Q
C	3,4	F	Y	L	V	S	S	D	K	Q	N	E
D	5,6	F	Y	L	V	S	S	D	K	Q	N	E
E	7	F	Y	L	V	S	S	D	K	Q	N	E
F	8	F	Y	L	V	S	S	N	K	Q	N	E
G	9,10	F	Y	L	V	S	S	D	K	Q	N	Q
H	11	F	Y	L	V	S	S	D	K	Q	N	E
I	12	S	N	L	V	S	S	D	K	Q	N	E
J	13	F	Y	L	G	S	S	D	K	Q	N	E
K	14,16	F	Y	L	V	S	S	D	K	Q	N	E
L	15	F	Y	L	V	S	S	D	K	Q	N	E
M	17	F	Y	L	V	S	S	D	E	Q	N	E
N	18,19	F	Y	L	V	S	S	D	E	Q	N	E
O	20,22,23	F	Y	L	V	S	S	D	K	Q	N	E
P	21	F	Y	L	V	C	S	D	K	Q	N	E
Q	24	F	Y	L	V	S	S	D	K	Q	N	E
R	25	F	Y	L	V	S	N	D	R	Q	K	E
S	26	F	Y	L	V	S	N	D	R	Q	N	E
T	27,28,35	F	Y	L	V	C	N	D	R	Q	K	E
U	29	F	Y	L	V	S	N	D	R	Q	K	E
V	30	F	Y	L	V	S	N	D	R	Q	K	E
W	31	F	Y	L	V	S	N	D	R	Q	K	E
X	32,33	F	Y	L	V	S	N	D	E	R	K	E
Y	34	F	Y	L	V	C	N	D	R	Q	K	E
Z	36,37	F	Y	L	V	C	N	D	R	Q	K	E

[a] Different amino acids: their positions, the letter code used for each. Number indicates a position of amino acid in the *AVR-Pita1* protein (AF207841), and bold letters indicate differences in amino acids in comparison with the *AVR-Pita1* protein. Single alleles and corresponding translated products were indicated by italics. All isolates included in the table were avirulent toward *Pi-ta*-containing cultivars. [Note: F = Phenylalanine, Y = tyrosine, L = leucine, V = valine, C = cysteine, S = serine, N = asparagine, D = aspartic acid, R = arginine, Q = glutamine, K = lysine, E = glutamic acid, G = glycine, I = isoleucine, H = histidine, P = proline].

[b] Groups of *AVR-Pita1* variants based on amino acid sequences.

[c] Groups of *AVR-Pita1* variants based on nucleotide; N/A = not applicable.

[d] Leucine insertion.

[e] Amino acid in the putative protease motif.

alleles in field isolates of *M. oryzae.*[a]

127	135	137	138	154	168	173[e]	187	191	194	197	206
N	G	H	N	P	G	V	K	Y	D	H	K
N	E	H	N	P	G	I	K	C	D	H	R
N	E	H	N	P	G	I	K	C	D	H	R
N	E	H	N	P	G	I	K	C	H	H	R
N	E	H	N	P	G	I	K	C	D	H	R
N	E	H	N	P	G	I	K	Y	D	H	R
N	E	H	N	P	G	I	K	Y	D	H	K
N	E	H	N	P	G	I	K	Y	D	H	K
N	E	H	N	P	G	I	K	Y	D	H	K
N	E	H	N	P	G	I	K	Y	D	P	K
N	E	H	N	P	G	I	K	Y	D	H	K
N	E	H	N	P	G	I	K	C	D	H	K
N	E	H	N	P	G	I	K	C	D	H	K
N	E	H	N	G	G	I	K	Y	D	H	K
D	E	H	S	G	G	V	K	Y	D	H	K
N	G	H	N	P	G	I	K	C	D	H	K
N	G	H	N	P	G	I	K	C	D	H	K
N	G	H	N	P	G	V	K	C	D	H	K
N	G	H	N	P	G	I	K	C	D	H	R
N	G	H	N	P	G	V	K	C	H	H	K
N	G	H	N	P	G	V	K	C	H	H	K
N	G	H	N	P	G	V	K	C	H	H	K
N	G	H	N	P	G	V	K	Y	H	H	K
N	G	H	N	P	V	V	K	Y	H	H	K
N	G	R	N	R	F	V	E	Y	H	H	K
N	G	H	N	P	G	V	K	C	H	H	R
N	G	H	N	P	G	V	K	C	D	H	R

Fig. 1a. A world map showing the collection sites of *M. oryzae* isolates used in this study.

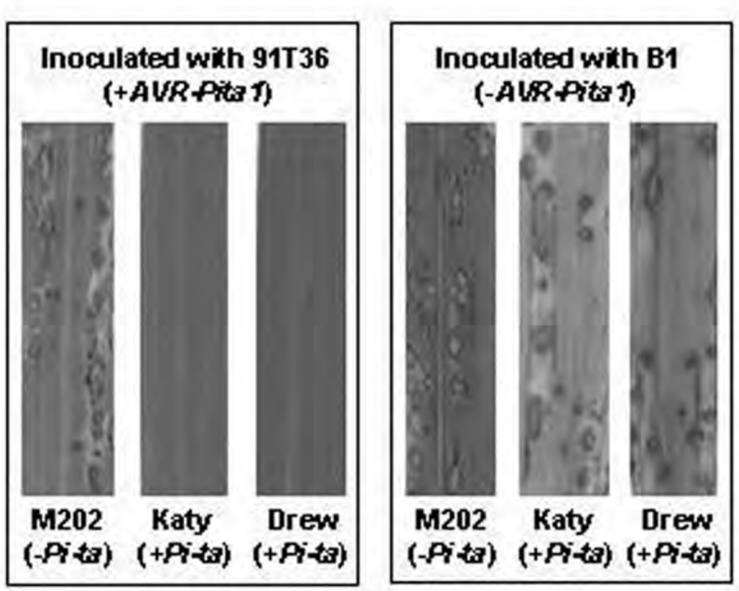


Fig. 1b. Disease reaction of rice cultivars to the U.S. isolates of *M. oryzae*. 1. M202 inoculated with 91T36; 2. Katy inoculated with 91T36; 3. Drew inoculated with 91T36; 4. M202 inoculated with B1; 5. Katy inoculated with B1; 6. Drew inoculated with B1. The pathogen isolates used: isolate 91T36 with *AVR-Pita1* and isolate B1 without *AVR-Pita1*. The cultivars used: Katy and Drew are *Pi-ta*-containing rice cultivars; M202 is a non-*Pi-ta*-containing rice cultivar.

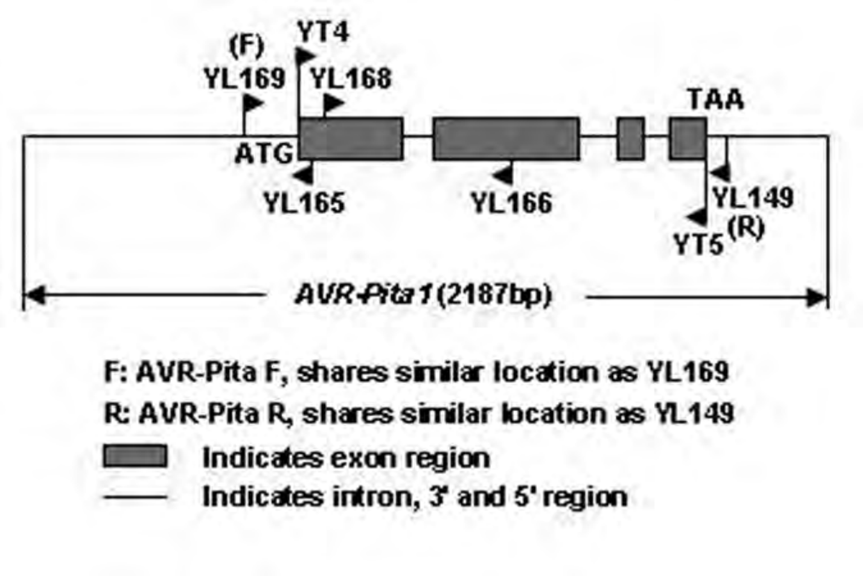


Fig. 1c. A graphic presentation of the *AVR-Pita1* allele showing the location of primers used in this study.

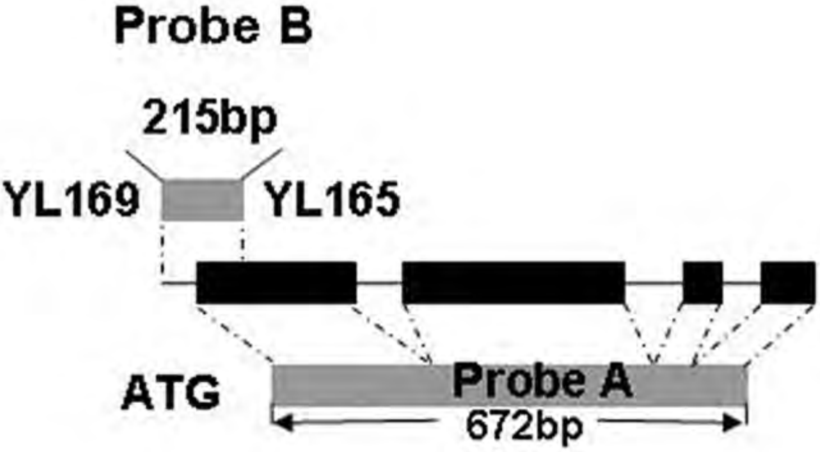


**Fig. 2a. Variation mechanisms of *AVR-Pita1*.
A schematic presentation of *AVR-Pita1* with indicated probes.**

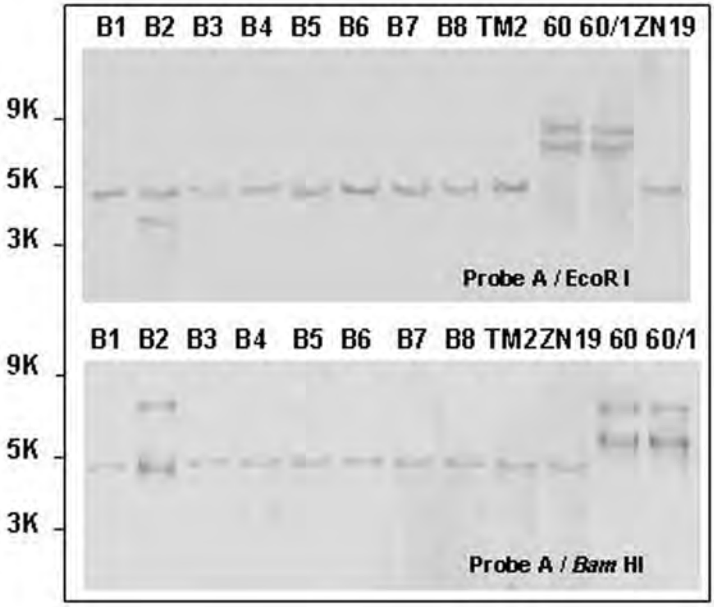


Fig. 2b. Variation mechanisms of *AVR-Pita1*. Genomic DNA was digested with *EcoR* I and *Bam*HI, respectively, and hybridized with the coding region of *AVR-Pita1*.

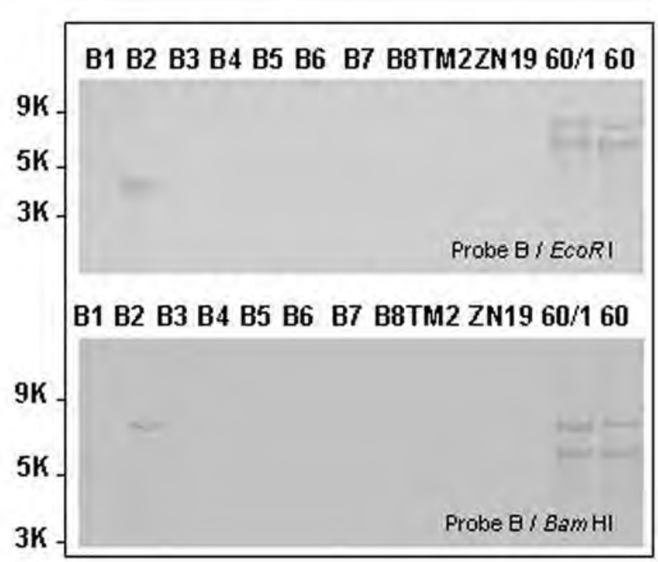


Fig. 2c. Variation mechanisms of *AVR-Pita1*. Genomic DNA was digested with *EcoR* I and *Bam*HI, respectively, and hybridized with the 5' portion of *AVR-Pita1*. Below each blotted membrane is the corresponding photograph showing the genomic DNA loaded.

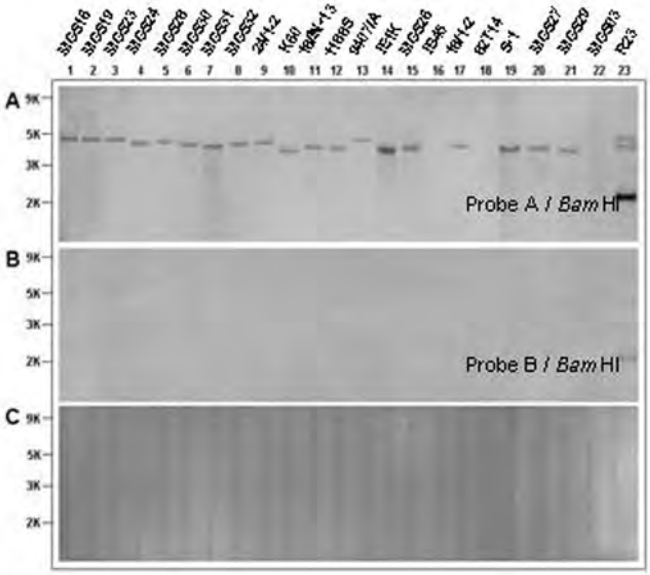


Fig. 2d. Variation mechanisms of *AVR-Pita1*. Genomic DNA of each isolate was digested with *Bam*HI, and hybridized with (1) *AVR-Pita1* coding region and (2) 5'-*AVR-Pita1*, respectively. (3) is the corresponding photograph showing the genomic DNA loaded.

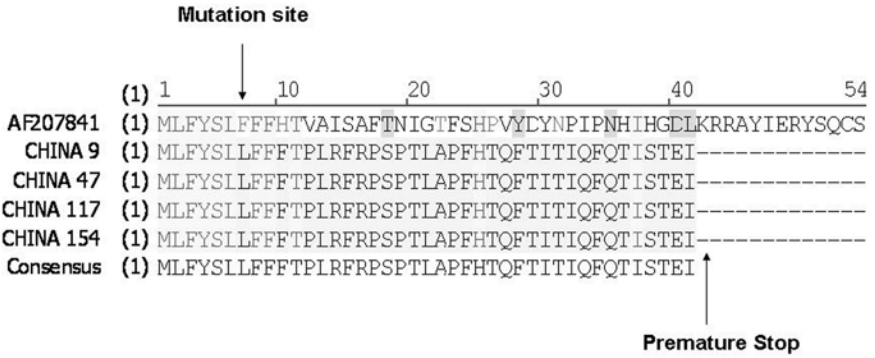


Fig. 2e. Variation mechanisms of *AVR-Pita1*. Alignments of portions of the DNA and amino acid sequences of *AVR-Pita1*. (1) An alignment of the DNA sequences of *AVR-Pita1* of the first exon shows that two-nucleotide insertion results in frame-shift mutation in four virulent isolates (China9, China47, China117, and China154). (2) An alignment of amino acid sequences of *avr-pita1* in four virulent isolates and one avirulent isolate O-137 where *AVR-Pita1* was originally isolated. Frame-shift mutation occurred at the 11th amino acid, which creates a premature stop codon after the 41st amino acid.

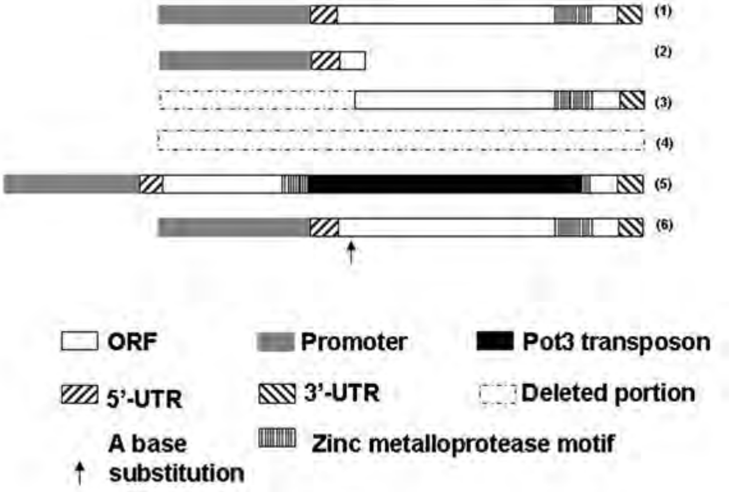


Fig. 2f. Variation mechanisms of *AVR-Pita1*. A schematic presentation of mutation types resulting in loss of function of *AVR-Pita1*. (1) Wild-type *AVR-Pita1*, (2) Frame-shift mutation that occurs in the first exon of *AVR-Pita1* (this study), (3) Deletion of the *AVR-Pita1* 5' region (this study); (4) Complete deletion of *AVR-Pita1* (this study), (5) Point mutation that occurs in the *AVR-Pita1* protease motif (Jia et al., 2000), (6) Pot3 transposon insertion in the coding region corresponding to the *AVR-Pita1* protease motif, (7) Pot3 transposon insertion in the promoter region of *AVR-Pita1*.

BREEDING, GENETICS, AND PHYSIOLOGY

Breeding and Evaluation for Improved Rice Varieties–the Arkansas Rice Breeding and Development Program

K.A.K. Moldenhauer, F.N. Lee, C.E. Wilson Jr., R.D. Cartwright,
Y. Wamishe, R.J. Norman, D.K. Ahrent, M.M. Blocker, V.A. Boyett,
J.M. Bulloch, E. Castaneda, D.L. Frizzell, and D. L. McCarty

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 provides an update of the long- and medium-grain pure line rice breeding effort at the University of Arkansas System Division of Agriculture Cooperative Extension Service.

INTRODUCTION

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

Breeding objectives for improved long-grain 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. Blast resistance has been addressed through research by visiting scholars, graduate students, and by the development and release of the cultivars 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 has been an ongoing concern and the cultivars from this program have had the best sheath blight tolerance of any in the U.S. Rough rice grain yield has become one of the most important characteristic in the last few years and significant yield increases have been realized with the release of the long-grain cultivars LaGrue, Wells, Francis, Banks, Taggart, 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, CIAT, IRRI and WARDA. 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 Dr. Wilson 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

Taggart, which was released in 2009 and originated from the cross LaGrue//Katy/Starbonnet/5/LaGrue//Lemont/Radiated Bonnet 73/3/LaGrue/4/LaGrue (cross no. 20001657), is one of the highest yielding cultivars available to producers. It has the longer and larger kernel size desired by the industry and was available as certified seed in 2011. It has high yield potential yielding 193 bu/acre in the 2009 to 2011 Arkansas Rice Performance Trials (ARPT) (Table 1).

Roy J was released to seed growers in 2010. It originated from the cross LaGrue//Katy/Starbonnet/5/Newbonnet/Katy//Radiated Bonnet 73/Lemont/4/Lebonnet/CI9902/3/Dawn/CI9695//Starbonnet (cross no. 20001692). This line has very high yield potential and excellent lodging resistance It yielded 187 bu/acre in the 2009 to 2011 ARPT compared to Wells and Francis which yielded 178 and 187 bu/acre, respectively (Table 1). It will be available as certified seed for the first time in 2012.

The Clearfield line CL142-AR was released to BASF in 2009 for breeder seed production. CL142-AR was available to producers in 2011 and had a yield of 157 bu/acre compared to CL151 at 158 bu/acre in the 2009 to 2011 ARPT (Table 1).

The experimental line 81081 is a high yielding short-season long-grain line which will be grown as foundation seed in 2012. This line which originated from the cross no. 20001653, has LaGrue, Katy, and Starbonnet in its parentage. During the hot weather of 2010, 81081 yielded 194 bu/acre compared to Francis and Roy J at 184 and 179 bu/acre, respectively, in the ARPT. The three year average of 81081 is 187 bu/acre, equal to Francis and Roy J (Table 1).

A Clearfield experimental line, 07I01-054, has yield and milling similar to CL142-AR. It is shorter and has very good quality (a clearer kernel with less chalk) than CL142-AR and CL151 (Table 1). Several Clearfield lines will be considered for the first time in the ARPT and IMI ARPT in 2012. Many of these lines appear to have good yield potential.

One medium-grain line in the Preliminary Test had very high yield in a single plot and it has been advanced directly into the ARPT for 2012. This line is a semidwarf with good cooking quality and a clear translucent kernel.

Crosses have been made for high yield, improved milling, and disease resistance in various combinations. The F_2 populations from these crosses will be evaluated in 2012 and selections will be grown in the winter nursery during the winter of 2012 to 2013. Currently, we have 8160 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 2012.

Further work is continuing with crosses between Clearfield lines and our better material. New selections are made each year and advanced in the program. In 2011 we had 3690 Clearfield F_3 to F_5 panicle rows at the RREC of which 328 lines will be in the Clearfield Stuttgart Initial Test in 2012.

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. The line 81081 with the stable grain yield in hot years could be the replacement for Wells. Improved lines will continue to be released from this program in the future. They will have the characteristics of improved 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 financial support of the Arkansas rice producers, through monies administered by the Arkansas Rice Research and Promotion Board and their continued interest in the breeding program. Thanks also go to the USDA-ARS for their cooperation, interest and evaluation of materials, and to the other 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 from *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 2009 to 2011 Arkansas Rice Performance Trials for promising experimental lines and check cultivars.

Cultivar	Grain type[a]	Yield[b] 2009	2010	2011	Mean	Height	50% Heading	Chalky kernels[c]	Milling[d]
		---------------------------(bu/acre)		--------------------------		(in.)	(days)	(no.)	(HR:TOT)
Francis	L	183	184	195	187	41	85	0.9	63:70
Wells	L	183	170	182	178	43	87	0.8	59:71
Cheniere	L	161	160	177	166	37	87	0.7	61:69
Templeton	L	170	166	182	173	43	89	0.8	60:69
Taggart	L	183	180	215	193	45	89	0.7	59:69
Roy J	L	187	179	196	187	44	91	0.9	60:69
81081	L	177	194	191	187	43	82	0.9	60:70
XL723	L	188	231	190	203	45	83	2.8	56:69
CL142-AR[e]	L	161	166	146	158	45	85	0.9	53:68
CL181-AR	L	153	151	181	162	35	87	0.6	55:66
CL151	L	155	182	142	160	40	83	0.7	55:66
07I01-054	L	--	157	170	164	40	83	0.5	54:66

[a] Grain type: L = long-grain.

[b] Yield trials in 2009 consisted of six locations, Rice Research and Extension Center, (RREC), Stuttgart, Ark.; Pine Tree Experiment Station, (PTES), Colt, Ark.; Southeast Branch Experiment Station, (SEBES), Rowher, Ark.; Northeast Research and Extension Center, (NEREC), Keiser, Ark.; and Lonoke County Farmer Field, (LC), Lonoke, Ark.; in 2010 the test was conducted at 7 locations RREC, PTES, SEBES, NEREC, LC, Newport Branch Experiment Station, (NBES), Newport, and Clay County Farmer Field, (CC), Corning, Ark.; and in 2011 the successful trials were grown at CC, NBES, and PTES.

[c] Data for chalk is from 2009 to 2010 Riceland data.

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

[e] CL stands for Clearfield lines.

BREEDING, GENETICS, AND PHYSIOLOGY

Expression Profiling of Two Rice (*Oryza sativa*) Genotypes Differing in Chilling Tolerance Using cDNA-Amplified Fragment Length Polymorphism

M.R. Morsy and J.McD. Stewart

ABSTRACT

Abiotic stress is a major limiting factor in crop production. Molecular comparisons between contrasting abiotic stress-tolerant genotypes may improve understanding of stress-tolerance mechanisms and can be used in discovery of stress-tolerance genes. We performed a cDNA Amplified Fragment Length Polymorphism (cDNA-AFLP) analysis on chilling tolerant and sensitive rice genotypes in order to identify genes involved in stress tolerance. Seventy-nine percent of the detected transcripts had similar expression patterns in both genotypes (66% constitutively expressed and 13% differentially expressed), whereas 14% and 7% were uniquely up-regulated and down-regulated, respectively, in the chilling-tolerant genotype. Selected up-regulated gene expression patterns represented by transcript-derived fragments (TDFs) differed in response to stress in the two genotypes as shown by Reverse Transcription Polymerase Chain Reaction (RT-PCR). Gene expression was higher for the vacuolar proton ATPase subunit B (*V-ATPase*) and inoistol 1, 3, 4-trisphosphate 5/6-kinase (*IP3K*) genes in response to chilling in the chilling-tolerant genotype compared to the chilling-sensitive genotype. The response of the chilling-tolerant genotype to chilling stress was complex, representing genes involved in signaling, transcription regulation, defense response, and transport-related proteins. Since the total number of TDFs with changed expression pattern was similar in both genotypes while the levels of expression differed, we hypothesize that both genotypes have the same chilling responsive genes but that the genes differ in the manner in which they are regulated. Further experiments are needed to confirm the role of identified genes in rice cold tolerance.

INTRODUCTION

Unlike other cereal crops, such as wheat, barley, and rye, rice (*Oryza sativa* L.) is not well adapted to cold weather and is damaged by temperatures below 15 °C. During rice development, germination and the 3-lf stage are two of the most sensitive stages to chilling stress. In a previous study, CT6748-8-CA-17 (CT) genotype was found to be more tolerant of chilling temperatures than the INIAP12 genotype (CS) (Morsy et al., 2005).

Cold acclimation reduces chilling injury due to chilling stress and is associated with the expression of a large number of genes involved in different cellular processes (Shinozaki and Yamaguchi-Shinozaki, 2000). While discovery of numerous stress-related functional genes and regulatory elements has increased our knowledge of abiotic stress mechanisms, the molecular basis and regulation of chilling tolerance in rice is not completely understood. Analysis of differentially expressed genes provides an opportunity to improve our understanding and utilization of the chilling-tolerant genotypes in rice by integration of these genes through conventional breeding or biotechnological means.

Identification and isolation of low abundant differentially expressed genes is a challenging process; however, cDNA-AFLP is an efficient and reproducible method to identify and isolate such transcripts (Bachem et al., 1998), especially those with low transcript abundance. We used cDNA-AFLP to identify genes with potentially important roles in tolerance to low temperature stress and also used semi-quantitative RT-PCR to identify differences in genotypic gene expression of selected candidate genes. Ultimately, molecular identification of stress-related responses of rice genotypes will provide candidate genes for use in breeding programs or transgenic technology.

PROCEDURES

Biological Material and Treatments

The chilling-tolerant genotype, CT6748-8-CA-17 (CT), and the chilling-sensitive genotype, INIAP12 (CS), of *Oryza sativa* L. (Morsy et al., 2005) were used in this study. Three replicates of each genotype (5 plants each) for each treatment and control were grown in soil pots in a growth chamber under a 12 h photoperiod (30/27 °C; day/night, 600 mE/m^2/sec) regime and 70% relative humidity until the 3-lf stage. Seedlings grown at control conditions were moved to hydroponic media (1X Hoagland's solution), kept at control conditions for 2 days and subsequently all but the control pots were subjected to either low temperature (13/10 °C; day/night), osmotic (Hoagland's solution plus 250 mM mannitol), or salt (Hoagland's solution plus 100 mM NaCl) stress treatments for 4 days. After treatment, shoots were collected and frozen in liquid nitrogen for RNA extraction.

RNA Extraction, cDNA Synthesis, and Amplified Fragment Length Polymorphism Analysis

Total RNA was extracted with an RNeasy kit (Qiagen, Germantown, Md.), followed by isolation of mRNA using PolyATract mRNA isolation system III (Promega, Madison, Wis.) following the manufacturers' protocols. Then, 500 ng of mRNA of control and chilling-stressed seedlings were each reverse transcribed into cDNA with an oligo-dT primer and 200 units of Moloney Murine Leukemia Virus Reverse Transcriptase (MMLV-RT) in the presence of RNase inhibitor (10 units). The 'AFLP Analysis System II' kit (Invitrogen, Carlsbad, Calif.) was used following the instructions of the manufacturer to generate an AFLP fingerprint. The Polymerase Chain Reaction (PCR) products representing both genotypes under control and chilling conditions were separated on a denaturing 5% polyacrylamide gel and stained using Silver Sequence Staining Reagents (Promega) following the manufacturer's protocol.

Characterization of Transcript-Derived Fragments

Clearly visible bands representing differentially regulated gene transcripts were excised from the gel with a clean scalpel and eluted into 100 µl of 50 mM KCl, 10 mM Tris-HCl, 0.1% Triton X-100, and 1.5 mM $MgCl_2$ by heating for 30 min at 90 °C. An aliquot of 1 ml of each eluted DNA was used as template for PCR with 2 pmol each of *Eco*RI-core and *Mse*I-core primers. The PCR products were purified with a QIAquick PCR purification kit (Qiagen), cloned in pCR2.1 vector (Invitrogen), and then sequenced using T3 promoter primer. Nucleotide sequences and derived amino acid sequences were compared with nucleotide and protein sequences of the GenBank databases with the BLAST sequence alignment program.

Semi-Quantitative Reverse Transcription Polymerase Chain Reaction

Semi-quantitative RT-PCR was used to compare the expression levels of differentially expressed genes in response to different abiotic stresses in seedlings of the CT and CS genotypes. Equal amounts of mRNAs were converted into cDNA with a RETROscript kit (Ambion, Austin, Texas) with oligo-dT primer according to the manufacturer's recommendations. Equal amounts (1 ml) of the first strand cDNA were used as templates for PCR amplification using specific primers designed for each clone (Table 1) and repeated 3 times. The RT-PCR products were resolved by electrophoresis through 1.2% agarose-ethidium bromide gels. Expression of the constitutively expressed actin gene was used as the positive control.

RESULTS

Identification of Chilling-Regulated Transcripts

Changes in gene expression within genotypes in response to chilling stress were resolved by the cDNA-AFLP analysis showing 540 bands. Among these bands 66% and 13% were constitutively and differentially expressed, respectively, in both genotypes following chilling stress. Also, 14% and 7% showed increased and decreased abundance, respectively, of mRNA in the chilling-tolerant genotype only (Fig. 1). Subsequent effort was focused on isolation and cloning of the transcript-derived fragments (TDFs) with increased mRNA abundance from the CT genotype. Sequence homology searches for successfully cloned TDFs (65% of total 75 isolated and cloned TDFs) showed similarities with sequences of genes with both known and unknown functions. Isolated genes with increased mRNA abundance were grouped into categories according to their putative or known functions (Table 2).

Expression Analyses of Selected Transcript-Derived Fragments

Semi-quantitative RT-PCR was performed on the two genotypes to confirm the differential expression of four TDFs with increased mRNA abundance under different stresses (Fig. 2). In agreement with cDNA-AFLP results, expression of the *MADS* box gene in CT was relatively higher than in CS in response to stresses. The *V-ATPase* transcript, which plays an important role in maintaining cell solute homeostasis, increased in response to low temperature, osmotic and salt stresses in the CT genotype. However, its expression in CS was higher than in CT in response to salt stress. On the other hand, clone (AA-CAG) with similarity to 20S proteasome was down-regulated by low temperature and water deficit in the CT genotype, while it was moderately induced by salt in CS and down-regulated in CT. The TDF (AG-CAT11) transcript which encodes to *IP3K* gene was induced by water deficit and salt stress in both CS and CT genotypes, but low temperature stress induced expression of *IP3K* was observed only in the CT genotype.

DISCUSSION

The expression profile obtained by cDNA-AFLP matched the overall changes in gene expression obtained by more global methods applied to *Arabidopsis* and rice (Seki et al., 2001; Rabbani et al., 2003). In this regard, the percentage distribution of genes with altered expression among the general categories was similar with both techniques despite the fact that fewer genes were obtained by cDNA-AFLP (Table 2).

We characterized the expression of four clones, selected for different cellular functions, in response to various abiotic stresses by RT-PCR. For the 20S proteasome gene, the up-regulation of expression by chilling stress revealed by cDNA-AFLP, was not supported by RT-PCR. The difference in expression profile detected by the two techniques might be due to differences among primers and PCR conditions or due to amplification of different isogenes. In the case of the other 3 TDFs (*IP3K*, *MADS* box and *V-ATPase*), their up-regulation in response to different abiotic stresses was confirmed. However, their response differed between the CT and CS genotypes, where the later genotype showed higher expression in response to salt stress than the former genotype. The differential response between the genotypes indicated that the mechanisms regulating gene expression may differ between the two.

SIGNIFICANCE OF FINDINGS

Expression profiles of chilling-responsive genes in rice genotypes contrasting in chilling tolerance showed notable differences in response to chilling. The general trend in gene expression was similar in both genotypes but they differed in the level of expression of specific critical genes. These results suggest that both genotypes probably have the same stress-responsive genes, but that the regulation of these genes differs between genotypes. The difference in regulation may be related to differences in the levels of signaling molecules, such as inositol, or to the activity of transcription factors and to the promoter motifs present in the genotypes. This latter suggestion could be verified only by promoter sequence analyses of the genes present in each genotype. Understanding the critical differences in molecular responses of contrasting genotypes will be helpful in gene selection to improve stress tolerance of crops by gene manipulation or by marker-assisted breeding methods.

ACKNOWLEDGMENTS

The authors would like to thank the Rice Research and Promotion Board for their financial support of the research and publication.

LITERATURE CITED

Bachem, C.W.B., R.J.F.J. Oomen, and R.G.F. Visser. 1998. Transcript imaging with cDNA-AFLP: A step-by-step protocol. Plant Mol. Biol. Rep 16:157-173.

Morsy, M., M.A. Almutairi, J. Gibbons, Y.S. Joon, and B.G. De los Reyes. 2005. The OsLti6 genes encoding low molecular weight membrane proteins are differentially expressed in rice cultivars with contrasting sensitivity to low temperature. Gene 344:171-180.

Rabbani, M., K. Maruyama, H. Abe, M.A. Khan, K. Katsura, Y. Ito, K. Yoshiwara, M. Seki, K. Shinozaki, and K. Yamaguchi-Shinozaki. 2003. Monitoring expression profiles of rice genes under cold, drought, and high-salinity stresses and abscisic acid application using cDNA microarray and RNA gel-blot analyses. Plant Physiol. 133:1755-1767.

Seki, M., M. Narusaka, H. Abe, M. Kasuga, K. Yamaguchi-Shinozaki, P. Carninci, Y. Hayashizaki, and K. Shinozaki. 2001. Monitoring the expression pattern of 1300 Arabidopsis genes under drought and cold stresses using a full-length cDNA microarray. Plant Cell 13:61-72.

Shinozaki, K. and K. Yamaguchi-Shinozaki. 2000. Molecular responses to dehydration and low temperature: differences and cross-talk between two stress signaling pathways. Curr. Opin. Plant Biol. 3:217-223.

Table 1. Polymerase Chain Reaction primers used to validate mRNA expression patterns of selected chilling-regulated transcript-derived fragments isolated by cDNA-AFLP techniques from rice.

Gene	Forward primer	Reverse primer
MADS box-like protein	aacgctgcaaaagacgcat	atcccagatatcaccagctga
Inositol 1, 3, 4-trisphosphate 5/6-kinase (IP3K)	tgctacacaaaataactgatg	taaaaagcatggtgctcg
V-ATPase	ttgacggtgaaaaggctgtt	agcagcagaaaagaggggaat
a2-20S proteasome	gaggtgccttctatttta	tgtctccaatgcaaagac
Actin	caaggccaatcgtgagaag	agcaatgccagggaacatagt

Table 2. Relevant homologies of up-regulated cDNA-AFLP sequence fragments of rice to sequences in the database.

No. of TDFs[a]	Putative function/homology	GenBank accession no.	e-value
Stress-related (35.4%)			
6	Paraneoplastic encephalomyelitis antigen	CX056242	1.00E-18
3	Non-cyanogenic beta-glucosidase precursor	CX056238	2.00E-29
2	Similar to Metallothionein-like protein type 3	CX056273	2.00E-23
1	20S proteasome alpha subunit B	CX056269	1.00E-65
1	RING-H2 finger protein ATL3F	CX056281	1.00E-27
1	Similar to Catalase isozyme 2	CX056280	6.00E-22
1	NADH-ubiquinone oxidoreductase B18	CX056279	2.00E-47
1	Floral organ regulator 1	CX056266	2.00E-53
1	snRNP protein	CX056258	4.00E-50
Transport (18.7%)			
3	Similar to Vacuolar ATP synthase subunit E	CX056274	8.00E-14
2	Similar to Peroxisomal ABC transporter	CX056246	7.00E-23
2	Antiporter/ drug transporter	CX056259	1.00E-60
1	Vacuolar ATPase B subunit	CX056276	1.00E-58
1	Similar to Peptide transporter 1	CX056278	2.00E-67
Biosynthetic pocesses (16.7%)			
3	Similar to Eukaryotic initiation factor 4A-3	CX056253	3.00E-43
2	Heat shock protein DnaJ family protein	CX056247	4.00E-38
1	Similar to Mannose-1-phosphate guanyltransferase	CX056264	3.00E-76
1	Peptidyl-prolyl isomerase FKBP12	CX056268	5.00E-56
1	Eukaryotic translation initiation factor 2 gamma subunit	CX056243	5.00E-32
Signaling and transcription (14.6%)			
2	Inositol 1, 3, 4-trisphosphate 56-kinase family protein	CX056249	2.00E-27
2	Pyruvate kinase	CX056261	1.00E-19
1	Similar to Transcription factor MADS55	CX056267	2.00E-16
1	BHLH transcription factor	CX056270	2.00E-21
1	Transcription factor Dp-1	CX056257	9.00E-14
Unknown function (14.6%)			
1	ATP-dependent RNA helicase-like protein DB10	CX056245	5.00E-42
1	Conserved hypothetical protein	CX056277	5.00E-20
1	Hypothetical protein	CX056272	2.00E-22
1	Similar to RNA-binding protein BRUNOL5	CX056234	2.00E-09
1	Conserved hypothetical protein	CX056250	1.00E-05
1	Retrotransposon protein, Ty3-gypsy subclass	CX056236	5.00E-20
1	Retrotransposon protein, unclassified	CX056251	5.00E-05

[a] TDFs = transcript-derived fragments.

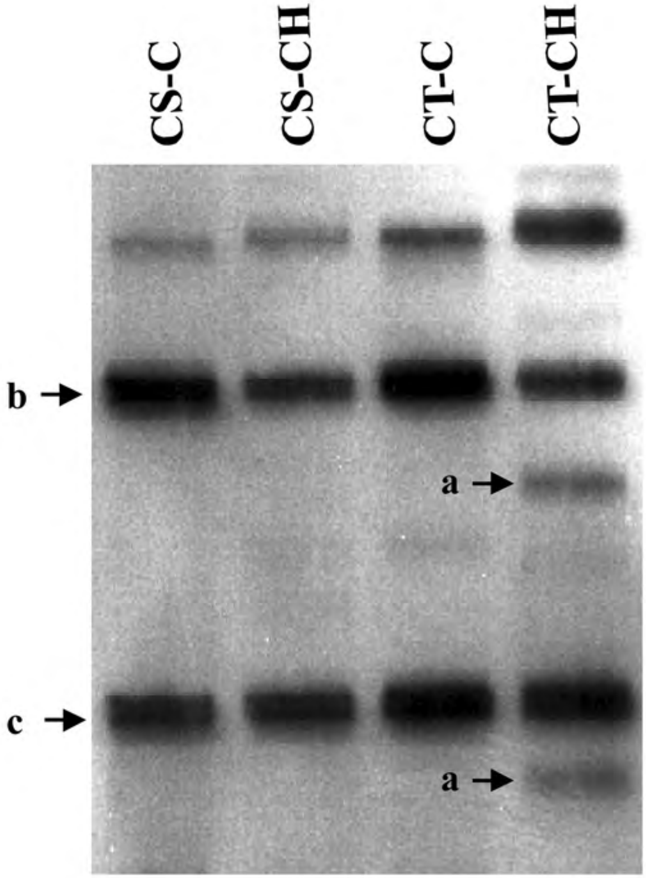


Fig. 1. Representative pattern of the cDNA-AFLP displays changes in gene expression of chilling-tolerant (CT) and chilling-sensitive (CS) genotypes in response to chilling stress (CH) compared to control plants (C). (a) Transcripts induced only in CT genotype, (b) Transcripts repressed in both genotypes, (c) Transcripts constitutively expressed in both genotypes.

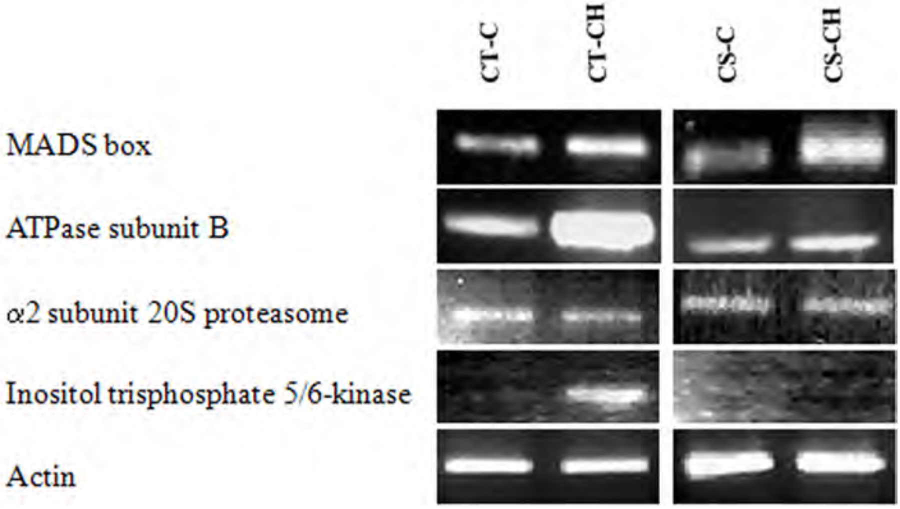


Fig. 2. RNA blot analysis for differentially expressed Transcript-Derived Fragments identified by comparing the chilling tolerant (CT) and chilling-sensitive (CS) genotypes under chilling stress (CH) against control (C) conditions. The actin gene was used as positive control for RNA loading.

BREEDING, GENETICS, AND PHYSIOLOGY

Hybrid Rice Breeding

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

ABSTRACT

Breeding lines developed in 2010 were tested in various hybrid combinations in 2011 for yield and for seed production. Replicated and single plot tests of various 2-line and 3-line combinations were evaluated at the Rice Research and Extension Center (RREC) for grain yield, plant type, heading date, and other traits related to general agronomic performance. Grain was evaluated for milling quality and will be quantified for amylose and alkalai spread. Hybrid seed production was evaluated for 6 male-sterile lines and 6 restorers.

INTRODUCTION

In 2010, accessions from diverse worldwide locations were used to develop male-sterile, restorer, and maintainer lines for 2-line and 3-line hybrids. Evaluation of potential breeding lines requires testing various combinations as F_1 hybrids for yield and the complete array of traits necessary for a rice variety to be commercially acceptable. In addition, potential parent lines must be tested for seed production, which requires evaluating isolation, planting schemes, synchronization of flowering, and pollen distribution, etc.

PROCEDURE

Yield Tests

Yield was evaluated in 2 tests, one with 3 replications, and another with single plots. In the replicated test, 21 2-line hybrids and 5 3-line hybrids were evaluated against Wells, Francis, Cybonnet, and CL 171AR as checks. Plots were drilled on 5 May. Seeds were planted in 6-row plots, 3-m long and 1.5-m wide. In the single plot test, 64 hybrids, 27 restorers, and the check varieties Wells, Francis, and CL171AR were planted in plots of the same size and conformation as the replicated test.

Hybrid Seed Production

Seed production was tested in 2 locations chosen for maximum isolation from other rice to reduce the chance of pollen contamination. Site 1 (Woods) contained 4 bays, with each bay planted with a different restorer: 190R, 376R, 378R, and 385R. Restorers were drilled on 15 April in single rows, 3 m apart, and 10 m long. Between the restorer rows, male sterile lines were transplanted on 30 May and water-seeded on 14 June. The male-sterile lines were 873A, 799s, 800s, 805s, 811s, and 810s. At Site 2 (Field), tests were planted with the same methods, distances, and male-sterile lines. However, only 2 bays were planted, one for restorer 190R and the second for 376R. Restorers were planted on 7 May, and the male-sterile lines were transplanted on 30 May and water-seeded on 14 June. 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, so all comparisons are made with that check. Twenty of the hybrids had yields greater than Francis. Of these, 12 had yields exceeding that of Francis by 20% or more. Based on these observations, several parent lines will be tested in new and repeated combinations in 2012. Only four hybrids had yields less than Francis. Of these, 3 were hybrids with restorer 181R as the male parent. Though those combinations did not perform well, 181R does show promise in other combinations.

In the single plot test, Francis was again the check with the greatest yield. Fifty-two of the hybrid combinations had grain yield equal to or greater than Francis. After consideration of all traits including plant height, heading date, pubescence, etc., some of these hybrids will go on for replicated testing in 2012.

Seed Production

Getting the parent lines synchronized for heading was a challenge, but planting at different dates and by both water-seeding and transplanting, some seed production was quite respectable. In the Field site, birds ate a lot of the male-sterile seed that was water-seeded. A deeper flood will need to be maintained. Restorer 190R was far superior to 376R in successful pollination of the 6 male sterile lines. Seed yields ranged from 253 kg/ha to 2763 kg/ha for the various combinations of restorer 190R.

In the Woods site, seed production was much greater. This was due in part to less bird damage. Seed yields ranged from 160 kg/ha to 1504 kg/ha. Transplanting gave the best stands for the male-sterile lines, but proper depth after water-seeding should improve stands as well.

SIGNIFICANCE OF FINDINGS

As very preliminary evaluations of selected hybrids for both yield and seed production, tests in 2012 were very informative. Selected hybrids will be tested in replicated, multi-location tests in 2012. 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 producer check-off monies administered by the Rice Research and Promotion Board.

Rice Genotype Response to Fungicide and Insecticide Seed Treatments

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. In 2011, seven trials at three locations examined the efficacy of seed treatment chemistries and genotypes in improving stand establishment. The study included seven genotypes which differed in their cold tolerance and resistance to seedling disease caused by *Pythium* spp. The seed from each genotype received no treatment or the seed treatments Allegiance (metalaxyl), Allegiance + Cruiser (thiamethoxam), or Allegiance + Cruiser + Dynasty (azoxystrobin). The plant stand for Kaybonnet was increased by seed treatments for each of the five trials having a response. The cultivar Templeton and two genotypes (PI560243 and RU0701124) which have previously shown some *Pythium* spp. resistance responded to fungicides with increased plant stands in one of the five trials. The genotypes PI560247, PI560281, and STG05F5-03-088, which have demonstrated some resistance to *Pythium* spp., did not respond to fungicide seed treatment. The fungicide Allegiance provided similar control to the combination fungicide treatments Allegiance + Cruiser and Allegiance + Cruiser + Dynasty. The fungicide metalaxyl has activity only against oomycetes indicating that *Pythium* spp. are the primary seedling pathogens causing stand losses of rice in Arkansas. Stand improvement from fungicides was greater for earlier planting dates compared to the final planting date for a location. Root scanning data demonstrated that for the susceptible cultivar, Kaybonnet, Allegiance was effective in improving root growth and development compared to no seed treatment. The research demonstrates that fungicide seed treatments or *Pythium*-resistant cultivars improve rice stand establishment.

INTRODUCTION

Pythium spp. are the most common seedling disease pathogens isolated from rice in producers' fields in Arkansas. These pathogens can cause seed rot and death of seedlings before or after emergence and may reduce vigor of surviving seedlings. *P. arrhenomanes* and *P. irregulare* are the most important *Pythium* seedling pathogens on rice (Cother and Gilbert, 1993; Eberle et al., 2008). Seed treatment fungicides, including metalaxyl and mefenoxam, that have activity against this group of pathogens are effective in increasing stands under cool soil temperatures and wet soils which favor *Pythium* seed and root rot. Research funded by the Rice Research and Promotion Board also has identified cold-tolerant *Pythium*-resistant rice genotypes that hold the promise for more reliable stand establishment for marginal planting environments in Arkansas rice fields (Rothrock et al., 2006, 2010).

This research examined the value of fungicide and insecticide seed treatments and genotypes on stand establishment and seedling root development over a range of planting environments.

PROCEDURES

Seven trials were conducted at three locations in Arkansas in 2011. Planting dates ranged from 21 March to 11 May. The trial locations were Pine Tree Branch Experiment Station (Colt), Northeast Research and Extension Center (Keiser), and Rice Research and Extension Center (Stuttgart) representing the White River, Delta, and Grand Prairie ecosystems, respectively. The trials evaluated seven genotypes (Kaybonnet, PI560243, PI560247, PI560281, RU0701124, STG05F5-03-088, and Templeton) which differed in their resistance to seedling disease caused by *Pythium* spp. Each genotype had no seed treatment or the seed treatments Allegiance (metalaxyl), Allegiance + Cruiser (thiamethoxam), or Allegiance + Cruiser + Dynasty (azoxystrobin). Each test was a split-plot design with genotype as the main plot and fungicide treatment as the subplot. Stand counts for each plot were the mean of three 1-m row counts. Analyses included stand and relative stand between the seed treatment and non-treated seed treatment.

In 2011, the effects of fungicide seed treatment on seedling growth also were examined for Kaybonnet, PI560281, RU0701124, and STG05F5-03-088. From the second planting date at Stuttgart (7 April), 15 to 20 seedlings were dug from each plot of selected genotypes. Rice seedlings were washed for 20 min in running tap water and roots and coleoptiles were assessed for disease. Root systems of seedlings were scanned using the WinRHIZO system (Regent Instruments Inc., Canada) for root length and volume. In addition, the WinRHIZO software characterized the root architecture including root tips and branching patterns; forks, links, link length, and altitude. Root parameters were averaged for each plot and analyzed by GLM using SAS (SAS Institute, Cary, N.C.). Treatment means for sites having a significant F-test were separated by using a protected LSD, $P = 0.05$.

RESULTS AND DISCUSSION

Minimal soil temperatures at 10 cm (4 in.) the first 3 days after planting for the trials ranged from 11 °C to 21 °C (51 °F to 70 °F) with a mean temperature of 14 °C to 24 °C (58 °F to 75 °F). One or more seed treatments increased stands for one or more genotypes for five of the seven trials (Table 1). The plant stand for Kaybonnet was increased by fungicide seed treatments in each of the five trials having a response. The cultivar Templeton and two genotypes (PI560243 and RU0701124) which have previously shown some *Pythium* spp. resistance responded to fungicides with increased plant stands in one of the five trials. The genotypes PI560247, PI560281, and STG05F5-03-088, which have also demonstrated some resistance to *Pythium* spp., did not respond to fungicide seed treatments. The fungicide Allegiance provided similar control to the combination fungicide treatments Allegiance + Cruiser and Allegiance + Cruiser + Dynasty. When differences among seed treatments were found Allegiance + Cruiser + Dynasty increased stands compared to Allegiance alone in two of eight comparisons and in one of eight comparisons Allegiance increased stands compared to Allegiance + Cruiser + Dynasty. There was no response observed when Cruiser was added to Allegiance. The fungicide metalaxyl (Allegiance) has activity only against oomycetes indicating that *Pythium* spp. are the primary seedling pathogens causing stand losses of rice in Arkansas. In addition, the frequency of fungicide response suggests that seedling diseases were common and reduced stands in 2011. Stand improvement from fungicides was greater for earlier planting dates compared to the final planting date for a location. Several genotypes did not have a response to fungicides suggesting greater resistance to *Pythium* seed and root rot than currently grown cultivars.

Root scanning technology demonstrated that for the susceptible cultivar, Kaybonnet, Allegiance was effective in improving root development, while Allegiance had little to no effect on root growth for *Pythium* resistant genotypes (Table 2). For example, relative root length and volume and number of root branches, forks, were increased on seedlings from Allegiance-treated seed compared to non-treated seed for Kaybonnet. This difference was significant for root forks compared to the two genotypes considered resistant which were close to 1 for the relative response. Root tips did not differ among genotypes and seemed to be increased for seedlings from Allegiance-treated seed. When root topology was examined, the relative number of links (individual root segments) and altitude (the largest path length, link total, to the base of the plant) for Kaybonnet were increased with Allegiance treatment compared to the other two genotypes, while relative link length was decreased by Allegiance treatment for Kaybonnet, indicating increased branching as indicated by number of root forks. This data suggest surviving rice seedlings treated with Allegiance have improved root system health in addition to seed treatment fungicides protecting the seed and emerging seedling.

SIGNIFICANCE OF FINDINGS

This research suggests seedling diseases are a common cause of stand establishment problems in Arkansas and fungicide seed treatment or *Pythium*-resistant cultivars hold the promise for more reliable stand establishment for rice. Fungicide seed treatments are an effective option for managing seedling diseases. In addition, this data suggest surviving rice seedlings treated with Allegiance have improved root health with a larger root system and increased root branching to explore more soil and allow greater water and mineral absorption. *Pythium*-resistant genotypes were demonstrated to be as effective as seed treatments in preventing seedling disease losses.

ACKNOWLEDGMENTS

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

LITERATURE CITED

Cother, E.J. and R.L. Gilbert. 1993. Comparative pathogenicity of *Pythium* species associated with poor seedling establishment of rice in Southern Australia. Plant Pathology 42:151-157.

Eberle, M.A., C.S. Rothrock, and R.D. Cartwright. 2008. *Pythium* species associated with rice stand establishment 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, Ark.

Rothrock, C.S., R.L. Sealy, J.W. Gibbons, and F.N. Lee. 2010. Developing cold-tolerant cultivars with seedling disease resistance to *Pythium* species: Evidence for and nature of resistance in RU0701124. *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 581:84-89. Fayetteville, Ark.

Rothrock, C.S., R.L. Sealy, F.N. Lee, J. Gibbons, and R.D. Cartwright. 2006. Relationship of cold-tolerance and *Pythium* resistance to rice stand establishment. *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 540:138-142. Fayetteville, Ark.

Table 1. Efficacy of seed treatments on stand establishment (plants/m) for seven trials.

Fungicide	Kaybonnet	PI560243	PI560247	PI560281	RU0701124	STG05F5-03-088	Templeton
Pine Tree (3/21/2011)							
None	7.6 b¶	15.2 a	12.6 a	17.1 a	11.5 b	14.3 a	15.9 a
Allegiance	19.8 a	16.6 a	15.2 a	17.6 a	17.9 a	15.2 a	16.5 a
Allegiance + Cruiser	17.7 a	15.2 a	16.3 a	15.2 a	15.4 a	15.2 a	15.3 a
Allegiance + Cruiser + Dynasty	18.6 a	16.5 a	14.8 a	17.8 a	15.5 a	16.5 a	20.4 a
P-value	0.0001	0.6596	0.4378	0.6550	0.0032	0.7101	0.0984
Pine Tree (3/31/2011)							
None	15.6 c	20.4 a	20.5 a	22.9 a	18.5 a	22.0 a	18.0 c
Allegiance	24.0 b	23.4 a	22.6 a	24.5 a	22.2 a	20.8 a	28.0 a
Allegiance + Cruiser	24.8 b	23.8 a	22.3 a	25.5 a	23.0 a	22.0 a	22.7 b
Allegiance + Cruiser + Dynasty	28.5 a	26.9 a	23.4 a	21.5 a	23.1 a	23.4 a	23.5 b
P-value	<.0001	0.0751	0.7703	0.3422	0.1117	0.3793	0.0021
Pine Tree (4/8/2011)							
None	23.3 a	29.4 a	34.1 a	25.3 a	28.8 a	24.8 a	28.7 a
Allegiance	29.2 a	31.3 a	28.9 b	26.3 a	29.6 a	28.9 a	28.1 a
Allegiance + Cruiser	32.9 a	33.1 a	30.1 b	26.9 a	30.3 a	27.7 a	29.4 a
Allegiance + Cruiser + Dynasty	38.5 a	36.1 a	31.5 ab	23.5 a	28.3 a	29.0 a	32.5 a
P-value	0.0614	0.4652	0.0295	0.1097	0.9445	0.6227	0.0983
Stuttgart (3/21/2011)							
None	18.5 b	32.5 a	21.6 a	25.0 a	25.9 a	21.9 a	27.1 a
Allegiance	33.6 a	27.7 a	28.2 a	26.6 a	23.1 a	24.2 a	31.9 a
Allegiance + Cruiser	25.1 ab	30.2 a	29.6 a	27.8 a	26.7 a	17.0 a	30.6 a
Allegiance + Cruiser + Dynasty	32.1 a	33.0 a	33.4 a	25.5 a	30.3 a	27.0 a	34.0 a
P-value	0.0223	0.3846	0.1247	0.9429	0.0837	0.1439	0.5342

continued

Table 1. Continued.

Fungicide	Kaybonnet	PI560243	PI560247	PI560281	RU0701124	STG05F5-03-088	Templeton
Stuttgart (4/7/2011)							
None	22.0 b	31.8 a	25.8 a	30.0 a	27.3 a	30.0 a	35.1 a
Allegiance	32.4 a	31.9 a	27.4 a	30.4 a	28.4 a	28.9 a	31.9 a
Allegiance + Cruiser	35.5 a	31.0 a	28.0 a	32.2 a	33.2 a	31.9 a	36.4 a
Allegiance + Cruiser + Dynasty	37.1 a	30.8 a	30.6 a	31.2 a	29.9 a	33.0 a	36.5 a
P-value	0.0009	0.9658	0.5967	0.9127	0.1808	0.6074	0.3014
Stuttgart (4/29/2011)							
None	31.9 a	34.3 a	40.8 a		33.9 a	40.6 a	38.6 a
Allegiance	40.8 a	39.6 a	37.2 a		35.1 a	39.2 a	44.6 a
Allegiance + Cruiser	37.3 a	37.1 a	39.0 a		37.8 a	36.6 a	43.2 a
Allegiance + Cruiser + Dynasty	40.0 a	38.7 a	38.1 a		36.9 a	39.7 a	44.6 a
P-value	0.1965	0.4877	0.8269		0.6191	0.5729	0.3987
Keiser (5/11/2011)							
None	18.3 b	19.8 b	23.1 a	21.6 a	24.4 a	22.5 a	27.3 a
Allegiance	28.0 a	20.5 b	27.9 a	24.3 a	24.8 a	22.8 a	26.6 a
Allegiance + Cruiser	32.1 a	21.3 b	25.4 a	24.8 a	27.8 a	26.6 a	32.8 a
Allegiance + Cruiser + Dynasty	27.4 a	26.8 a	26.4 a	24.9 a	28.4 a	24.5 a	29.0 a
P-value	0.0017	0.0005	0.2853	0.4938	0.2638	0.2147	0.1482

¶ Seed treatments within a trial and genotype followed by the same letter are not significantly different, protected LSD ($P = 0.05$).

Table 2. Effect of fungicide seed treatment on relative root development and root architecture (Allegiance treated seed/non-treated seed) for selected rice genotypes[¶].

	Root length	Root volume	Root forks	Root tips	Number of links	Altitude	Link length
Kaybonnet	1.64 a[§]	1.30 a	2.17 a	1.36 a	2.05 a	1.51 a	0.60 b
PI 560281	0.97 a	0.78 a	0.96 b	1.21 a	0.98 a	0.93 b	1.05 a
RU0701124	1.03 a	0.94 a	1.03 b	1.22 a	1.03 a	0.97 b	0.98 a
P-value	0.0928	0.1971	0.0443	0.5417	0.0519	0.0347	0.0286

[¶] Seedlings were dug on 12 May 2011 from the Stuttgart planting date study planted on 7 April 2011. Mean of ≥ 15 seedlings.

[§] Genotypes within a column followed by the same letter are not significantly different, protected LSD ($P = 0.05$).

PEST MANAGEMENT: DISEASES

A Preliminary Investigation of the Reactions of Selected Rice Cultivars to *Ustilaginoidea virens* in Arkansas

D.O. TeBeest and A. Jecmen

ABSTRACT

False smut, caused by *Ustilaginoidea virens*, was recently found in Arkansas and it 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 problem of rice is poorly understood and it's erratic nature on many cultivars across locations has hampered the development of effective management strategies. In 2011, we conducted preliminary experiments at two locations in Arkansas in which 12 selected cultivars were planted in replicated plots for the purpose of investigating their reaction to false smut. In these tests, we determined the number of infected panicles per square meter (incidence) at harvest from each of the plots and we also determined the number of sori per panicle (severity). We then compared the severity and incidence of sori on panicles of all 12 cultivars at each location and across the locations. The results of these preliminary investigations suggested that there may be differences among the cultivars in reaction to seedborne and soilborne inoculum of the fungus. These results also suggested that disease resistance may offer a strategy for managing this disease in Arkansas.

INTRODUCTION

False smut of rice is caused by the fungus *Ustilaginoidea virens*. This clavicipitaceous pathogen has been in the United States for many years, but was first reported in Arkansas in 1997 (Cartwright and Lee, 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 (Lee and Gunnell, 1992). More recently, research conducted by Ashizawa et al. (2010), Ditmore and TeBeest (2006), Ditmore et al. (2007), Ikegami (1963), Schroud and TeBeest (2006), TeBeest et al. (2011), and Zhou et al. (2003) suggest that rice plants are infected from seedborne and soilborne inoculum within a few weeks after emergence. Fungicides are currently being used to suppress the disease at heading.

These facts place greater importance on disease resistance as 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 (Cartwright et al., 1999b; Hedge and Anahosur, 2000), the maximum number of sori per head (Cartwright et al., 1999a), the number of sori per pound of harvested grain (Brooks et al., 2009, 2010; Parsons et al., 2001). In addition, Hedge and Anahosur (2000) developed a scoring system containing seven categories based on the number of sori per panicle. Category one was described as zero sori/panicle while category seven consisted of panicles with greater than ten sori/panicle. Further, they showed that plants grown from seed from category seven showed significant reductions in shoot growth, root length, chaffiness, and panicle weight. Brooks et al. (2009, 2010) reported that the severity of disease on several selected cultivars depended on soil fertility and flood water depth. In 2011, TeBeest et al. reported that the occurrence of sori on panicles differed according to location. Nevertheless, many rice cultivars grown in Arkansas were evaluated or rated for resistance to false smut between 2001 and 2009 largely based on the number of sori produced per panicle, the number of sori per pound of harvested seeds, or observation (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 although Bengal, Clearfield 121, 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, 2001; Parsons et al., 2004). One cultivar, Cocodrie, was rated resistant to infection by false smut in 2001 (Cartwright et al., 2002) but subsequently was rated as susceptible to infection (Parsons et al., 2001; Wilson et al., 2005; Branson et al., 2009) based on historical data and field observations. Lu et al. (2009) suggested that there were six groups among 59 isolates of *U. virens* in China that differed in pathogenicity to three rice hybrids and that the resistance of the three hybrids differed significantly among the isolates tested. They suggested that these assessments, based on the ability of the isolates to produce sori on the three hybrids, could be used to differentiate pathogenicity of *U. virens*.

Previously, the overall goal of our research, described above, was to clarify the disease cycle and increase understanding of disease development to improve management. In this report, we describe work initiated with the overall goal of gaining an understanding of the disease reaction of selected rice cultivars grown in Arkansas to false smut occurring on the seed and in the soil.

The specific objectives of the preliminary work reported here were 1) to quantify the number of heads infected by false smut per unit area, and 2) to examine the number of sori produced on the panicles of these selected cultivars.

PROCEDURES

Twelve rice cultivars were selected for the field tests that were conducted at the Newport Research Station, Newport, Ark., and the Pine Tree Experiment Station, Colt, Ark., in 2011. Five hundred gram samples of 10 cultivars (Cheniere, Francis, JES, Jupiter, Katy, Kaybonnet, Neptune, Roy J, Taggart, and Wells) were obtained from the Rice Research and Extension Center in Stuttgart, Ark. The seeds were stored at room temperature until used (approx. 2 months). Remaining samples of all seed lots were stored at -20 °C in sealed glass containers in the laboratory for further testing as warranted. In addition, cleaned and naturally infested seeds of Clearfield 151 and Templeton were obtained from R.D. Cartwright and several Arkansas rice producers in 2010 for our field tests conducted in 2010 and 2011. Despite cleaning, the Clearfield 151 and Templeton seeds were visibly infested with sporophores of *U. virens* and visibly contaminated (blackened) with false smut spores.

Two, 200-g samples of each of the 12 cultivars were prepared. One 200-g sample was immersed in water and subjected to a vacuum treatment for 20 min at 22 inches of Hg. After the vacuum treatment, seeds were removed from the water and air dried at 26 °C for 24 to 48 hours (or until dry). These samples were considered non-inoculated controls. The other 200-g sample of seed from each cultivar were placed in a beaker and immersed in inoculum consisting of 1 million spores of *U. virens*. The inoculum was prepared by vortexing three sori collected from Clearfield 151 and Templeton in 2 liters of water. After immersion in inoculum, infested seeds were vacuum infiltrated as described above for the ‘water controls’, separated from excess inoculum by filtering, and dried as described above. From each of the 200-g samples of each of the two treatments for each cultivar, four separate 50-g samples were weighed out and placed in paper coin envelopes. When completely dried, we prepared two 50-g samples of seeds from the two treatments for each cultivar for planting at Newport and Pine Tree.

Plots were planted at both locations in an identical manner. Treatments (cultivar by inoculated or controls) were planted in a randomized complete block design with two replications of each treatment. The replications were planted in separate paddies. Each paddy contained 24 plots (eight plots wide with three ranges). Plots consisted of seven rows 10-ft long with a 7-in. row spacing. The design of the test was intended to minimize differences that might occur within the area with respect to fertility which can affect incidence of disease (Brooks et al., 2009, 2010). There were no additional inoculations made at any time at either location. Because there were limited amounts of seed available for some cultivars and the tests were to be conducted at two locations, the size of the plots, the number of treatments, and replications of each treatment were limited. As a result this data can only be considered as preliminary in nature.

Plots were planted on 17 May 2011 at Pine Tree and seedlings began to emerge on 26 May 2011. Plots were treated with several herbicides, including 3 qt/acre Superwham and 2 pt/acre of Prowl in water and 0.4 lb/acre Facet on 27 May 2011, 0.75 oz/acre Permit applied on 3 June and Duet on 15 June 2011. In addition, plots were treated with 200 units of Nitrogen (435 lb/acre urea) applied preflood. The plots were flushed on 8 June 2011 and put into permanent flood on 10 June 2011. Plots were drained on 16 September 2011and harvested on 19 October 2011.

Plots were not planted at Newport until 1 June 2011 due to heavy flooding (approx. 120 cm) of the test area on the date at which the Pine Tree test was planted. The plots were treated with several herbicides, including, 0.33 lb/acre Facet and 0.5 pt/acre Command on 3 June with 15 oz/acre of Clincher applied in 1 quart oil with an additional treatment of 10 oz Clincher applied in 1 qt/acre of oil 14 days later. The plots received 150 units of nitrogen (326 lb urea/acre) preflood on 6 July 2011. The plots were flushed with water 10 days after planting and put into permanent flood on 6 July 2011. Plots were harvested on 25 October 2011.

Polymerase Chain Reaction Detection of *U. virens* in Rice Seedlings

Seedlings grown from seeds of two cultivars (Templeton and Cl-151) used in these studies were tested for the presence of DNA consistent with *U. virens* in order to determine if plants were infected or colonized in the absence of symptoms. In these tests, seedlings were collected within three weeks after emergence and stored at 4 °C until used. Polymerase Chain Reaction (PCR) primers specific for *U. virens* were selected and used as previously described (Ditmore and TeBeest, 2006; Zhou et al., 2003). Infection of 3-wk-old seedlings was confirmed following PCR amplification of samples by procedures established as described. A seedling (or tissue sample) was considered to be infected or colonized by *U. virens* if bands consistent with *U. virens* were found in each sample.

Symptom Development, Disease Severity, and Collection of Infected Panicles

In order to determine when signs and/or symptoms of false smut appeared in the tests on the twelve cultivars, all plots at Pine Tree and Newport were examined weekly beginning with the milk stage of the first cultivar reaching maturity. Data were recorded approximately one week before harvest of all cultivars to permit full expression of the disease on all cultivars and all cultivars were harvested on the same day. We collected data on two dependent variables, the number of infected panicles per square meter and the number of typical sori on infected panicles. The average number of infected panicles per plot was determined by counting infected panicles in two random square meter counts in the interior 5 rows. These two counts were averaged for each plot. After the data on infected heads were collected, infected panicles were collected at random from within each plot (whenever possible) and taken to the lab. In the lab, the number of sori per panicle were determined by counting the number of typical sori on heads collected from each plot. Although we tried to collect a minimum of eight infected panicles from each plot, in some plots we were not able to collect the minimum number which resulted in a non-normal distribution of the dependent variables.

Statistical Analyses

The design for this experiment was a two-way factorial arrangement in a randomized complete block design with two replications of each treatment. The field plots were planted in two replications (= paddies) of 24 plots per replication with 8 treatments planted in 3 rows within each paddy (replications). This design was intended to minimize the potential effects of any variation within soils in the fields.

Treatments were planted in random order within each replication (block) and treatments were combinations of two factors, cultivars (12) and inoculation method. Inoculation methods consisted of 1) water controls, and 2) inoculated. Treatments were planted randomly within replications, with each cultivar × inoculation method combination planted once per block. The number of blocks is the number of replications (2). This entire test was conducted at two locations, Newport and Pine Tree, Ark., as described above.

Due to the non-normal distribution of the data on the number of infected panicles/m^2 and the number of sori/panicle, the recorded data were converted to $\log^{10}$ values before statistical analysis. Each location was analyzed separately. An analysis of variance (ANOVA) showed that while there were no significant differences between controls and inoculated treatments and cultivars, the ANOVA test (applied to the dependent variables) showed highly significant differences between cultivars for both dependent variables. A least square different (LSD) means separation procedure was used to describe these differences.

RESULTS AND DISCUSSION

Symptom Development and Disease Severity

Polymerase Chain Reaction analysis of seedlings collected approximately 3 wk after emergence indicated that most of the seedlings grown from infested seeds of these two cultivars were already colonized by *U. virens* (data not shown). Schroud and TeBeest (2006) have previously shown that rice roots were infected by spores within days after germination by the spores on roots. Ditmore and TeBeest (2006), Zhou et al (2003), and Ashizawa et al. (2010) have established that rice was infected by *U. virens* before heading and TeBeest et al. (2011) showed that as few as 25 spores per gram pasteurized field soil resulted in the infection of approximately 44% of the emerging seedlings.

Visible symptoms of infection did not appear on any cultivar at any time and due to the different planting dates and different cultivars used in the study we found that signs (sori) of infection developed over an extended period of time. The cultivars used in this study were previously described as susceptible or moderately susceptible and all of the cultivars used developed signs of infection. But, it was visibly evident that there were widely different levels of incidence and severity of false smut across cultivars and locations. In general, incidence of false smut was more severe at Newport than at Pine Tree.

We observed two different basic levels of infection of the rice cultivars by *U. virens* in 2011. At the chronic level (Fig. 1), we observed from one to as many as 5 sori per panicle with the remainder of the seed seemingly uninfected or at least absent of signs of infection although seeds near the sori were heavily contaminated with spores. At the acute level (Fig. 2), we observed panicles with 10 or more typical sori and others in which nearly every seed was replaced by spores of *U. virens* even though relatively few sori normally associated with *U. virens* infections were seen.

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

In the absence of visible symptoms of infection, 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 per unit area, while 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/sq m in individual field plots and the number of sori on infected panicles from each of 12 cultivars planted as previously described as either susceptible or moderately susceptible to *U. virens*. Analysis of variance indicated that there were no significant differences between the treatments (water controls and inoculated) so the data were combined (ANOVA tables not given) and are given in Tables 1 and 2 and in Fig. 3.

The average number of panicles visibly infected by false smut/sq m was collected shortly before harvest by counting two 1-sq m portions of the plots at random. The data were then averaged for each plot. Because the data were not normally distributed, the means were transformed to $\log^{10}$ values before means were compared. In Table 1, the mean number of panicles/plot show a wide and statistically significant range of incidence of infection by false smut in plots at Newport and Pine Tree. The incidence of infection ranged from 0 panicles/sq m on Jupiter to more than 27 and 38 infected panicles/sq m on Francis and Clearfield 151, respectively, at Newport. Less than two infected panicles were found in plots of Jupiter, JES, and Katy at Newport. However, at Pine Tree, the incidence of false smut ranged from 0.5 panicles/sq m for Kaybonnet and Cl-151 to greater than 17 infected panicles/sq m on Taggart. In addition, less than two infected panicles were found per square meter in plots of Cheniere, Francis, Jupiter, and JES. These results suggest that there were statistically significant differences in the incidence of false smut on the different cultivars at both locations, although there were differences in the incidence of false smut between locations. There were several large differences in the number of infected panicles at the two locations for several cultivars. At Pine Tree, there was an average of 0.5 infected heads/sq m for Cl-151 and an average of 1.2 infected heads for Francis at Pine Tree while at Newport there were more than 38 and 27 infected heads/sq m, respectively. In contrast, there was a six-fold increase in the number of infected heads/sq m for Neptune at Newport over the number found at Pine Tree.

Other investigators have used the number of sori per head as an indicator of resistance or disease severity (Hedge and Anahosur, 2000; Lu et al., 2009). Table 2 shows that there were statistically significant differences in the number of sori produced on panicles among the 12 cultivars in our tests at the two locations. The number of sori/panicle ranged from 1.5 on Katy to more than three on Francis, Taggart, and Templeton at Newport. At Pine Tree, there was less than one sorus per panicle on Katy, Jupiter, and JES. In contrast to the severity data given in Table 1, there was little uniformity in the number of sori per head between Newport and Pine Tree although we did not statistically test this across locations. At Pine Tree, the number of spore balls per head ranged from 0.140 on Katy to more than 0.6 sori per infected panicle on Taggart and Templeton. These results suggest that there were statistically significant differences in the number of false smut sori on the cultivars used in this study at both locations. The data also suggest that there were differences in sorus production on some of the different cultivars between the two locations. More spore balls were produced on panicles on plants grown at Newport than at Pine Tree for all 12 cultivars. These differences across locations may have been partially due to differences in fertility and or water management as noted by Brooks et al. (2009, 2010) although the differences in reactions of the different cultivars suggest a genetic component.

While the data in Tables 1 and 2 shows statistically significant differences in both the severity of false smut and in the incidence (= number of sori produced per panicle) on the 12 cultivars used in the study, the relationships are not clear. Figure 3 shows the results of plotting the log of the number of infected panicles against the log of the number of sori per panicle on the 12 cultivars at the two locations. In general, there was positive correlation between the number of infected heads per sq m and the number of sori per head at both locations for all 12 cultivars. Only Katy and Jupiter had a higher number of infected panicles at Pine Tree than at Newport. On closer examination, four general groups of cultivars emerge. Group 1, composed of Katy, Jupiter, and JES, are found with approximately 0.2 ($\log^{10}$) sori per head and approximately 0.0 to 0.2 ($\log^{10}$) infected heads per sq m. Group 2 consists of Kaybonnet, Neptune, and Wells, with approximately 0.3 to 0.4 ($\log^{10}$) sori per panicle and 0.0 to 1.2 ($\log^{10}$) infected heads per sq m. Group three is composed of Roy J, Taggart, and Templeton with approximately 0.5 to 0.6 ($\log^{10}$) sori per panicle and 1.0 to 1.5 ($\log^{10}$)infected heads per sq m. Group four is composed of Cheniere, Clearfield 151, and Francis, three cultivars which showed very large increases in the number of infected heads per sq m at Newport in comparison to Pine Tree.

The data suggests that conditions at Newport favored a dramatic increase in the incidence and severity of the disease on most of the cultivars. The most dramatic example of this effect occurred with Clearfield 151. 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 per panicle. On that basis, and at Pine Tree, Clearfield 151, Katy, Jupiter, and Kaybonnet are more resistant than Cheniere, Francis, and JES and these are more resistant than Neptune, Roy J, Taggart, Templeton, and Wells. However, this categorization does not correspond to rankings at Newport in which case Clearfield 151 is dramatically more susceptible at Newport. Only Jupiter and Katy appeared to remain within the same ranking across locations suggesting that these two cultivars had more stable reaction to infection across locations.

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. Previous work showing that the disease is seedborne may have helped to explain its emergence statewide.

Disease resistance is a mainstay of managing plant diseases. Finding germplasm with resistance or tolerance to false smut across the different soil and environmental conditions in the state will be crucial to a successful and integrated disease management system. Based on the preliminary data in this test and the literature cited, methodologies are being developed to evaluate germplasm with reasonable assurance of success. The results of the work conducted in 2011 warrant further investigation. Understanding that seed and soil infested with viable spores can lead to infections raises new questions relative to cultivar genetics, soil fertility, seed contamination, and even the possibility that pathotypes of the fungus may exist in Arkansas.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Arkansas Rice Research and Promotion Board and the Director of the University of Arkansas System Division of Agriculture, Agricultural Experiment Station. We are grateful for the seed of CL-151 and Templeton initially provided by R. Cartwright and the seeds of ten cultivars provided by K.A.K. Moldenhauer and the Arkansas Rice Foundation Seed program. The authors are indebted to Mr. J. Velie, Systems Analyst, University of Arkansas Agricultural Statistics Laboratory for his assistance with the statistical analyses.

LITERATURE CITED

Ashizawa, T., M. Takahashi, J. Moriwaki, and K. Hirayae. 2010. Quantification of the rice false smut pathogen *Ustilaginoidea virens* from soil in Japan using real-time PCR. Eur. J. Plant Pathol. 128:221-232.

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., 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. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:148-156. Fayetteville.

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. Johnston (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 ricecultivars/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. and F.N. Lee. 2001 Rice Production Handbook. MP 192. N.A. Slaton, (ed). Cooperative Extensive Service, University of Arkansas. 94 pp.

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.

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

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.

Parsons, C.E., E.A. Sutton, B.J. Dodgen, R.M. Chlapecka, B. Thiese, R. Thompson, and R.D. Cartwright. 2001. Management of false smut of rice in Arkansas. *In:* R.J. Norman and J.-F. Meullenet (eds.). B.R. Wells Rice Research Studies 2000. University of Arkansas Agricultural Experiment Station Research Series 485:142-148. Fayetteville.

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*. *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 Series 540:143-151. Fayetteville.

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 524:149-158. Fayetteville.

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*. Phytopathology 151:513-518.

Table 1. The mean number of infected panicles counted per square meter in field plots of selected cultivars grown at two locations in Arkansas in 2011.

Newport		Pine Tree	
Cultivar	Infected panicles[¶]	Cultivar	Infected panicles
	(no./m^2)		(no./m^2)
Jupiter	0.866 A	Kaybonnet	0.500 A
JES	1.118 A	Cl-151	0.500 A
Katy	1.655 AB	Cheniere	0.794 AB
Neptune	2.590 ABC	Francis	1.225 ABC
Kaybonnet	3.873 BCD	Jupiter	1.581 ABC
Cheniere	7.566 CDE	JES	1.936 ABCD
Taggart	9.758 DEF	Templeton	3.325 ABCDE
Wells	12.109 DEFG	Katy	3.500 BCDE
Roy J	14.927 EFG	Wells	4.386 BCDE
Templeton	18.740 EFG	Roy J	5.660 CDE
Francis	27.276 FG	Neptune	11.398 DE
CL-151	38.125 G	Taggart	17.790 E

[¶] Means followed by the same letter within a column are not significantly different according to LSD at P = 0.05. Each location was analyzed separately by ANOVA.

Table 2. The mean number of typical sporophores of *U. virens* found on panicles of selected cultivars grown in our tests at two locations in 2011.

Newport		Pine Tree	
Cultivar	Sporophores[¶]	Cultivar	Sporophores
	(no./panicle)		(no./panicle)
Katy	1.5 A	Katy	0.146 A
Jupiter	1.52 A	Jupiter	0.192 AB
Jes	1.63 A	Kaybonnet	0.201 AB
Kaybonnet	2.02 AB	Cl 151	0.243 AB
Cheniere	2.07 AB	Jes	0.334 BCD
Neptune	2.09 AB	Francis	0.447 BCD
Wells	2.41 AB	Cheniere	0.449 BCD
Roy J	2.95 B	Wells	0.535 CD
CL 151	2.98 B	Neptune	0.578 CD
Francis	3.03 B	Roy J	0.586 CD
Taggart	3.14 B	Taggart	0.619 D
Templeton	3.28 B	Templeton	0.628 D

[¶] Means followed by the same letter within a column are not significantly different according to LSD at $P = 0.05$. Each location was analyzed separately by ANOVA.

Fig. 1. The image shows the signs of the typical or "chronic" level of infection found on panicles of cultivars infected by *U. virens* in our field plots at Pine Tree in 2011. Only one or two grains are replaced by sori while the other grains are visibly unaffected.

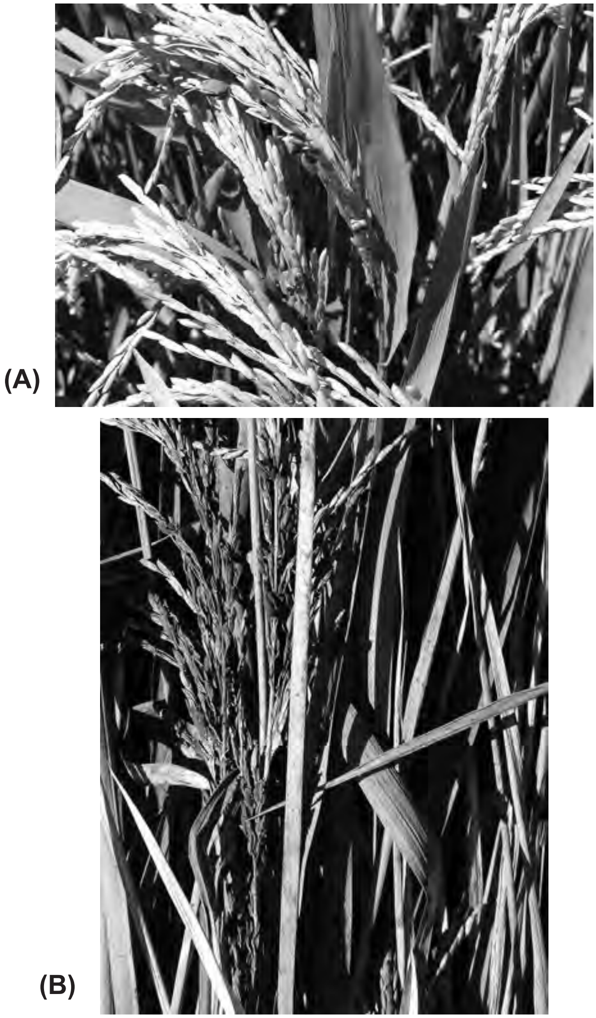


Fig. 2. These images show two examples of high or "acute" levels of infection that can be found on panicles of very susceptible cultivars infected by *U. virens* on plants grown at Newport, Ark., in 2011. On panicles with 'acute' infection levels, we find that many of the grains have been replaced by sori (A). In the most severely affected cultivars, all of the grains have been replaced by sori although many do not exhibit the typical sorus for this disease (B).

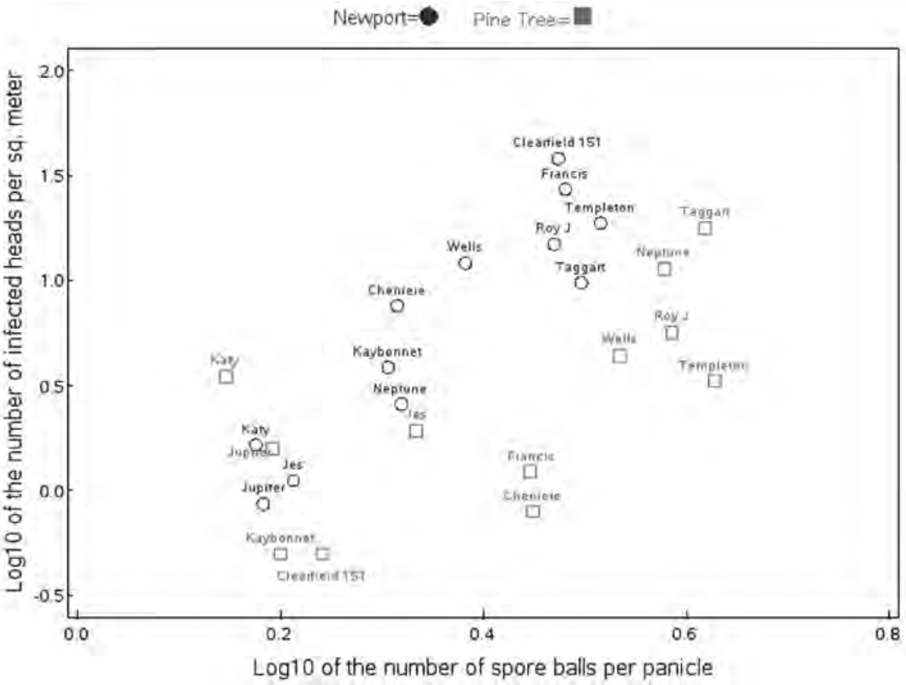


Fig. 3. Diagram of the number of sporophores per panicle plotted against the number of infected heads per square meter on 12 cultivars grown in Arkansas in 2012. The data are the logarithms of the means of the number of infected heads per square meter from replicated plots and the logarithms of the number of sori found on infected panicles within plots. The work was conducted at the Newport Research Station, Newport, Ark. (closed circle), and the Pine Tree Experiment Station, Colt, Ark. (closed square).

PEST MANAGEMENT: INSECTS

The Presence of *Burkholderia* and Arthropods in Arkansas Rice Fields

A.P.G. Dowling and R.J. Sayler

ABSTRACT

Bacterial panicle blight (BPB) caused by *Burkholderia glumae* has become the most important disease of 'Bengal' rice in Arkansas. Many arthropods with the capability to vector bacteria are commonly found in rice fields, however no link has been made to any arthropod vectors of BPB. This study was the second year of sampling rice fields for the presence of BPB and any small arthropods typically implicated in disease vectoring such as mites and sucking insects. Selective agar and Polymerase Chain Reaction (PCR) screening were used to test for the presence of BPB in rice samples and arthropods were collected and identified from the same samples. Out of 91 rice samples, only 13 tested positive for BPB. Of the 91 samples, 32 contained mites and other arthropods; however, only five of these samples also tested positive for BPB. There appears to be no correlation between presence of mites and BPB infection, likely due to the fact that the mite species found are not known plant feeders. Other than mites, thrips, rice stinkbug, and the occasional beetle larva were found on some of the rice samples.

INTRODUCTION

Bacterial panicle blight (BPB), caused by *Burkholderia glumae*, has become the most important disease of Bengal rice in Arkansas, causing up to 35% yield losses in some fields each year. This single disease has turned the high yield potential Bengal variety into only an average yielding one. In certain years, the disease has affected the entire medium-grain production area, but it is unknown how the bacterial blight may be associated with mites or insects feeding on the plants. Many mites and insects are known to transport and infect plants with bacteria, viruses, and other pathogens. The spread of blight and other pathogens may be heavily influenced by mite activity and may have synergistic effects with mite feeding damage. In addition to bacterial panicle blight, extension personnel have witnessed panicle browning and kernel abortion to be common in hot dry years. In many cases, no pathogens could be isolated, suggesting that mite feeding alone may cause these symptoms. To our knowledge, the only systematic survey of mites and pathogens in the southern U.S. was performed by the authors in 2010, however, due to heavy pesticide use that season, arthropod populations were very low, or non-existent, making it impossible to draw a possible correlation between mite presence and BPB infection (Dowling et al., 2011). Only a few studies have examined the relationship between mites and pathogens worldwide; although this interaction appears to be the crucial factor in the rice panicle mite's ability to cause up to 90% yield losses in Central America (Almaguel et al., 2000). Minimizing the activity of mites in the fields may be the key to minimizing or even eliminating the appearance and spread of bacterial blights in Arkansas rice fields. Solving this problem should not only help medium-grain growers, but hopefully help prevent the disease from spreading to the major long-grain rice varieties as well.

To better understand the interaction between mites, stinkbugs, rice, and bacterial panicle blight we conducted a second year of medium-grain rice sampling around the state, with sampling after panicle emergence and lasting through later season maturation.

PROCEDURES

Rice samples were collected from 1 August through 15 September 2011. Collection involved locating rice plants displaying potential symptoms of BPB infection, cutting a handful of these plants near the base and placing them into a large plastic bag. Several samples were taken from each location and then shipped up to the University of Arkansas in Fayetteville. Once received, samples were stored in a walk-in refrigerated storage closet to keep arthropods, bacteria, and fungus alive, but in stasis. Each sample was removed from the refrigerator and first sampled for the presence of bacterial blight and then checked for mites and other arthropods.

Leaf samples were analyzed for the presence of the *B. glumae* by randomly removing three ten gram leaf samples and placing them in 50 ml conical tubes. The tubes were filled with 20 ml of 10 mM sodium phosphate buffer pH 7.0 supplemented with 0.05% Tween 20. Each subsample was vortexed on high for 5 s. After vortexing the subsamples, 100 ul of the subsample buffer was plated on CCNT media that is selective for *Burkholderia* species (Kawaradani et al., 2000). The media was incubated at 37 °C for 48 h. Populations of *B. glumea* were quantified by counting bacterial colonies producing yellow pigment on the CCNT after incubation at 37 °C for 48 h.

Plant samples were also screened using molecular techniques, as were some of the mites collected from samples. Polymerase chain reaction (PCR) focused on a 529 bp fragment of the gyrb gene from *B. glumae* and the following primers were used: glu-FW GAAGTGTCGCCGATGGAG and 18 glu-RV CCTTCACCGACAGCACGCAT (Maeda et al., 2006). The protocol from these authors was selected because it allows multiplex PCR detection of *B. gladioli* and *B. plantarii* in addition to *B. glumae*. The large 500 bp fragment produced by these primers facilitates easy visualization on an agarose gel and reduces the potential for false positives that is more likely to occur with primers that amplify smaller fragments. Extraction of DNA was performed using the Qiagen DNeasy Tissue Kit and protocols therein (Qiagen, Germantown, Md.). Each 25 µl PCR sample contained 15.25 µl dH_2O, 2.5 µl PCR buffer, 1.5 µl $MgCl_2$, 1.5 µl dNTP's, 1 µl of each primer, 0.25 µl of Platinum Taq polymerase (Invitrogen), and 2 µl template DNA. Polymerase chain reaction conditions were as follows: 95 °C for 3 min; 35 cycles each of 95 °C for 20 s, 60 °C annealing for 30 s, and 72 °C extension for 15 s; followed by a 10 minute extension at 72 °C; and an indefinite hold at 4 °C. Polymerase chain reaction products were visualized using gel electrophoresis on a 1% agarose gel stained with GelRed (Biotium). Presence of a band around 500 bp in length indicated confirmation of BPB.

Arthropod sampling involved visual inspection from a subsample of each rice plant under the dissecting microscope. The leaves were inspected and rolled parts of the plant were also dissected to look for arthropods inside. Any arthropods found were collected and placed in a 2 ml microcentrifuge tube containing 95% EtOH. The rest of the plant sample was cut up into small pieces (5 to 10 cm long) and placed in a sealed container about one third full of 70% EtOH. If panicles were present, many of the developing grains were cut in half and placed in the sealed container as well. The container was then shaken for 5 min, allowed to settle, shaken again for 5 min, and then strained through a #320 fine mesh screen. All arthropods from the sample plus plant debris were too big to pass through the screen and were trapped on the top. This debris was washed into a petri dish with 70% EtOH and examined for arthropods under the dissecting microscope. All arthropods found in the wash were transferred to a 2 ml microcentrifuge tube containing 95% EtOH. After all washings were complete, a representative subsample of mites was slide mounted and examined under the compound microscope for identification. Any insects collected were identified under the dissecting microscope.

RESULTS AND DISCUSSION

A total of 91 different samples were collected and processed for both bacterial infection and arthropod presence. Only 13 samples tested positive for BPB infection on the agar plates, all of which were confirmed with PCR. Locality of the positive samples is displayed on the map in Fig. 1.

Of all 91 samples examined for the presence of mites or insects (exclusive of stinkbugs and grasshoppers), 32 produced mites, some of which exhibited large populations. Only three samples had thrips and only two had rice stinkbug; however, with the latter, due to the collecting method, we would expect most adult hemipterans to fly off and the immatures to possibly drop off the plant as it is harvested. The most common mite species was *Tarsonemus bilobatus* (family Tarsonemidae) which is a common mite associated with plants. The mite typically feeds on fungi growing on plants and has been implicated as a vector of certain strains of fungi. There appeared to be no immediate correlation between the presence of this mite and BPB. The other mite commonly collected was a predatory mite in the family Phytoseiidae genus *Neoseiulus* (species not yet determined), likely feeding on *T. bilobatus*. Only five of the samples possessing arthropods also tested positive for BPB infection and none of the mites found are known plant feeders. Additionally, no plant feeding insects were found on those samples. None of the mites examined with PCR tested positive for *Burkholderia*.

Overall, BPB prevalence was rather low in fields throughout Arkansas although samples were taken from plants showing symptoms of possible infection. However, this must have been due to other stressors, such as the extreme heat exhibited during the 2011 summer. On the other hand, mite presence was moderate, with individuals found on about one third of the sampled plants. No significant correlation between the presence of mites and BPB infection was found. Mite abundance also appeared to have no correlation to infection on the plant as populations ranged from 10 to 76 mites on infected plants and 10 to 145 mites on uninfected plants.

SIGNIFICANCE OF FINDINGS

These findings lead to a few preliminary conclusions. First, 2011 was another year of high pesticide use that may have knocked down mite and other insect populations. This was evident in our sampling where two thirds of the plants were completely free of any arthropods, a finding much unexpected based on samples from other years. The few mites found on samples are not typical mites expected in transmission of BPB and none tested positive for the presence of *Burkholderia*.

ACKNOWLEDGMENTS

The authors thank the producers of Arkansas for the check-off funds administered by the Rice Research and Promotion Board for funding this research. The authors would like to thank Gus Lorenz and Nicki Taillon for collection of rice samples.

LITERATURE CITED

Almaguel, L., J. Hernandez, P.E. de la Torre, A. Santos, R.I. Cabrera, A. García, L.E. Rivero, L. Báez, I. Cácerez, and A. Ginarte. 2000. Evaluación del comportamiento del acaro *Steneotarsonemus spinki* (Acari: Tarsonemidae) en los estúdios de regionalización desarrollados en Cuba. Fitosanidad. 4:15-19 [in Spanish].

Dowling, A.P.G., R.J. Sayler, and R.D. Cartwright. 2011. Survey of mites and bacteria associated with Arkansas rice and the potential link between the spread and pathogenicity of bacteria and mite activity. *In:* R.J. Norman and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies. University of Arkansas Agricultural Experiment Station Research Series 591:82-86. Fayetteville.

Kawaradani, M., K. Okada, and S. Kisakari. 2000. New selective medium for isolation of *Burkholderia glumae* from rice seeds. General Plant Pathololog*y*. 66:234-237.

Maeda, Y., H. Shinohara, A. Akinori Kiba, K. Ohnishi, N. Furuya, Y. Kawamura, T. Ezaki, P. Vandamme, S. Tsushima, and Y. Hikichi. 2006. Phylogenetic study and multiplex PCR-based detection of *Burkholderia plantarii*, *Burkholderia glumae,* and *Burkholderia gladioli* using gyrB and rpoD sequences. Int. J. System. Evol. Microbiol. 56:1031–1038.

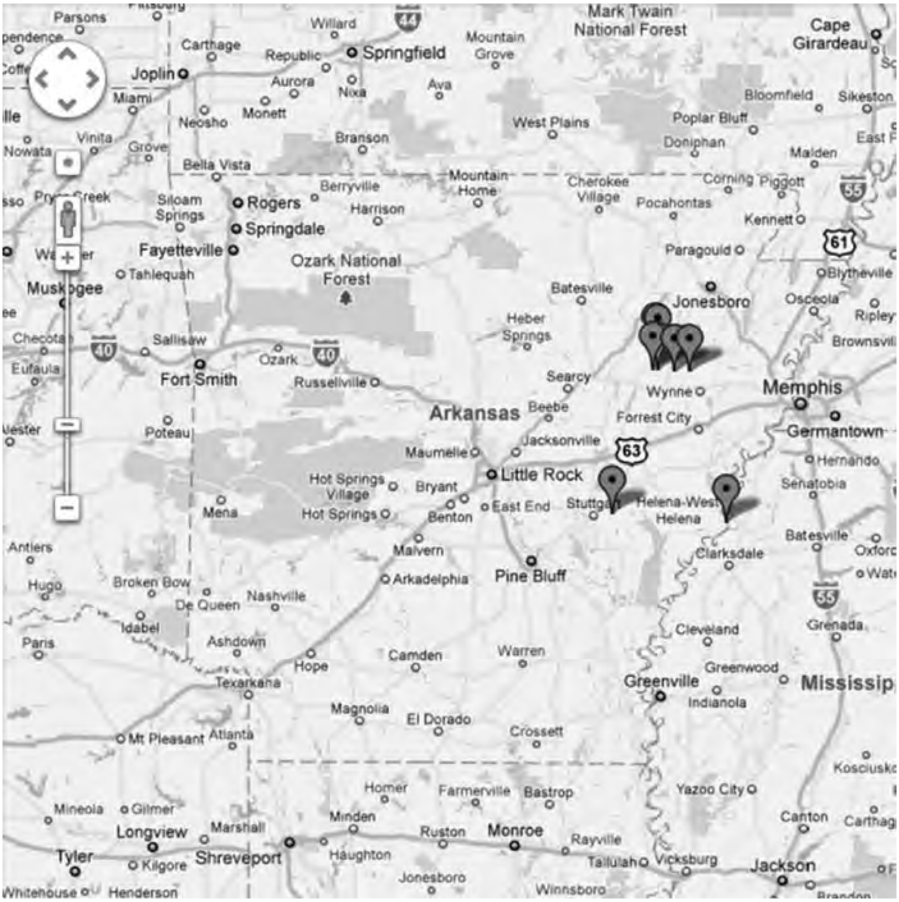


Fig. 1. Localities of the 13 rice samples that tested positive for bacterial panicle blight infection.

PEST MANAGEMENT: INSECTS

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

G.M. Lorenz III, A. Plummer, N. Taillon, B. Thrash, J. Fortner, and K. Colwell

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, and foliar insecticide applications 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 these trials was to evaluate the efficacy of foliar treatments compared to insecticide seed treatments. Studies indicated an overall increased efficacy of insecticide seed treatments compared to foliar treatments. It may be that timing of foliar applications is very critical and, when compared with the residual control of seed treatments, may have reduced overall effectiveness.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus*, has historically been a problem for 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). 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.

PROCEDURES

Two trials were conducted during the 2011 growing season. Trial 1 was located in three locations in St. Francis (1 location) and Prairie (2 locations) counties. Trial 2 was located in Desha and Lincoln counties. Plots were 5 ft × 25 ft in a randomized complete block design with four replications. All insecticide applications were seed-applied treatments except the foliar treatments Karate Z and Belay, which were applied at flood, 1 to 2 days postflood, and 8 to 10 days postflood with a hand boom fitted with TX6 hollow cone nozzles at 19-in. nozzle spacing. Spray volume was 20 gal/acre at 40 psi. Rice water weevil larvae were evaluated by taking 3 core samples per plot with a 4-in cylinder core sampler. Rice water weevil samples were taken 21 to 28 days after permanent flood. 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 (Gylling Data Management, Inc., Brookings, S.D.), AOV, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

Results for Trial 1 indicated that Belay (4.5 oz/acre) + Karate (5.12 oz/acre) at 8 to 10 days postflood provided the best control but only differed from Belay (4.5 oz/acre) at 1 to 2 days postflood (Table 1). All Other treatments did not differ from each other. Harvest totals indicated no significant differences between treatments. Early flood conditions most likely had an effect on rice water adult densities providing a range of populations within individual treatments. Results from Trial 2 were summarized across locations (Table 2). Studies indicated all treatments were better than the untreated check. Dermacor X-100 provided the best control compared to all other treatments. Karate Z provided no additional control when added to Cruiser Maxx Rice. Harvest totals showed all treatments except Cruiser Maxx Rice + Karate Z had significantly higher yields compared to the untreated check (Table 3). Cruiser Maxx Rice + Karate did not differ from all other treatments. It is likely that the addition of Karate controlled beneficial insect populations potentially causing the decrease in yield.

SIGNIFICANCE OF FINDINGS

Results were consistent with previous research. Foliar applications targeting rice water weevils can be costly and inaccurately timed. Insecticide seed treatments are easily applied and give producers a more reliable option against rice water weevils. Foliar applications lower beneficial insect populations potentially generating a need for another application if another pest becomes present. Further research of insecticide applications is vital to the continued control of rice water weevil damage.

ACKNOWLEDGMENTS

We would like to acknowledge Lee Walt Farms, Desha County; John Freeman Farms, Lincoln County; Price Brothers Farms, Sidenstricker Farms, Prairie County; and Pine Tree Experiment Station, St. Francis, County. Funding for this project was provided by monies from grower check-off funds administered by the Rice Research and Promotion Board, DuPont, Syngenta, and Valent. We also express appreciation to the following county agents for their assistance with these trials: Wes Kirkpatrick, Chad Norton, Brent Griffin, Noel Goodwin, and program technician Shawn Clark.

LITERATURE CITED

Bernhardt, J.L. 2001. Rice Production Handbook "Insect Management in Rice" www.uaex.edu/otherareas/publications/PDF/MP/192Chapter11.pdf

Table 1. Trial 1 Rice weevil core samples, Lincoln County, 2010.

Treatment	Timing	Rice water weevil[a] (no./core)
Untreated check	----	6.60 AB
Karate Z 5.12 oz/acre	1 to 2 days postflood	2.65 AB
Belay 3.5 oz/acre + Progibb 40%	1 to 2 days postflood	4.25 AB
Belay 3.5 oz/acre	1 to 2 days postflood	5.28 AB
Belay 4.5 oz/acre	1 to 2 days postflood	8.33 A
Belay 3.5 oz/acre + Progibb 40%	8 to 10 days postflood	5.68 AB
Belay 3.5 oz/acre	8 to 10 days postflood	4.60 AB
Belay 4.5 oz/acre	8 to 10 days postflood	2.60 AB
NipsIt Inside	Seed treatment	3.83 AB
Dermacor X-100	Seed treatment	5.25 AB
Belay 4.5 oz/acre + Karate Z 5.12 oz/acre	1 to 2 days post flood	2.18 B

[a] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 2. Trial 2 Summary across locations, rice water weevil core samples.

Treatment	Rice water weevil[a]
	(no./core)
Apron + Maxim 4 FS + Dynasty	9 A
Cruiser Maxx Rice 2.87 FS	4 B
A17469	5 B
Apron XL + Maxim 4 FS + Dynasty 0.83 FS + Cruiser Maxx Rice 5 FS	5 B
Apron XL + Maxim 4 FS + Dynasty .83 FS + Dermacor X-100	2 C
Apron XL + Maxim 4 FS + Dynasty 0.83 FS + NipsIt Inside	4 B
Cruiser Maxx Rice + Karate with Zeon 2.08 CS	5 B

[a] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 3. Trial 2 Summary across locations, harvest totals, 2010.

Treatment	Yield[a]
	(bu/acre)
Apron + Maxim 4 FS + Dynasty	198 B
Cruiser Maxx Rice 2.87 FS	212 A
A17469	209 A
Apron XL + Maxim 4 FS + Dynasty 0.83 FS + Cruiser Maxx Rice 5 FS	206 A
Apron XL + Maxim 4 FS + Dynasty 0.83 FS + Dermacor X-100	209 A
Apron XL + Maxim 4 FS + Dynasty 0.83 FS + NipsIt Inside	209 A
Cruiser Maxx Rice + Karate with Zeon 2.08 CS	205 AB

[a] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

PEST MANAGEMENT: INSECTS

Effect of Thiamethoxam Seed Treatment on Rice Water Weevil Control in Conventional and Hybrid Rice Varieties

R.S. Mazzanti, J.L. Bernhardt, and S. Ntamatungiro

ABSTRACT

Seed treatment with insecticides is a convenient method for farmers to prevent a select group of insects from causing damage to rice and minimize yield losses. A study was conducted to test thiamethoxam seed treatment at the rate of 3.3 oz/100 lb seed for control of rice water weevil in a conventional and a hybrid variety. Seed treatment with thiamethoxam significantly reduced rice water weevil densities; however, percent control in conventional was 91% and 62% in the hybrid. The hybrid had significantly more biomass (tillers and vegetative growth) three weeks after permanent flood than the conventional, and the dispersal of available thiamethoxam into a larger plant (hybrid) probably compromised control of rice weevil larvae. Grain yields were not significantly different between treated and untreated seed, but the percentage yield loss was 0.7% (1.7 bu/acre) for CL XL745 and 2.6% (5 bu/acre) for Roy J. The conventional variety averaged 13.6 larvae/core in the untreated while the hybrid averaged 16.6 larvae/core. The hybrid CL XL745 tolerated the moderate level of rice water weevils better than the conventional variety Roy J.

INTRODUCTION

Flooded rice fields provide a temporary aquatic habitat for many animals including numerous species of insects. Among the insects, one of the major pests is the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel. The semi-aquatic adults feed on rice leaves and the immature forms (larvae) feed in and on rice roots and cause injury. When the injury is severe, plant vigor and yield will be reduced.

Even though pyrethroid insecticides were available after the loss of fipronil (Icon®) in 2006, growers continued to express the desire for the convenience of a seed treatment to control water weevils and grape colaspis. Tests with thiamethoxam as a seed treatment began in 2001 and continued through registration of the chemical in 2009 (Walsh and Johnson, 2003; Way et al., 2004; Bernhardt, 2009). In 2007 rynaxypyr (Dermacor® X-100), another new insecticide applied as a seed treatment, was given to entomologists for efficacy tests on rice water weevil and grape colaspis. Rynaxypyr was found to give very good control of weevils (J.L. Bernhardt, unpublished data). In 2008 rynaxypyr was tested on conventional and hybrid rice varieties and control of weevils in conventional rice was 18% to 23% better than that in hybrid rice (Hummel and Stout, 2009; J.L. Bernhardt, unpublished data). The cause of the reduced control by rynaxypyr in hybrid rice was unknown and posed a potential problem for growers. Prior to 2010, thiamethoxam seed treatment had not been tested in hybrid rice to determine if control of weevils would be compromised similar to that of rynaxypyr. A study was planned to use seed treated with the recommended rate of 3.3oz/100 lb of seed and untreated seed of conventional and hybrid cultivars to determine (1) if seed treatment influences rice water weevil control, (2) if seeding rate of varieties influences rice water weevil infestation and control, and (3) if hybrid rice plants have more tillers and biomass than the conventional rice cultivar.

PROCEDURES

A factorial field experiment was conducted at the Rice Research and Extension Center near Stuttgart, Ark., on a silt loam soil. The design was a split-split plot with four replications. Main plots were untreated rice seed and rice seed treated with insecticide. Subplots were rice varieties and sub-subplots were seeding rates. Each sub-subplot was nine rows wide with a 7-in. row spacing and 25 ft long. Earthen levees were used to prevent movement of water between main plots and subplots. The plots relied on a natural infestation of the rice water weevil. The two varieties chosen for this experiment were a conventional rice variety, Roy J, and a hybrid variety from RiceTec®, CL XL745. Seed from both varieties were treated with the fungicides fludioxonil (Maxim® 4FS), mefenoxam (Apron XL®), azoxystrobin (Dynasty®), and thiamethoxam (Cruiser® 5FS) at 3.3 oz/100 lb of seed.

Rice was drill-seeded on 21 April. The seeding rates for the hybrid were 20, 30, and 40 lb/acre and the seeding rates for the conventional were 45, 67.5, and 90 lb/acre. Rice emerged to a stand on 2 May. Stand counts were taken on 24 May and consisted of 3, 1-ft counts taken at random within each sub-subplot excluding the outside rows. For the hybrid rice, a total of 150 lb N/acre was applied with a shaker jar with 80% applied 2 June 1 h before permanent flood and the remaining 20% applied at boot-split (14 July). The conventional rice had a total of 135 lb/acre N with 67% applied before flood on 2 June and the remaining 33% applied at mid-season (27 June). A 4-in. flood was applied on 2 June and maintained until 12 August for the hybrid rice and 27 August for the conventional rice.

Rice water weevil infestation was evaluated by estimating the densities of immatures (larvae and pupae) in plots. Three soil/plant core samples were taken from plots in replication 1, 2, 3, and 4 on 23, 24, 25, and 26 June, respectively. A core sampler (4 in. × 4 in. diameter × depth) was pushed into the soil, the soil/plant core removed from the sampler, and placed in a plastic bag. Cores samples were taken at random locations from the interior seven rows of plots and at least 2 ft from the ends of rows.

In the laboratory, plants in each core were separated and the roots were thoroughly washed with enough water pressure to loosen and remove soil, larvae, and pupae from the roots into a 40-mesh sieve. The sieve was immersed in a saturated salt solution that caused larvae and some pupae to float to the water surface. Larvae were removed from the saltwater, visually categorized by body and head capsule size, and counted. Debris on the bottom of sieves was searched for pupae. For analyses, larval and pupal (immature) densities were added together. Percent control was calculated as follows: % control = (mean # in untreated – mean # in treated) / mean # untreated) * 100. The number of plants in each core was recorded and then set aside after washing was completed. Individual plants were examined and the number of tillers recorded. All plants from a core sample were placed into a paper bag and held in a plant dryer set at 50 °C for 7 days. Plant samples were removed from the dryer, allowed to achieve room temperature, and then weighed.

Plots were drained when grain moistures were approximately 22% to 20% and the soil was allowed to dry. After 10 to 12 days, plots were shortened to 20 ft. A binder was used to cut and bind rice plants from the central 4 rows of the 9-row plot. Rice bundles were threshed with Vogel thresher. Grain was dried for 48 hr in a heated forced-air dryer. Grain moistures were taken with a moisture computer and yields were corrected to 12% moisture before analysis. Percent yield loss was calculated by the equation: percent loss = ((avg. wt. of treated – avg. wt. of untreated) / avg. wt. of treated) * 100.

RESULTS AND DISCUSSION

Thiamethoxam, the active ingredient in Cruiser® 5FS and CruiserMaxx®, is a second generation neonicotinoid insecticide. As with other neonicotinoid insecticides, thiamethoxam has a broad spectrum of activity, low application rates, excellent uptake and translocation in plants, and residual activity. Thiamethoxam has many benefits in rice: (1) seed treatment delivers the insecticide directly to the root zone and vegetative parts of plants; (2) allows the amount of chemical put into the environment to be reduced; (3) reduces any chance of chemical drift from the target area onto other crops or sensitive aquatic habitats; and (4) systemic activity is important to pest management because it reduces the risk of exposure of non-target organisms to the insecticide and specifically targets pests that injure the plant or damage economically important plant parts.

As mentioned in the introduction, the systemic insecticide rynaxypyr when applied at the same rate to conventional and hybrid rice had adequate control of rice water weevils in conventional rice, but had less control when used in hybrid rice. The question becomes, what is different about hybrid rice that would cause this problem? In rice breeding, hybrid rice is created by crossing two or more different parental lines. The improved qualities of the F1 generation are referred to as 'hybrid vigor' (heterosis). In temperate areas of rice production, hybrids have a yield advantage over pure-bred rice (conventional rice) due to: (1) a higher growth rate during early vegetative stages as a result of rapid expansion of leaf area and a higher biomass throughout the crop season; (2) a more efficient sink formation (more non-structural carbohydrate in the culm) after an early cessation of prolific tillering; (3) a high grain-filling percentage despite a large number of florets; and (4) efficient translocation of carbohydrates from the culm and sheath to developing grain (Yang et al., 2007).

The above-ground vegetative parts of hybrids have been observed in commercial fields to have more biomass than that of conventional plants. In this study, the hybrid was no exception to those observations. Plant biomass (plant dry weight) and tiller counts were significantly different between the hybrid and conventional rice varieties at three weeks after permanent flood (Table 1) and confirmed field observations. Tiller counts and biomass per plant of the hybrid and conventional rice varieties were also significantly influenced by seeding rate, but not equally. Significant interactions were found between variety and seeding rate for tillers and biomass per plant and averages from the hybrid were 2 to 3 times more than those of the conventional variety (Table1). This indicates that rice, in general, has a wide adaptability to plant density; but, the hybrid responded differently than the conventional to decreased plant density by increasing biomass and tillers. Larger plants in thin plant densities have been attributed to more efficient use of available nutrient resources and solar radiation (Horie et al., 2005).

Insect Counts

Rice water weevil larvae were significantly reduced by treatment of seed with thiamethoxam (Table 2). Nearly four times more weevils were found in untreated rice than in treated rice. Significant differences were also found between varieties where the per plant and per core infestation by rice water weevil on the hybrid was more than 3 and 1.5 times more, respectively, than the infestation observed on the conventional rice variety (Table 1). The number of weevils averaged over varieties and seed treatment was the same regardless of seeding rate (Table 3). This was somewhat unexpected and a disappointment, but most likely was due to the physical arrangement of plots and levees. All sub-subplots of a variety and insecticide treatment were contained within the same paddy and irrigation water. Thus, adult weevils could move easily from plot to plot.

A significant interaction was found between seed treatments and varieties for infestation of weevils per plant averaged over seeding rates. The number of weevil larvae per treated plant was 11 times less (91% control) for the conventional and only 3 times less (62% control) in the hybrid. These results on percent control are comparable to results from Hummel and Stout (2009) where the average percent control across all sample dates was 89% in a conventional rice variety (Cocodrie) and was only 66% in a hybrid (XL723) when both were treated with a comparable rate of insecticide rynaxypyr as a seed treatment. We must conclude that control of rice water weevils using the same rate of thiamethoxam (3.3 oz/100 lb of seed) is less on hybrid rice when compared to control on conventional rice. We hypothesized that the concentration of thiamethoxam, already reduced by low seeding rates, would also be influenced by plant size. Concentrations of thiamethoxam were not measured in the plants, yet it was confirmed that the hybrid responds to seeding rates by increasing plant size (biomass and tillers) greater than that of the conventional.

YIELDS

High grain yields are achieved either by increasing biomass production or harvest index (weight of grain as a percentage of the total plant weight) or both (Yoshida, 1981). Although the mechanism of why hybrids have better performance than other plant types is a controversial subject, hybrids in the temperate zones tend to have high yields due to a positive balance between biomass, numbers of florets per panicle, and numbers of filled florets. However, each of these components is dependent on the other and is determined at a particular stage in plant development. Biomass accumulation is important because non-structural carbohydrates stored in culms and sheaths are necessary during the grain-fill stage. Biomass accumulations begin during early stages of vegetative growth and tillering, but continue through the early part of the grain-fill stage. Biomass accumulation is also negatively associated with plant stand density, and data from this study confirmed this statement for both rice varieties. Dense plant stands can cause a reduction of tillering, vegetative growth, number of panicles, and number of grains per panicle (Yoshida, 1981). The number of grains per panicle is determined during the early reproductive stage and during the latter part of biomass accumulation.

Rice water weevil larvae cause damage by consuming young secondary roots and/or tunneling into the root and consuming a portion of older roots. The severity of damage and consequences may not be immediately noticeable. Plants with damaged roots may appear normal if the damage is slight or stunted and chlorotic if the damage is severe. But damage can cause an interruption of carbohydrate storage and growth of tillers due to resources being shifted to replace damaged roots. In addition, damage can reduce plant vigor, competitiveness for nutrients, influence formation of panicles, and reduce the number of grains per panicle. Thus, damage by weevils may result in yield reduction, but the amount of reduction depends on other factors such as the infestation level, root volume, and varietal susceptibility to damage.

Unfortunately not enough studies have been completed to determine the susceptibilities of Roy J and CL XL745 to yield losses from various rice water weevil infestations. In this study, the hybrid had a significantly higher yield than the conventional (Table1), but yields of neither variety were significantly reduced by the level of infestations from rice water weevils. The yield reduction between treated and untreated (averaged over seeding rates) was 2.6%, (5.0 bu/acre) for the conventional and 0.7% (1.7 bu/acre) for the hybrid. The conventional variety averaged 13.6 larvae per core in the untreated while the hybrid averaged 16.6 larvae per core. The conventional variety was more susceptible to damage by moderate levels of rice water weevil than the hybrid even with a lower percent control (62%). The hybrid had significantly more biomass (tillers and vegetative growth) three weeks after permanent flood than the conventional, and perhaps the dispersal of available thiamethoxam into a larger plant compromised control of weevil larvae. Even with more rice water weevil larvae causing damage to plants, the hybrid tolerated the moderate levels of weevils better than the conventional. The root system of the hybrid was undoubtedly bolstered by the large number of tillers produced by each plant. We can only be curious as to the level of rice water weevil infestation that can cause yield loss in the hybrid varieties.

SIGNIFICANCE OF FINDINGS

Seed treatment with thiamethoxam significantly reduced rice water weevil densities; however, percent control in conventional was 91% and 62% in the hybrid. The hybrid had significantly more biomass (tillers and vegetative growth) three weeks after permanent flood than the conventional, and the dispersal of available thiamethoxam into a larger plant (hybrid) likely compromised control of rice weevil larvae. Grain yields were not significantly different between treated and untreated seed, but the percentage yield loss was 0.7 % (1.7 bu/acre) for CL XL 745 and 2.6% (5 bu/acre) for Roy J. The conventional variety averaged 13.6 larvae per core in the untreated while the hybrid averaged 16.6 larvae per core. The hybrid CL XL 745 tolerated the moderate level of rice water weevils better than the conventional variety Roy J.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture for funding of this research and the Arkansas rice growers for check-off dollars that make the promotion board possible.

LITERATURE CITED

Bernhardt, J.L. 2009. Efficacy of Cruiser and Dermacor X-100 for control of rice water weevil, 2008. Arthropod Management Tests. 34: F48.

Horie, T., T. Shiraiwa, K. Homma, K. Katsura, S. Maeda, and H. Yoshida. 2005. Can yields of lowland rice resume the increases that they showed in the 1980s? Plant Prod. Sci. 8:259-274.

Hummel, N.A. and M.J. Stout. 2009. Rice water weevil control with Dermacor X-100 seed treatment, 2008. Arthropod Management Tests. 34:F6-51.

Walsh, K.D. and D.R. Johnson. 2003. Rice water weevil control in dry-seeded rice. In: R.J. Norman and J.-F. Meullenet (eds.). B.R. Wells Arkansas Rice Research Studies 2002. University of Arkansas Agricultural Experiment Station Research Series 504: 200-203. Fayetteville.

Way, M.O., R.G. Wallace, M.S. Nunez, and G.N. McCauley. 2004. Seed treatments for rice water weevil control, 2003. Arthropod Management Tests. 29:F72.

Yang, W., S. Peng, R.C. Laza, R.M. Visperas, and M.L. Dionisio-Sese. 2007. Grain yield and yield attributes of new plant type and hybrid rice. Crop Sci. 47:1393-1400.

Yoshida, S. 1981. Fundamentals of rice crop science. IRRI, Los Baños, Philippines.

Table 1. Main effect of variety (averaged over seed treatments and seeding rates) on stand count, number of rice water weevils, number of tillers, plant dry weight, and grain yield.

Variety	Stand count	Rice water weevils Plant	Rice water weevils Core	Tillers Plant	Tillers Core	Dry weight Plant	Dry weight Core	Yield
	(no./ft)	(no./plant)	(no./core)	(no./plant)	(no./core)	(lb/plant)	(lb/core)	(lb/acre)
Conventional	13.95	1.40	7.40	2.88	14.57	0.009	0.047	8660.3
Hybrid	8.13	4.47	11.44	8.26	21.64	0.025	0.063	10933.2
Probability > F¶	<.0001	<.0001	<.0001	0.0018	<.0001	<.0001	<.0001	<.0001

¶ Means are significantly different if the probability level is < 0.05.

Table 2. Main effects of seed treatments (averaged over varieties and seeding rates) on stand count, rice water weevils, tillers, plant dry weight, and grain yield.

Seed treatment	Stand count	Rice water weevils Plant	Rice water weevils Core	Tillers Plant	Tillers Core	Dry weight Plant	Dry weight Core	Yield
	(no./ft)	(no./plant)	(no./core)	(no./plant)	(no./core)	(lb/plant)	(lb/core)	(lb/acre)
Untreated	11.06	4.67	15.11	5.52	17.90	0.018	0.056	9720.7
Treated	11.03	1.20	3.74	5.63	18.30	0.016	0.054	9872.7
Probability > F¶	0.9886	<.0001	<.0001	0.8510	0.6393	0.2917	0.4325	0.6117

¶ Means are significantly different if the probability level is < 0.05.

Table 3. Main effects of seeding rate (averaged over seed treatment and variety) on yield, stand count, rice water weevil count, number of tillers, and plant dry weight.

Seeding	Stand	Rice water weevils		Tillers		Dry weight		
rate[¶]	count	Plant	Core	Plant	Core	Plant	Core	Yield
	(no./ft)	(no./plant)	(no./core)	(no./plant)	(no./core)	(lb/plant)	(lb/core)	(lb/acre)
Low	7.54 a[§]	3.23 a	10.00 a	7.30 a	18.71 a	0.022 a	0.059 a	9823.6 ab
Medium	10.89 b	2.88 a	8.58 a	5.26 b	18.12 a	0.016 b	0.053 a	9503.5 b
High	14.71 c	2.69 a	9.69 a	4.14 b	17.48 a	0.012 b	0.054 a	10063.1 a
Probability > F	<.0001	0.2689	0.4635	0.0003	0.2393	<.0001	0.0893	0.0497

[¶] The seeding rates were 45, 67.5 and 90 lb/a for Roy J, and 20, 30, and 40 lb/a for CL XL745.

[§] Means within a column followed by the same letter are not significantly different at the 0.05 probability level.

PEST MANAGEMENT: INSECTS

Impact of Insecticide Seed Treatments in Large Block Field Trials in Arkansas, 2009 to 2011

W.A. Plummer, G.M. Lorenz, N.M. Taillon,
B.C. Thrash, J.W. Fortner, and C.K. Colwell

ABSTRACT

The rice water weevil (RWW) is one of the most destructive insect pests of rice production in the mid-south. Large block trials were conducted in grower fields from 2009 to 2011 to evaluate the impact of insecticide seed treatments for control of rice water weevil larvae and yield. Results of studies conducted in Arkansas the past three years indicated the use of seed treatments provided excellent control of RWW larvae and increased yields.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus*, is one of the most widely distributed and destructive early season insect pests of rice (Way, 1990). It is estimated that 90% of rice fields in the mid-South are infested with this pest each year. Initiation of permanent flood attracts RWW adults to the field. Once plants are submerged, females begin to lay eggs in leaf sheaths which will hatch about 4 to 9 days later (Godfrey et al., 1997). The presence of adult weevils is indicated by the appearance of leaf scarring; however, the most damage is caused by larval feeding on the roots. Larvae can cause severe root pruning resulting in stand and yield loss. Severe damage can result in loss of roots to the point that plants will become dislodged from the soil and will float to the water's surface when disturbed (Bernhardt, 2001). Historically, producers have increased seeding rates to offset feeding damage, or drained the field after the initial flood was established until soil cracking occurs to control larval populations. With the increasing cost of seed and irrigation, many producers are looking for more economical practices.

The introduction of insecticide seed treatments has given producers a better option for RWW control. The objective of these studies was to evaluate the impact of insecticide seed treatments in large block field trials in typical grower fields.

PROCEDURES

Trials were located in several rice-producing counties throughout the state with 30 total locations from 2009 to 2011 (Fig. 1). Treatments in 2009 and 2010 included Cruiser 5 FS (Thiamethoxam) at a rate of 3.3 oz/cwt and Dermacor X-100 (Rynaxypyr) at a floating rate between 1.5 to 1.6 oz/cwt depending on seeding rate. In 2011, Cruiser 5 FS was replaced with CruiserMaxx Rice (7 oz/cwt)and NipsIt Inside (Clothianidin, 1.92 oz/cwt) was added. Plot design was a randomized complete strip block with 3 or 4 replications. RWW larvae were evaluated by taking 10 core samples per plot with a 4-in. diameter cylinder core sampler, 21 to 28 days after permanent flood. Each core was washed with water to loosen soil and remove larvae from the roots into a 40-mesh sieve. The sieve was then immersed in a saturated salt solution to float the larvae for counting. All samples were evaluated at the Lonoke Agricultural Extension and Research Center. Yield samples were taken and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 8 (Gylling Data Management, Inc., Brookings, S.D.), Analysis of Variance, and Duncan's New Multiple Range Test (*P* = 0.10).

RESULTS AND DISCUSSION

In 2009, Cruiser and Dermacor reduced RWW numbers by 78% and 81% compared to the untreated check and increased yields by 15 bu/acre (Table 1). In 2010, RWW numbers were not significantly different between any treatments, however; yields were 5 to 7 bu better than the UTC (Table 2). In 2011, all insecticide seed treatments reduced RWW numbers compared to the UTC and increased yields (Table 3).

SIGNIFICANCE OF FINDINGS

The purpose of these trials was to determine the efficacy of insecticide seed treatments for control of RWW. Results indicated seed treatments reduce RWW numbers and increased yields.

ACKNOWLEDGMENTS

We would like to express our appreciation to Arkansas rice producers, Rice Research and Promotion Board, Dupont, Syngenta, and Valent for their support. We would also like to acknowledge the county agents that helped with these trials.

LITERATURE CITED

Bernhardt, J.L. 2001 Rice Production Handbook “Insect Management in Rice” www.uaex.edu/otherAreas/publications/PDF/MP/192Chapter11.pdf

Godfrey, L.D., C. Wick, S.C. Scardaci, R. Webster, J. Hill, D.E. Bayer, and J.F. Williams. 1997. UC IPM Pest Management Guidelines:Rice. C.13-C.15.

Lorenz, G.M. III. 2006. Agriculture Rice. “Insect Management in Rice” www.aragriculture.org/instects/ricewaterweevil.htm

Way, M.O. 1990. Insect pest management in rice in the United States. *In:* B.R. Grayson, M.B. Green, and L.G. Copping (eds.). Pest management in Rice. Barking, UK: Elsevier Applied Science Publishers pp.181-189.

Table 1. Summary across locations, Large block, 2009.

Treatments	Rice water weevil	Yield
	(no./core)	(bu/acre)
UTC	37 a[¶]	168 b
Cruiser 5 FS (3.3 fl oz)	8 b	183 a
Dermacor X-100[§]	7 b	183 a

[¶] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

[§] Floating rate between 1.5 and 1.6 fl oz depending on seeding rate

Table 2. Summary across locations, Large block, 2010.

Treatments	Rice water weevil	Yield
	(no./core)	(bu/acre)
UTC	32 a[¶]	172 b
Cruiser 5 FS (3.3 fl oz)	7 a	177 a
Dermacor X-100[§]	12 a	180 a

[¶] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

[§] Floating rate between 1.5 and 1.6 fl oz depending on seeding rate.

Table 3. Summary across locations, Large block, 2011.

Treatments	Rice water weevil	Yield
	(no./core)	(bu/acre)
UTC	12 a[¶]	182 c
CruiserMaxx Rice(7 fl oz)	2 b	189 ab
Dermacor X-100[§]	2 b	187 a
NipsIt Inside (1.92 fl oz)	5 b	191 ab

[¶] Means followed by same letter do not significantly differ (*P* = 0.10 DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL

[§] Floating rate between 1.5 and 6 fl oz depending on seeding rate.

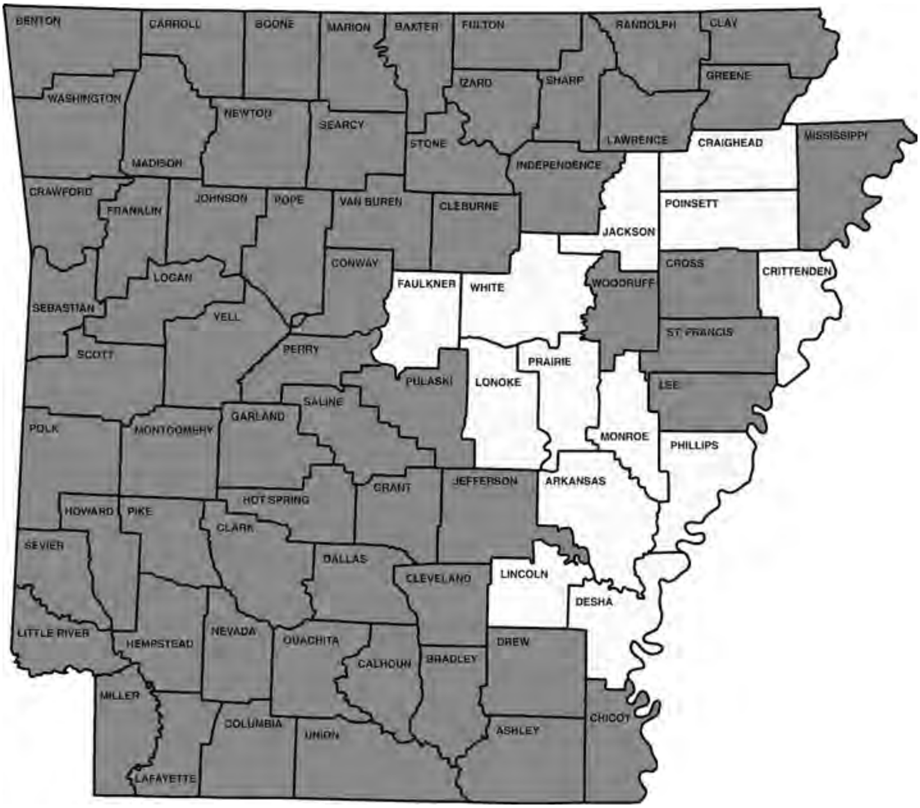


Fig. 1. Arkansas County Map of Trial Locations, 2009 to 2011.

PEST MANAGEMENT: INSECTS

Efficacy of Selected Insecticide Seed Treatments at Various Seeding Rates for Conventional, Clearfield, and Hybrid Cultivars

N.M. Taillon, G.M. Lorenz, W.A. Plummer,
B.C. Thrash, J.W. Fortner, and C.K. Colwell

ABSTRACT

The rice water weevil, *Lissorhoptrus oryzophilus*, is one of the most important insect pests of rice in Arkansas. Recently, insecticide seed treatments for control of larval feeding on the seedling root system have been made available to growers. In 2010 and 2011, insecticide seed treatments were evaluated for control of rice water weevil (RWW) in conventional, Clearfield, and hybrid cultivars at various seeding rates to determine if the efficacy of the seed treatments was consistent within each cultivar and seeding rates. Results indicated that across seeding rates and cultivar types, whether conventional, Clearfield, or hybrid, RWW numbers were reduced and yield was increased compared to the untreated check.

INTRODUCTION

Control of the rice water weevil (RWW) is a common practice in rice production, as it is one of the most destructive pests in rice. Until recent years, foliar application to control adults was the only effective chemical control available to producers. As rice water weevils arrive in the field at permanent flood, they feed on leaf blades leaving elongated scars parallel with the vein. Although leaf scars normally do not cause yield loss, the leaf scar is the first sign of infestation. Foliar applications, based on leaf scars and presence of adult weevils in the field can be less efficient if not applied before female adult weevils lay eggs; therefore, timing of application is crucial and often missed (Bernhardt, 2008), and foliar applications are unable to penetrate the soil to kill larvae feeding on the root system. With limited chemical options for control of the rice water weevil, producers have learned to rely on cultural practices. Studies have shown that oviposition of female rice water weevils is directly affected by the presence or absence of flood, as well as the depth of flood (Hesler and Grigarick, 1992, Stout et al., 2002). One method of control has been to drain fields infested with the weevil to reduce larval infestation; however, this practice is not economical due to the costs associated with flooding (Thompson et al., 1994). According to observations by Rolston and Rouse (1964) and Thompson and Quisenberry (1995), fields with lower seeding rates, are preferred by the adult weevils over those with higher seeding rates; and when larvae are present in thicker stands, maximum yields can still be achieved (Stevens, 2008). This has been adopted as another cultural practice by producers. The introduction of several different insecticide seed treatments has given producers the ability to limit or control rice water weevil damage in the larval stage (Wilf et al., 2008). With the increasing cost of seed, growers have a tendency to reduce seeding rates as much as possible to reduce production costs which can lead to a lower than adequate plant population. The objective of this study was to evaluate the effect of seeding rate within each cultivar on the efficacy of seed treatments, thus allowing growers to reduce seeding rates while still achieving optimum plant populations and yield levels.

PROCEDURES

The sites for the Conventional Seeding Rate trials in 2010 were Prairie County (Price Brothers), Lonoke County (Brantley), Conway County (Stobaugh), and Jackson County (Tommy Young). The sites for Clearfield Seeding Rate in 2010 were Lawrence County (Ray Stone) and St. Francis County (Pine Tree). The Hybrid Seeding Rate trial in 2010 was conducted in Prairie County (Hardke). Clearfield Seeding Rate trials in 2011 were located at (Bear Craft), St. Francis County (Pine Tree), and Arkansas County (Stuttgart). Trials for Hybrid Seeding Rate in 2011 were located in St. Francis County (Pine Tree), Craighead County (Joe Christian), and Prairie County (Price Brothers). Plot design was a randomized complete strip block with 4 replications. Seeding rates for conventional rice plots was 60, 90, and 120 lb/acre, Clearfield rice plots were planted at 50, 60, and 70 lb/acre, and Hybrid rice plots were planted at 20, 25, and 30 lb/acre in 2010, and 18, 23, and 28 lb/acre in 2011. RWW larvae were evaluated by taking 3 to 4 core samples per plot (3 in 2011, 4 in 2010) with a 4-in. diameter cylinder core sampler, 21 to 28 days after permanent flood. Each core was washed with water to loosen soil and remove larvae from the roots into a 40-mesh sieve. The sieve was then immersed in a saturated salt solution to float the larvae for counting. All samples were evaluated at the Lonoke Agricultural Extension and Research Center. Yield samples were taken and adjusted to 12% moisture. Data were processed using Agriculture Research Manager Version 8 (Gylling Data Management, Inc., Brookings, S.D.), Analysis Of Variance, and Duncan's New Multiple Range Test ($P = 0.10$).

RESULTS AND DISCUSSION

In the Conventional Seeding Rate 2010 trial, all treatments lowered rice water weevil populations across all seeding rates when compared the UTC (Table 1). NipsIt Inside was the only treatment to have increased yields at the 60 and 90 lb seeding rates, and Cruiser was the only treatment to increase yields at the 120 lb seeding rate.

In the Clearfield Seeding Rate Trial, 2010, all treatments at all seeding rates had fewer rice water weevils than the UTC (Table 2). At the 50 lb seeding rate, both Cruiser and NipsIt Inside increased yields over the UTC. Only NipsIt Inside had higher yields than the UTC within the 60 lb seeding rate, while at the 70 lb seeding rate only Cruiser provided greater yields compared to the UTC. In the Clearfield Rice Seeding Rate Trial, 2011, all seed treatments improved rice water weevil control across each respective seeding rate as compared to the UTC (Table 3). CruiserMaxx was the only treatment to increase yields over the UTC at the 50 lb seeding rate. At the 60 lb seeding rate, no treatments increased yields relative to the UTC. Within the 70 lb seeding rate, Dermacor X-100 was the only treatment to increase yield compared to the UTC.

No improved rice water weevil control was apparent when compared to the UTC in the Hybrid Seeding Rate, 2010 trial across seed treatments or seeding rates (Table 4). No yield differences were observed across seed treatments or seeding rates when compared to the UTC.

Insecticide Seed Treatment at Selected Seeding Rates in Hybrid Rice, 2011, showed Dermacor X-100 as the only treatment at the 18 lb seeding rate to reduce weevil numbers when compared to the UTC (Table 5). At the 23 and 28 lb seeding rate, all treatments reduced RWW numbers compared to the UTC at the same seeding rates. Dermacor X-100 and NipsIt Inside were the only treatments to increase yield above the UTC at the 18 lb seeding rate. No treatments produced yields higher than the UTC at the 23 and 28 lb seeding rate.

ACKNOWLEDGMENTS

We would like to express our appreciation to Arkansas rice producers, Rice Research and Promotion Board, Dupont, Syngenta, and Valent for their support. We would also like to acknowledge the county agents that helped with these trials.

LITERATURE CITED

Bernhardt, J.L. 2008. Control of rice water weevil by seed treatments with Rynaxypyr and Thiamethoxam. *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 571:109-113. Fayetteville.

Hesler, L.S. and A.A. Grigarick. 1992, Aquatic arthropods in California rice paddies: Effects of water drainage versus continuous-flood regimes on abundance and species composition. Environ. Entomol. 21:731-736.

Rolston, L.H. and P. Rouse. 1964. Some factors influencing larval infestations of the rice water weevil. J. Kans. Entomol. Soc. 37:29-35.

Stevens, W.E. 2008. Progress report of three year project. Unpublished.

Stout, M.J., M.R. Rizzio, L. Zou, and R. Roberts. 2002. Flooding influences ovipositonal and feeding behavior of the rice water weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 95(4):715-721.

Thompson, R.A., S.S. Quisenberry, F.K. N'Guessan, A.M. Heagler, and G. Giesler. 1994. Planting date as a potential cultural method for managing the rice water weevil (Coleoptera: Curculioidae) in water seeded rice in southwest Louisiana. J. Econ. Entomol. 87:1318-1324.

Thompson, R.A. and S.S. Quisenberry. 1995. Rice plant density effect on rice water weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 95:715-721.

Wilf, H., G.M. Lorenz III, K. Colwell, and N.M. Taillon, 2008. Efficacy of rice insecticide seed treatments for control of grape colaspis (*Colaspis brunnea*) and rice water weevil (*Lissorhoptrus oryzophilus* Kuschel). *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 571:135-139. Fayetteville.

Table 1. Conventional seeding rate, 2010: Summary across locations of rice water weevil (RWW) core sample and yield data.

	Seeding rate					
	60 lb		90 lb		120 lb	
Treatments	RWW	Yield	RWW	Yield	RWW	Yield
	(no./core)	(bu/acre)	(no./core)	(bu/acre)	(no./core)	(bu/acre)
Untreated check	19 a[¶]	171 d	19 a	172 d	14 b	175 bcd
Dermacor X-100	5 e	172 d	6 de	173 cd	6 de	175 bcd
Cruiser	10 c	173 cd	9 c	174 bcd	8 cd	180 a
NipsIt Inside	6 de	176 bc	4 e	177 ab	4 e	174 bcd

[¶] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 2. Clearfield seeding rate, 2010: Summary across locations of rice water weevil (RWW) core sample and yield data.

	Seeding rate					
	50 lb		60 lb		70 lb	
Treatments	RWW	Yield	RWW	Yield	RWW	Yield
	(no./core)	(bu/acre)	(no./core)	(bu/acre)	(no./core)	(bu/acre)
Untreated check	11 a[¶]	171 de	12 a	176 bcd	12 a	181 b
Cruiser 5 FS	9 b	177 bc	3 e	177 bcd	9 b	175 bcd
Dermacor X-100	7 bc	173 cde	4 e	177 bc	5 de	169 e
NipsIt Inside	9 b	180 b	8 bc	189 a	6 cd	179 bc

[¶] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 3. Insecticide seed treatment at selected seeding rates in Clearfield rice, 2011; Summary across locations of rice water weevil (RWW) core sample and yield data.

	Seeding rate					
	50 lb		60 lb		70 lb	
Treatments	RWW	Yield	RWW	Yield	RWW	Yield
	(no./core)	(bu/acre)	(no./core)	(bu/acre)	(no./core)	(bu/acre)
Untreated check	7 a[¶]	174 bcd	6 a	173 efg	4 b	180 bc
Dermacor X-100	1 f	172 fg	1 f	174 efg	1 f	180 a
CruiserMaxx Rice	4 bc	178 ab	2 ef	174 ef	3 cde	175 cde
NipsIt Inside	3 cd	172 g	2 def	173 fg	2 def	175 de

[¶] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 4. Hybrid seeding rate, 2010: Rice water weevil (RWW) core sample and yield data.

	Seeding rate					
	20 lb		25 lb		30 lb	
Treatments	RWW	Yield	RWW	Yield	RWW	Yield
	(no./core)	(bu/acre)	(no./core)	(bu/acre)	(no./core)	(bu/acre)
Untreated check	4.8 a[¶]	220.9 a	2.8 a	223.13 a	2.5 a	225.21 a
Dermacor X-100	4 a	225.66 a	3 a	232.56 a	1 a	226.04 a
Cruiser	4 a	222.09 a	4.3 a	226.04 a	2.8 a	214.63 a
NipsIt Inside	4.3 a	228.7 a	3 a	217.05 a	3.8 a	226.81 a

[¶] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 5. Insecticide seed treatment at selected seeding rates in hybrid rice, 2011: Rice water weevil (RWW) core sample and yield data.

	Seeding rate					
	18 lb		23 lb		28 lb	
Treatments	RWW	Yield	RWW	Yield	RWW	Yield
	(no./core)	(bu/acre)	(no./core)	(bu/acre)	(no./core)	(bu/acre)
Untreated check	21 bc[¶]	165 cd	26 a	174 ab	28 a	179 a
Dermacor X-100	7 e	180 a	6 e	180 a	5 e	166 d
Cruiser	16 cd	171 bc	13 d	184 a	13 d	181 a
NipsIt Inside	23 ab	182 a	14 d	179 a	17 cd	177 a

[¶] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Efficacy of Selected Insecticides for Control of Rice Stink Bug, *Oebalus pugnax*, in Arkansas

B.C. Thrash, G.M. Lorenz, N.M. Taillon,
W.A. Plummer, C.K. Colwell, and J.W. Fortner

ABSTRACT

The 2011 rice growing season experienced extremely high populations of rice stink bug, *Oebalus pugnax*. These high numbers proved to be more difficult to control than in typical years. Trials were conducted to evaluate selected insecticides for control of rice stink bug. Results indicated multiple compounds were effective in providing control; however, in seasons such as this, multiple insecticide applications in many cases were required to bring numbers below threshold.

INTRODUCTION

Rice stink bug (*Oebalus pugnax*) can be an important pest of rice. Early feeding from pre-fertilization through early milk stage causes the heads to blank or abort resulting in yield reduction. Feeding during the milk-to-soft-dough stage results in kernel shrinkage or slight discoloration commonly referred to as "pecky rice" (Johnson et al., 2002). Past trials have shown standard insecticides used to control rice stink bug hold up well in situations when typical populations of this pest are present. However, in years with extremely high pressure, such as 2011, stinkbug numbers can increase rapidly in just a few days. The enormous influx of this pest into fields can overwhelm standard insecticides. During these situations the insecticide choice and the rate applied can have significant effects on achieving control and in some cases multiple applications may be required to reduce numbers below Cooperative Extension Service thresholds.

PROCEDURES

Trials were located in Arkansas in Lonoke and Lawrence counties. Plots were 12 ft × 40 ft in a randomized complete block design with four replications. Treatments were applied on the grower field at 50% heading. Insecticides were applied with a hand boom fitted with TX6 hollow cone nozzles with a 19-in. nozzle spacing and spray volume of 10 gal/acre at 40 psi. Rice stink bug numbers were evaluated by taking 10 sweeps per plot with a standard 15-in. sweep net and compared using the Cooperative Extension Service threshold of 5 rice stink bugs per 10 sweeps. Data were processed using Agriculture Research Manager Version 8 (Gylling Data Management, Inc., Brookings, S.D.), Analysis Of Variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

RESULTS AND DISCUSSION

In the first trial, no differences were observed 3 days after the first spray application (3 DAT 1) (Table 1). At 6 DAT 1, all treatments provided control except the low rates of Karate, Declare, and Mustang Max. Endigo ZC, Endigo ZCX, Centric, Tenchu, and the high rates of Karate and Declare provided the greatest control of stink bugs. No control was observed 10 DAT 1 which indicated a new influx of rice stink bugs into the trial area and loss of residual control. All treatments reduced rice stink bug numbers below threshold 3 DAT 2 except Endigo ZC (Table 2). The untreated check remained above threshold through the last rating date while all treatments remained below threshold at 6 and 10 DAT 2.

In the second trial, all treatments reduced stink bug numbers below threshold at 3 and 6 DAT (Table 3). No differences were observed in the amount of control provided between treatments. Tank mixes did not increase control over single products.

The third trial contained an untreated check (UTC), Diamond, Karate, and Diamond plus Karate (Table 4). Karate and Diamond plus Karate reduced stink bug numbers compared to the UTC at 3 and 6 DAT 1. During these two sampling dates, Diamond alone did not lower insect populations compared to the UTC. At 10 DAT 1, no treatments were better than the UTC. At 3 and 6 DAT 2 all treatments reduced rice stink bug numbers compared to the UTC. Karate plus Diamond did not increase control over Karate alone.

SIGNIFICANCE OF FINDINGS

Heavy reliance on pyrethroids for control of rice stink bug has led to resistance in some states. Alternate insecticides such as Tenchu and Centric may help lessen the potential for increasing resistance to pyrethroids. The information from these trials will help in making current and future recommendations for effective and economic control of rice stink bug.

ACKNOWLEDGMENTS

We would like to thank the grower, Brandon Parker, for allowing us to use his field and Keith Perkins, Lonoke County Extension Agent for his help. Funding for this project was provided by the Rice Research and Promotion Board, Syngenta, Cheminova, and FMC.

LITERATURE CITED

Johnson, D.R., J. Bernhardt, J. Greene, G. Lorenz, and G. Studebaker. 2002. Rice stink bug in Arkansas. http://www.uaex.edu/Other_Areas/publications/PDF/FSA-7057.pdf

Table 1. Rice stink bug counts, 2011.

		Average rice stink bug count		
Treatment	Rate	7/11/2011 3 DAT 1	7/14/2011 6 DAT 1	7/18/2011 10 DAT 1
		---------------	(no./10 sweeps)	---------------
Untreated check		43.3 a[§]	83.3 a	160.8 a
Endigo ZC[¶]	5 oz/acre	17.0 a	17.5 e	186.5 a
Endigo ZCX[¶]	5 oz/acre	9.3 a	15.3 e	165.0 a
Karate Z	1.6 oz/acre	28.5 a	60.3 abc	131.8 a
Karate Z	1.8 oz/acre	20.5 a	48.0 bcd	105.0 a
Karate Z	2.56 oz/acre	17.3 a	35.8 cde	109.3 a
CENTRIC[¶]	3.5 oz/acre	31.0 a	26.0 de	151.0 a
Tenchu[¶]	9 oz/acre	19.0 a	22.8 de	162.8 a
Declare	1.54 oz/acre	47.3 a	72.3 ab	110.5 a
Declare	2.05 oz/acre	37.5 a	39.5 cde	111.8 a
Mustang Max	2.65 oz/acre	27.8 a	62.5 abc	125.5 a
Mustang Max	4 oz/acre	24.5 a	47.0 bcd	124.3 a

[§] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

[¶] Products not yet labeled for use in rice.

Table 2. Rice stink bug counts, 2011.

		Average rice stink bug count		
		7/23/2011	7/26/2011	7/29/2011
Treatment	Rate	3 DAT 2	7 DAT 2	10 DAT 2
		(no./10 sweeps)		
Untreated check		25.5 a[§]	30.5 a	6.5 a
Endigo ZC[¶]	5 oz/acre	5.3 b	3.0 b	0.3 b
Endigo ZCX[¶]	5 oz/acre	2.5 b	2.0 b	0.5 b
Karate Z	1.6 oz/acre	2.8 b	2.3 b	1.5 b
Karate Z	1.8 oz/acre	1.0 b	2.8 b	0.3 b
Karate Z	2.56 oz/acre	1.3 b	1.5 b	0.5 b
CENTRIC[¶]	3.5 oz/acre	2.0 b	2.0 b	0.8 b
Tenchu[¶]	9 oz/acre	1.3 b	1.5 b	0.0 b
Declare	1.54 oz/acre	4.0 b	1.5 b	1.8 b
Declare	2.05 oz/acre	1.0 b	1.5 b	0.0 b
Mustang Max	2.65 oz/acre	4.3 b	0.5 b	0.3 b
Mustang Max	4 oz/acre	2.3 b	1.8 b	1.0 b

[§] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

[¶] Products not yet labeled for use in rice.

Table 3. Tankmix trial No. 1.

		Average rice stink bug count	
		7/26/2011	7/29/2011
Treatment	Rate	3 DAT	6 DAT
		(no./10 sweeps)	
Untreated check		40.5 a	5.8 a
Karate Z	2.56 oz/acre	0.8 b	0.3 b
Karate Z + Sevin	1.83 oz/acre + 2 pt/acre	0.3 b	0.3 b
SEVIN	3 pt/acre	1.5 b	0.5 b
Karate Z + Malathion	1.83 oz/acre + 1 pt/acre	1.0 b	0.5 b
Malathion	1 pt/acre	2.0 b	1.5 b

[§] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

Table 4. Tankmix trial No. 2.

		Average rice stink bug count				
		7/11/2011	7/14/2011	7/18/2011	7/26/2011	7/29/2011
Treatment	Rate	3 DAT-1	6 DAT-1	10 DAT-1	3 DAT-2	6 DAT-2
		(no./10 sweeps)				
Untreated check		190.8 a	106.3 a	83.8 a	46.8 a	8.5 a
Diamond[¶]	9 oz/acre	182.8 a	85.0 ab	98.5 a	11.5 b	1.8 b
Diamond[¶] + Karate Z	9 oz/acre + 1.6 oz/acre	42.5 b	64.5 bc	74.8 a	1.8 b	0.8 b
Karate Z	1.6 oz/acre	52.0 b	55.5 c	83.8 a	0.8 b	0.5 b

[§] Means followed by same letter do not significantly differ (*P* = 0.10, DNMRT). Mean comparisons performed only when AOV Treatment P (F) is significant at mean comparison OSL.

[¶] Products not yet labeled for use on rice.

PEST MANAGEMENT: WEEDS

Pollen-Mediated Movement of Herbicide Resistance in Barnyardgrass

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

ABSTRACT

Barnyardgrass (*Echinochloa crus-galli*) is an important herbicide-resistant weed in mid-South rice production systems, but the role of pollen-mediated gene flow in the spread of herbicide resistance is poorly understood for this species. An experiment was conducted in the summer of 2010 at the Agricultural Experimental Station, Fayetteville, Ark., to quantify pollen-mediated gene flow in barnyardgrass, using quinclorac resistance as the marker. The experiment was implemented using a Nelder-wheel design consisting of eight directions. The resistant population (male parent) was placed in each direction at nine different distances from the center: 1.7, 3.3, 6.6, 9.8, 16.4, 32.8, 65.6, 114.8, and 164 feet. Weather parameters, including wind direction, wind speed, air temperature, and relative humidity were recorded. Upon maturity, inflorescences were harvested four times at weekly intervals and seeds were germinated in plastic trays in the greenhouse. At the 2- to 3-lf stage, seedlings were sprayed with quinclorac at 1 lb ai/acre and a week later, survivors were sprayed with quinclorac at 5 lb ai/acre. Gene flow was quantified as the number of surviving seedlings out of the total seedlings emerged. Gene flow was observed within a short-distance of up to 32.8 ft, except for one event at 65.6 ft. Gene flow declined with distance from the source with an average frequency of 3% at 1.7 ft, although frequencies of up to about 10% were observed at this distance. Wind speed exhibited a positive influence on gene flow, whereas air temperature and relative humidity influenced negatively on gene flow.

INTRODUCTION

Gene flow is the transfer of alleles from one population to another, and in plant populations, gene flow typically occurs through the movement of seed, vegetative propagules, and pollen. Although gene flow can promote genetic homogeneity among arable weed populations at the landscape level (Delye et al., 2010), this process can have evolutionary consequences in the recipient population. Gene flow can introduce advantageous alleles to a population and, when coupled with a strong selection force, the population spread can be unidirectional (Slatkin, 1976; Morjan and Rieseberg, 2004). Traditionally, gene flow and transfer of alleles has not been considered a management issue in arable weed populations. This view has been changed with the evolution of herbicide resistance in arable weed communities because gene flow can introduce new resistance alleles to a previously susceptible population. If pollination is mediated by insects or wind, then the distance of gene flow can be greater. For instance, Busi et al. (2008) demonstrated the transfer of sulfometuron resistance among wind-pollinated rigid ryegrass (*Lolium rigidum*) populations that were 1.9 miles apart.

Barnyardgrass is an important weed of rice worldwide and herbicide resistance in barnyardgrass is a serious issue confronting sustainable rice production in the mid-South. Barnyardgrass populations resistant to propanil and/or quinclorac have been widespread in this region. However, the processes contributing to the rapid spread of resistance remain largely unknown. In particular, the role of pollen-mediated gene flow in the spread of resistance has been poorly understood for this species. The primary objective of this study was to understand the level of pollen-mediated gene flow in barnyardgrass.

PROCEDURES

The study was conducted at the Agricultural Research and Extension Center at the University of Arkansas, Fayetteville, during the summer of 2010. Quinclorac resistance was used as the marker for assessing gene flow. The resistant (R) and known susceptible (S) populations used in this study were collected from rice production fields in eastern Arkansas. Initial characterization revealed that resistance in the R population was conferred by a single, completely dominant nuclear gene. The R and S populations were established in plastic trays in the greenhouse. At the 2- to 3-lf stage, the R seedlings were sprayed with quinclorac at 0.61 lb ai/acre to ensure that the individuals were resistant. At the time of tillering, seedlings were transplanted to 5-gal buckets (4 seedlings each) containing potting soil mix, and plants were allowed to grow in an open environment. At panicle initiation, the S and R populations were transported to the experimental field.

The experiment was implemented in a Nelder-wheel design (Nelder, 1962) consisting of 8 directions (Fig. 1). The R population was used as the pollen donor (male parent) and placed in the center (9.8 ft in diameter), whereas the S population was used as the pollen recipient (female parent) and placed at 9 different distances from the pollen source at each direction. The distances include 1.7, 3.3, 6.6, 9.8, 16.4, 32.8, 65.6, 114.8, and 164 feet. The barnyardgrass plants were watered and fertilized as required. A weather station was installed in the experimental site to record weather parameters, including wind direction, wind speed, air temperature, and relative humidity. Upon seed maturity, panicles were harvested four times at weekly intervals. The seeds were scarified using conc. H_2SO_4 for 20 min and were planted in the greenhouse using plastic trays containing potting soil mix. A sampling strategy given by Alibert et al. (2005) was adapted. According to this, 4,606 seeds were required to detect gene flow at levels as low as 0.1% with 99% confidence. The seedlings were sprayed with quinclorac at 1 lb ai/acre at the 2- to 3-lf stage and again at 5 lb ai/acre a week later. Seedling survival was documented at 21 days after the first application. Gene flow was determined as the number of survivors out of total seedlings emerged. The presence of gene transfer in the survivors was confirmed by verifying progeny segregation in randomly selected individuals.

RESULTS AND DISCUSSION

Results showed pollen-mediated gene transfer is possible in barnyardgrass, although at low levels within short distances. In this study, the majority of the gene flow was noted within a short distance of 32.8 ft, except for one event at 65.6 ft (Fig. 2). Overall, the level of gene flow declined with distance from the source population, irrespective of direction. The exponential model predicted that gene flow was 3% at the shortest distance of 1.7 ft (Fig. 3). The direction at which gene flow occurred to the farthest distance (65.6 ft) corresponded to a high wind event (~18 kmph, data not shown). However, the number of wind events did not influence gene flow, suggesting that wind speed was perhaps more important. Air temperature and relative humidity negatively influenced gene flow, possibly via their effect on pollen viability and wind-borne transportation.

Overall, very long-distance transfer of herbicide resistance alleles is less likely to occur through pollen-mediated transfer in barnyardgrass. Within short distances, the levels of gene flow were very low, but thresholds rarely matter in the context of herbicide resistance transfer and spread because a single allele could be sufficient to establish resistance in new sites, given the enormous selection pressure. In this regard, Slatkin (1976) suggested that selection pressure is more important than the rate of gene flow for the spread of advantageous alleles in the population.

SIGNIFICANCE OF FINDINGS

Although long-distance, pollen-mediated transfer of herbicide resistance is less likely in barnyardgrass, gene flow at the observed levels can still result in the movement of resistance alleles among fields within close proximity to one another and also aid the expansion of resistant patches through short-distance pollen movement and outcrossing. In the context of herbicide resistance mitigation and management, flowering in any suspected resistant patch should be prevented (as opposed to prevention of seed production). If resistance is suspected in neighboring fields, prevention of barnyardgrass seed production may be warranted, especially in the field boundaries, because a single outcrossing event can introduce the resistant trait to the previously susceptible population. The findings will also be valuable for parameterizing herbicide resistance simulation models for barnyardgrass.

ACKNOWLEDGMENTS

Funding for this research was provided by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Alibert, B., H. Sellier, and A. Soure. 2005. A combined method to study gene flow from cultivated sugar beet to ruderal beets in the greenhouse and open field. Europ. J. Agron. 23:195-208.

Busi, R., Q. Yu, R. Barrett-Lennard, and S. Powles. 2008. Long distance pollen-mediated flow of herbicide resistance genes in *Lolium rigidum*. Theor. Appl. Genet. 117:1281-1290.

Delye, C., J.A.J. Clement, F. Pernin, B. Chauvel, and V. Le Corre. 2010. High gene flow promotes the genetic homogeneity of arable weed populations at the landscape level. Basic Appl. Ecol. 11:504-512.

Morjan, C.L. and L.H. Rieseberg. 2004. How species evolve collectively: implications of gene flow and selection for the spread of advantageous alleles. Mol. Ecol. 13:1341-1356.

Nelder, J.A. 1962. New kinds of systematic designs for spacing experiments. Biometrics 18:283-307.

Slatkin, M. 1976. The rate of spread of an advantageous allele in a subdivided population. Pages 767-780 *In:* S. Karlin and E. Nevo (eds.). Population Genetics and Ecology. Academic Press, Inc; New York.

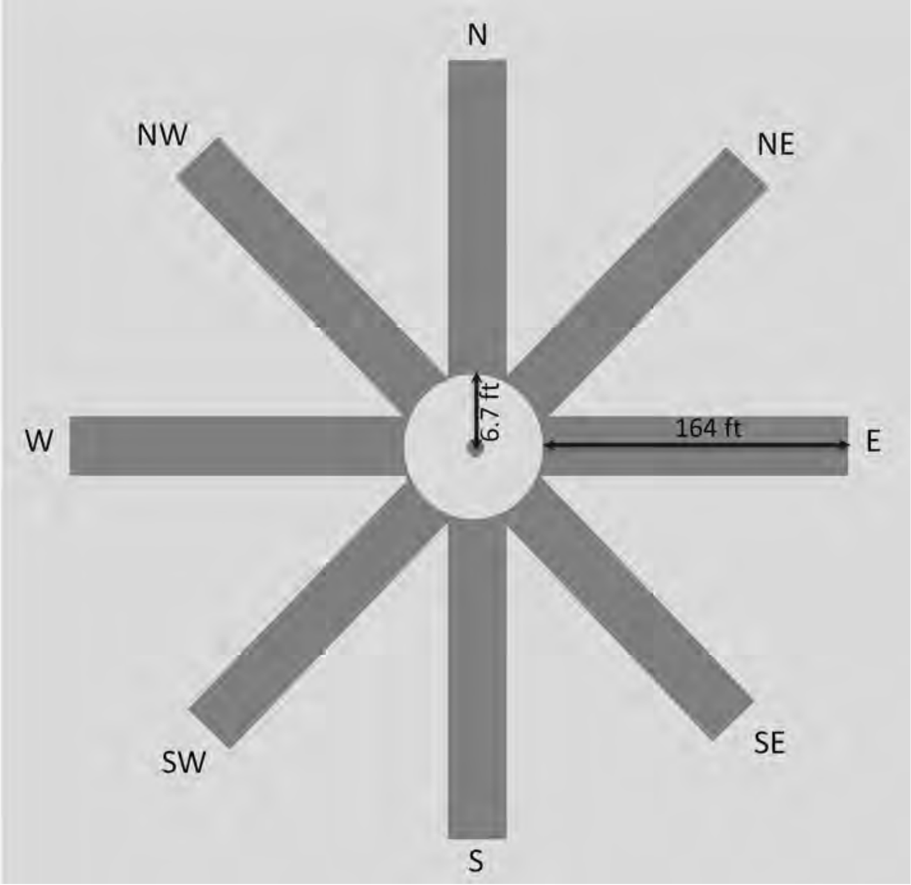


Fig. 1. Experimental design for quantifying pollen-mediated gene flow in barnyardgrass. The pollen source (male parents) was placed at the center of the wheel, whereas the pollen recipients (female parents) were placed at different distances at each direction.

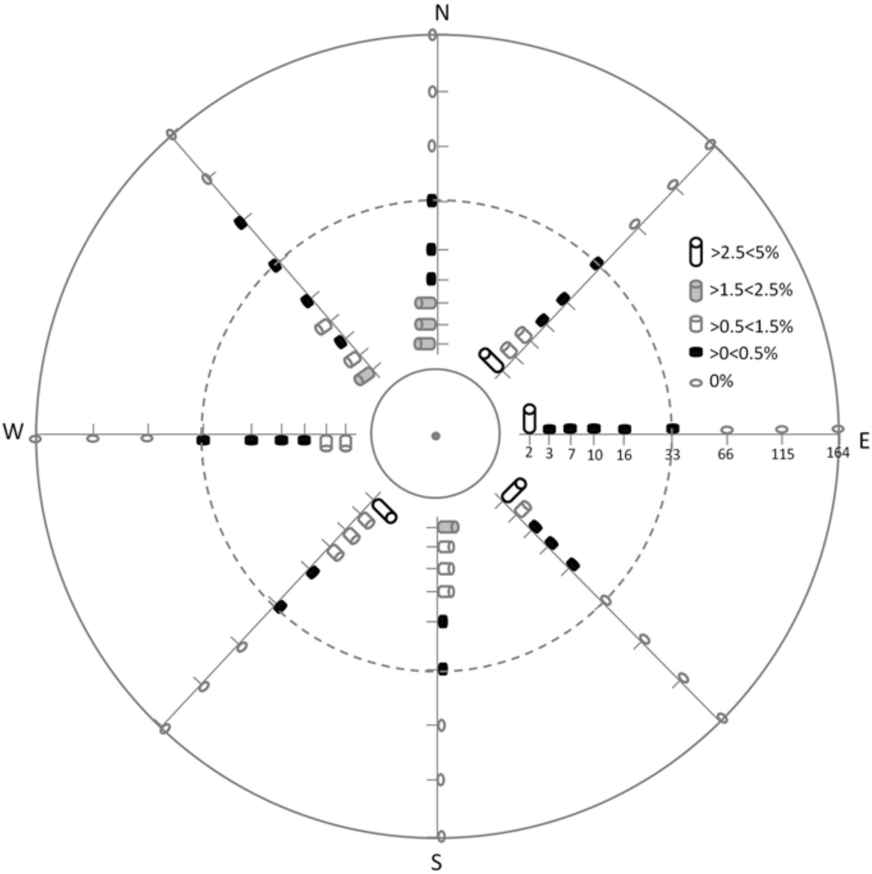


Fig. 2. Observed levels of gene flow at various distances from the center at the eight different directions.

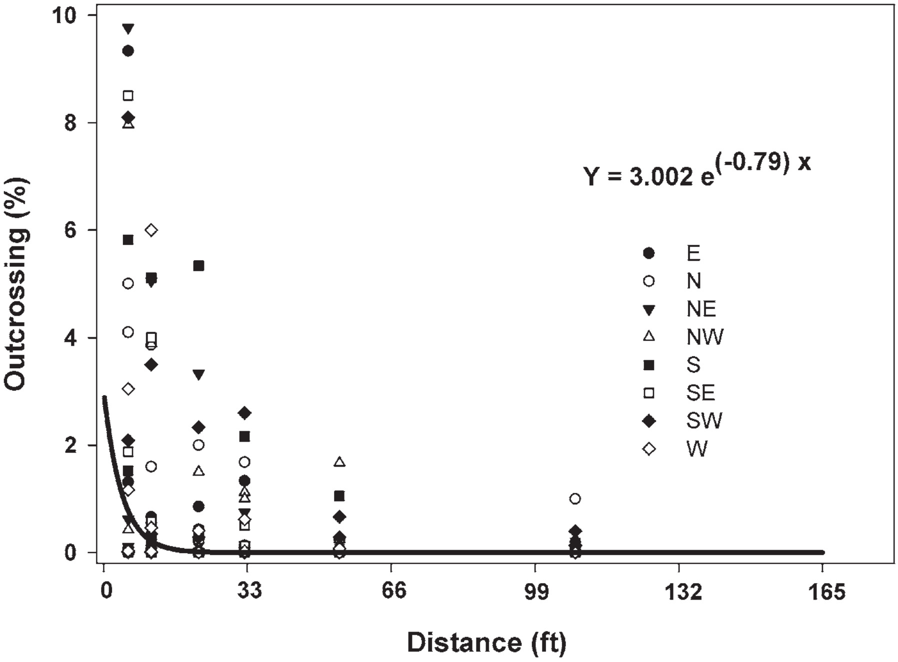


Fig. 3. Effect of distance from the pollen source on the levels of gene flow, illustrated by an exponential decay function.

Quinclorac Resistance in Barnyardgrass Is Conferred by a Single, Completely Dominant Nuclear Gene

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

ABSTRACT

Quinclorac-resistant barnyardgrass (*Echinochloa crus-galli*) populations are widespread in mid-South rice fields, but little is known about the genetic mechanisms of resistance. Experiments were conducted in a greenhouse at the Agricultural Experimental Station, Fayetteville, Ark., to understand the mode of inheritance of quinclorac resistance in a resistant (R) barnyardgrass population collected from a rice field in eastern Arkansas. The susceptible (S) population used in the study was also collected from the same region. Initial characterization revealed that the R and S populations were homozygous. Subsequently, these populations were subjected to a dose-response analysis. The R populations were used as male parents for crossing, which occurred naturally under field conditions. The F_1 progeny was sprayed with quinclorac at 0.61 lb ai/acre, a dose that killed all S plants, which was determined using the dose-response analysis. Twelve F_1 survivors (i.e., successful crosses) were grown in pots, and the plants were covered individually using polyethylene mesh bags to facilitate self-pollination. The F_2 seeds were harvested upon maturity, and 150 F_2 seedlings were established for each cross in plastic trays. At the 2- to 3-lf stage, F_2 seedlings were sprayed with quinclorac at 0.61 lb/acre. Phenotypic observations were carried out at 21 days after application to document segregation. The F_2 progeny exhibited two different phenotypes, S and R, with no intermediate phenotype, indicating that resistance is conferred by completely dominant gene(s). The chi-square analysis of the F_2 segregants confirmed that resistance is conferred by a single gene. Thus, quinclorac resistance in the barnyardgrass population used in this experiment was conferred by a single, completely dominant gene with a Mendelian pattern of inheritance.

INTRODUCTION

Barnyardgrass is the sixth most important herbicide-resistant weed worldwide (Heap, 2011). Quinclorac-resistant barnyardgrass has been a serious issue in rice production systems of the Mississippi Delta region. In this region, the first incidence of quinclorac-resistant barnyardgrass was confirmed in Arkansas rice in 1999 (Lovelace et al., 2000). A consultant survey conducted in 2006 revealed that quinclorac-resistant barnyardgrass has been widespread, infesting about 30% of the scouted rice fields in Arkansas (Norsworthy et al., 2007). The annual barnyardgrass resistance screening program at the University of Arkansas further confirms the prevalence of this problem (Norsworthy et al., 2011). However, the genetic mechanisms of quinclorac resistance remain unknown for barnyardgrass. The mode of inheritance of resistance allele(s) plays an important role in the rapidity of resistance evolution and spread.

So far, quinclorac resistance has been reported in barnyardgrass (Lopez-Martinez et al., 1997; Lovelace et al., 2000), false cleavers (*Galium spurium*) (Van Eerd et al., 2004), and smooth crabgrass (*Digitaria ischaemum*) (Koo et al., 1994). According to the only available inheritance study on quinclorac resistance (in false cleavers), it was a single, recessive nuclear trait (Van Eerd et al., 2004). The mode of inheritance of quinclorac resistance in barnyardgrass, which is not known, is the focus of this experiment.

PROCEDURES

A classical genetic approach was followed in studying the mode of inheritance of quinclorac resistance, as shown by Van Eerd et al. (2004), Ng et al. (2004), and Davis et al. (2010). Experiments were conducted in a greenhouse at the University of Arkansas Agricultural Experimental Station in Fayetteville, Ark., from September 2010 to November 2011. The quinclorac-resistant (R) and -susceptible (S) barnyardgrass populations (i.e., parents) used in the experiment originated from rice production fields in eastern Arkansas.

Prior to testing inheritance, the R and S populations were subjected to initial experimentation to achieve homogeneous and homozygous parent populations. About 1,000 seeds of each parent were planted in plastic trays in the greenhouse and the seedlings were sprayed with a field application rate of quinclorac (0.5 lb/acre) at the 2- to 3-lf stage. All S plants were killed, whereas all R plants survived at this application rate. Ten R survivors were randomly selected and transplanted to individual pots containing potting soil mix and allowed to grow until maturity. To facilitate self-pollination, the plants were covered individually with perforated mesh bags with pore sizes small enough to prevent the entry of foreign pollen. Upon maturity, seeds from each plant were harvested separately, planted in plastic trays, and the seedlings were sprayed with quinclorac at 0.5 lb/acre at the 2- to 3-lf stage. Survivors were documented at 21 days after treatment (DAT). This procedure was also carried out using 10 S seedlings to further confirm that the progenies were susceptible.

Following this, dose-response analyses were carried out on the parents at the following rates: R – 0.25, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, and 16.0 lb/acre; S – 0.0078, 0.0156, 0.0313, 0.0625, 0.125, 0.25, 0.375, 0.5, and 0.75 lb/acre. For each dose, 20 seedlings were sprayed using a spray chamber calibrated to deliver 20 gal/acre. The dose-response experiment was repeated to confirm the findings. Data pertaining to the dose-response experiment were analyzed using the PROBIT procedure of the statistical analysis software (SAS) version 9.1 (SAS Institute, Cary, N.C.).

The next step involved the production of hybrids between the R and S population. Crossing occurred naturally under field conditions in a parallel experiment involving the R population as the male parent and the S population as the female parent. Seeds collected from the S population were planted in the greenhouse and the successful crosses (i.e., F_1 progeny of R X S) were selected by applying quinclorac at 0.61 lb/acre, a dose sufficient to cause 100% mortality of the S population, determined using the PROBIT analysis (Fig. 1). A dose-response analysis was carried out on the F_1 progeny at rates including 5x, 10x, 15x, 20x, and 25x rates of 0.61 lb/acre. Twelve F_1 survivors were randomly selected and self-pollinated to obtain F_2 progeny. Upon maturity, F_2 seeds were harvested, scarified, and germinated in petri dishes in a growth chamber. At the 1-lf stage, 150 seedlings were planted in nursery trays to determine the pattern of segregation. The seedlings were sprayed with quinclorac at 0.61 lb/acre at the 2- to 3-lf stage and phenotypic observations were carried out at 21 DAT. Whether the observed frequencies of F_2 progeny differed from hypothesized values (1:3; 1:15) was tested using a chi-square goodness of fit test using the PROC FREQ procedure of SAS.

RESULTS AND DISCUSSION

Initial characterization revealed that the R and S populations used in this study were homogeneous and homozygous. The dose-response analysis showed that all the R parents (RR) survived the highest herbicide dose used in the study (i.e., 16 lb/acre), whereas a dose of 0.61 lb/acre was required to achieve 100% mortality in the S (rr) population (Fig. 1). Thus, the R population exhibited >26-fold resistance compared with the S population. The phenotype of the F_1 progeny (Rr) resembled the R parents and it exhibited a high level of resistance to quinclorac, up to 25 times the rate of 0.61 lb/acre. The F_2 progeny comprised two different phenotypes, S and R, with no intermediate phenotype, indicating the action of completely dominant gene(s). A chi-square analysis of the F_2 phenotypes revealed that the F_2 segregants conformed to a frequency of 3R:1S (Table 1), meaning that resistance is conferred by a single gene. Thus, resistance to quinclorac in the barnyardgrass population used in this experiment was conferred by a single, completely dominant nuclear gene with Mendelian pattern of inheritance. The action of a single, dominant nuclear gene suggests that resistance could evolve and spread quickly in this population.

SIGNIFICANCE OF FINDINGS

The determination of the mode of inheritance of quinclorac resistance in barnyardgrass will further our understanding of the genetics of herbicide resistance in arable weed communities. This information is valuable for developing herbicide-resistance simulation models and for making management decisions.

ACKNOWLEDGMENTS

Funding for this research was provided by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Davis, V.M., G.R. Kruger, S.G. Hallett, P.J. Tranel, and W.G. Johnson. 2010. Heritability of glyphosate resistance in Indiana horseweed (*Conyza canadensis*) populations. Weed Sci. 58:30-38.

Heap, I. 2011. The international survey of herbicide resistant weeds. http://www.weedscience. com. Accessed: 13 December 2011.

Koo, S.J., J.C. Neal, and J.M. DiTomaso. 1994. Quinclorac-induced electrolyte leakage in seedling grasses. Weed Sci. 42:1-7.

Lopez-Martinez, N., G. Marshall, and R. De Prado. 1997. Resistance of barnyardgrass (*Echinochloa crus-galli*) to atrazine and quinclorac. Pest. Sci. 51:171-175.

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

Ng, C., W. Ratnam, S. Surif, and B.S. Ismail. 2004. Inheritance of glyphosate resistance in goosegrass (*Eleusine indica*). Weed Sci. 52:564-570.

Norsworthy, J.K., M. McClelland, G. Griffith, S.K. Bangarwa, and J. Still. 2011. Evaluation of cereal and Brassicaceae cover crops in conservation-tillage, enhanced, glyphosate-resistant cotton. Weed Technol. 25:6-13.

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.

SAS Institute. 2003. SAS 9.1 for windows. SAS Institute Inc, Cary, N.C., USA.

Van Eerd, L.L., M.D. McLean, G.R. Stephenson, and J.C. Hall. 2004. Resistance to quinclorac and ALS-inhibitor herbicides in *Galium spurium* is conferred by two distinct genes. Weed Res. 44:355-365.

Table 1. Chi-square test for F_2 progenies for the activity of a single gene (3:1) or two genes (15:1) in conferring resistance to quinclorac.

				Test for 3:1 (R:S[a])		Test for 15:1 (R:S)	
Cross	S	R	Total	$\chi^2_{0.05,1}$	*P*	$\chi^2_{0.05,1}$	*P*
1	28	117	145	2.5	0.11	33.75	<0.0001
2	35	115	150	0.22	0.64	61.47	<0.0001
3	32	118	150	1.08	0.30	47.33	<0.0001
4	33	117	150	0.72	0.40	51.84	<0.0001
5	36	114	150	0.08	0.78	66.59	<0.0001
6	34	116	150	0.44	0.51	56.55	<0.0001
7	34	116	150	0.44	0.51	56.55	<0.0001
8	33	117	150	0.72	0.40	51.84	<0.0001
9	39	110	149	0.11	0.74	84.15	<0.0001
10	41	109	150	0.44	0.51	95.26	<0.0001
11	42	108	150	0.72	0.40	101.61	<0.0001
12	34	115	149	0.38	0.54	57.27	<0.0001
Total (O)	421	1372	1793	2.21	0.14	748	<0.0001
Total (E) 1:3	448.25	1344.75					
Total (E) 1:15	112	1681					

[a] S = susceptible; R = resistant; O = observed; and E = expected.

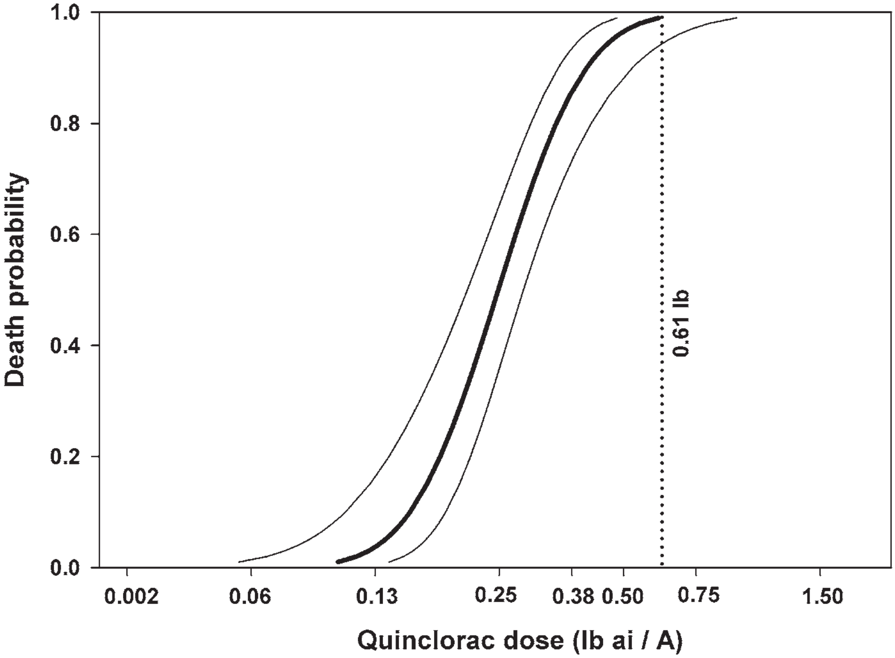


Fig. 1. Death probabilities of a known susceptible barnyardgrass population for a range of quinclorac doses.

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 in Stuttgart, Ark. (silt loam soil) and will be continued for the next three 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 treatments' visual estimates of control and red rice seed production showed a reduction in red rice compared to the checks. There were no statistical differences in red rice control or production bu/a 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.

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. (2007) 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.

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 will be continued for 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 replications. Multiple parameters were evaluated in this study, the baseline treatment consisted of a conventional tillage practice where 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. The variety 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 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 were 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. All applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 10 gal/acre. Red rice counts per square foot were recorded at 3, 5, 9, and 12 wk after planting. Total red rice seed production was characterized at maturity by hand harvesting three, 10.8 ft^2 (1 m^2) quadrants in each plot. Red rice control was visually estimated at harvest using a scale of 0 to 100% where 0 is no control and 100% is complete control. Data was subjected to ANOVA and means were separated using Fisher's Protected Least Significant Difference (LSD) Test ($P = 0.05$).

RESULTS AND DISCUSSION

Year 1

At 3 weeks after planting (WAP), the delayed planted and the fallow with tillage had reduced red rice counts compared to the tilled check (Table 1). The delayed planting 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 with Clearfield rice, then the delayed planting 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 planting, 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 to 21 plants/ft^2. All treatments reduced red rice counts by 12 WAP compare 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 (7) had a lower red rice density compared to the tilled check (14).

Although red rice density counts were similar for the delayed planting and baseline Clearfield programs, total red rice produced and final visual control data indicated a significant reduction in red rice with delayed planting. This may be due to reduced tillering and lower seedhead production where delayed planting 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 compare 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, and all treatments following soybeans, with the exception of Roundup Ready soybeans, reduced red rice counts compared to the checks, 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 (bu/acre) 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.

SIGNIFICANCE OF FINDINGS

In year one, 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/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 (Table 1). If there is a problem with red rice in a particular field, producers can reduce red rice numbers with any of the production options. Both soybean production treatments reduced plant numbers to 0, where as 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 bu/acre 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. 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. This research will be carried out and Clearfield rice will be planted next year.

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*) withpreemergence 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 2010. University of Arkansas Agricultural Experiment Station Research Series 581:11-21. Fayetteville.

Table 1. 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 3 WAP	5 WAP	9 WAP	12 WAP	Red rice	Control at harvest
	------------------- (no./ft^2)			--------------------	(bu/acre)	(%)
Clearfield rice (Baseline)	14	9	1	1	6	80
Delayed-plant - 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)	8	7	6	2	15	17

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	7 WAP	9 WAP	12 WAP	Red rice	% Control at harvest
		------------------------(no./ft^2)------------------------				(bu/acre)	(% control)
Clearfield rice (Baseline)	Roundup Ready soybean	1	1	2	0	0	100
	Clearfield rice	1	0	1	2	1.17	90
Delayed-plant - Clearfield rice	Roundup Ready soybean	1	0	1	1	0	99
	Delayed plant - Clearfield rice	0	0	1	1	0.03	93
Tilled check	Tilled check	2	2	3	6	10.3	0
	Tilled check (flooded)	3	2	3	9	11.28	0
No-till check	No-till check	2	1	2	4	7.5	0
	No-till check (flooded)	2	2	1	4	5.21	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)		1	1	1.5	2	3.8	15

PEST MANAGEMENT: WEEDS

Influence of Application Timing of Ricebeaux on Control of Propanil-Resistant and -Susceptible Barnyardgrass (*Echinochloa crus-galli*) With and Without Command

D.B. Johnson, J.K. Norsworthy, C. Starkey, J. DeVore, and B. Scott

ABSTRACT

Barnyardgrass (*Echinochloa crus-galli*) is the most troublesome weed in Arkansas rice culture. Barnyardgrass biotypes known to be resistant to propanil, quinclorac, and clomazone currently exist in Arkansas. Control of these resistant biotypes often requires preemergence, delayed preemergence, early postemergence, preflood, and postflood herbicide applications. Thiobencarb was used throughout the 1990s as a delayed preemergence herbicide for barnyardgrass control. A field study was conducted in 2010 at the Rice Research and Extension Center near Stuttgart, Ark., on a Dewitt silt loam soil to determine the efficacy of propanil + thiobencarb on propanil-resistant and -susceptible barnyardgrass at different application timings. Propanil at 3 lb ai/acre + thiobencarb at 3 lb ai/acre (mixture sold as Ricebeaux) was applied alone and in combination with clomazone (Command) at 0.3 lb ai/acre at 1, 2, 3, and 4 weeks after planting (WAP). Visible weed control and crop injury ratings were taken weekly throughout the growing season. Crop injury was noted only after the 2 WAP application (25%) and injury was slightly increased by the addition of Command (32%); however, injury symptoms had diminished 14 days after treatment. Ricebeaux applied 2 WAP controlled propanil-resistant and -susceptible barnyardgrass 88% and 100%, respectively. Ricebeaux applied in combination with Command at 1 and 2 WAP provided 96% to 100% control of propanil-resistant and -susceptible barnyardgrass. Increased barnyardgrass size at the time of application (6 to 8 in.) resulted in poor control with applications of Ricebeaux alone or in combination with Command at 3 or 4 WAP.

INTRODUCTION

Barnyardgrass infests almost all Arkansas rice acreage making it the most problematic weed in Arkansas rice culture (Norsworthy et al., 2007). Season-long barnyardgrass competition can cause lodging, poor grain quality, and can reduce yields up to 80% (Smith, 1988). Propanil is a Group 7 Photosystem II-inhibiting herbicide that was introduced in the early 1960s and quickly became the primary means of barnyardgrass control in rice (Malik et al., 2010). Sole reliance on propanil for barnyardgrass control led to the evolution of propanil-resistant barnyardgrass in 1990 (Carey et al., 1994). Barnyardgrass biotypes resistant to quinclorac and clomazone also currently exist in Arkansas (Baltazar and Smith, 1994; Carey, 1994; Lovelace et al., 2002; Norsworthy et al., 2009). Because of the presence of multiple-resistant barnyardgrass biotypes in Arkansas, herbicide programs must be developed to control these resistant biotypes and prevent or delay the evolution of additional herbicide-resistant biotypes. Ricebeaux is a new herbicide that is a prepackaged mix of propanil + thiobencarb. In a study conducted by Wilson et al. (2011), Ricebeaux applied delayed preemergence (DPRE; 1 week after planting) provided 100% control of propanil-resistant and -susceptible barnyardgrass. We hypothesized that Ricebeaux alone or in combination with Command applied 1 to 2 WAP will control propanil-resistant and -susceptible barnyardgrass more consistently than applications made 3 to 4 WAP.

PROCEDURES

Field experiments were conducted in a randomized complete block design with four replications at the Rice Research and Extension Center near Stuttgart, Ark., in 2010. Wells rice was seeded with a nine-row drill on 7-in. spacings. Propanil-resistant barnyardgrass was planted in rows perpendicular to the 6- × 20-ft rice rows. The test area contained a natural infestation of barnyardgrass that was susceptible to propanil. Ricebeaux at 4 qt/acre was evaluated alone or in combination with Command at 0.8 pt/acre. Herbicide applications were made at 1, 2, 3, and 4 weeks after planting (WAP). All herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/acre. A nontreated control was also included. Visible weed control and crop injury ratings were taken weekly throughout the growing season to evaluate barnyardgrass control. 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.

RESULTS AND DISCUSSION

When the 1 WAP application was made, only a few barnyardgrass plants had emerged. Of the plants that had emerged, Ricebeaux alone controlled susceptible barnyardgrass 71% compared to only 44% control of the propanil-resistant biotype (Table 1). However, the addition of Command significantly improved control of both biotypes (≥96%) because of its residual activity on barnyardgrass. At 29 days after the 2 WAP application, Ricebeaux alone and in combination with Command controlled 1- to 2-in. tall resistant and susceptible plants 88% to 100%. At the time of the 3 and 4 WAP applications, barnyardgrass had reached 6 to 10 in. tall, which resulted in a significant decrease in control (≤27%) with Ricebeaux alone and in combination with Command. Applications of Ricebeaux in combination with Command at the proper time can provide effective residual barnyardgrass control and postemergence control of propanil-resistant barnyardgrass.

SIGNIFICANCE OF FINDINGS

Use of Ricebeaux in combination with Command at 1 to 2 WAP will effectively control seedling propanil-resistant barnyardgrass as well as residual control of barnyardgrass. This herbicide program would allow producers to only make two herbicide applications prior to flood.

ACKNOWLEDGMENTS

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

LITERATURE CITED

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.

Carey, V.F. III. 1994. Propanil-resistant barnyardgrass in Arkansas: Competitive ability, distribution, and mechanism of resistance. Ph.D. dissertation. Fayetteville, Ark. University of Arkansas. 113 pp.

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.

Malik, M.S., N.R. Burgos, and R.E. Talbert. 2010. Confirmation and control of propanil-resistant and quinclorac-resistant barnyardgrass (*Echinochloa crus-galli*) in rice. Weed Tech. 24:226-233.

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., R.C. Scott, S. Bangarwa, G.M. Griffith, M.J. Wilson, and J.A. Still. 2009. Control of clomazone-resistant barnyardgrass in rice with preeemergence herbicides. *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 571:190-193. Fayetteville.

Smith, R.J. Jr. 1988. Weed thresholds in southern U.S. rice, *Oryza sativa*. Weed Tech. 2:232-241.

Wilson, M.J., J.K. Norsworthy, D.B. Johnson, R.C. Scott, and C.E. Starkey. 2011. Herbicide programs for managing herbicide-resistant barnyardgrass in Arkansas rice. Proc. South. Weed. Sci. Soc. 64: *In press*.

Table 1. Control of propanil-resistant and -susceptible barnyardgrass at the Rice Research and Extension Center near Stuttgart, Ark.

	Barnyardgrass control			
	Resistant[a]		Susceptible	
Application time	Ricebeaux	Ricebeaux + Command	Ricebeaux	Ricebeaux + Command
	-----(%)-----			
1 WAP[b]	44 b	96 a	71 b	99 a
2 WAP	88 a	100 a	98 ab	100 a
3 WAP	10 d	36 bc	18 c	71 b
4 WAP	18 cd	5 d	34 c	15 c

[a] Means followed by the same letter within each biotype (resistant and susceptible) are not significantly different.

[b] Evaluations were taken at 35 days after 1WAP, 29 days after 2 WAP, 23 days after 3 WAP, and 14 days after 4 WAP.

PEST MANAGEMENT: WEEDS

Environmental Implications of Pesticides in Rice Production

J.D. Mattice, A. Smartt, T. Scott, and R.J. Norman

ABSTRACT

Extensive flooding and reduced acreage planted was likely responsible for the reduced number of detections and lower concentrations of rice pesticides in water in 2011 compared to 2010. Percent detections in the main channel and tributaries were the same within each year but different between years (68.1% and 66.3% in 2010 and 47.3% and 48.8% in 2011). Seven of the ten highest concentrations in 2011 were for quinclorac (Facet) and the remaining three were for clomazone (Command). All ten of the highest concentrations were from tributaries. No detectable concentrations of the pesticides were found in sediment. Specific conductance readings showed the same pattern over time and location as in 2010, but the readings were lower. For both years, the values were not high enough to damage paddy rice according to the literature. The 25th percentile for the concentration of total nitrogen for 2010 and 2011 was almost the same as the historic value for EPA Subecoregion 73 of Ecoregion X, but 14.2% of the values were higher than the historic high value in this region.

INTRODUCTION

The goal is to determine if environmental problems are developing in Arkansas surface water as a result of pesticides used in rice production. Early detection of a problem may allow us to address it before it becomes a major problem. Weekly analysis at multiple sites on both the main channel and tributaries will allow us to determine if a problem is widespread or localized either geographically or temporally.

Small rivers in watersheds that are growing primarily rice are the most sensitive barometers of potential problems due to pesticide use, because a high percentage of the water in the rivers comes from areas growing rice. Previously, we had analyzed water from the Cache, L'Anguille, and St. Francis rivers and also Lagrue Bayou (Mattice et al., 2010). Since the Cache had the most detections and also the highest concentrations, in 2010 we changed to analyzing water from the same four sites on the Cache plus water from one site on each of six small tributaries. Our objective was to measure the difference in concentrations and frequency of detections between the tributaries and the main Cache. We also compared our results to stream flow as measured on the United States Geological Survey (USGS) gauges on the Cache. Sediment was also collected and analyzed to see if it was acting as a sink for sorption of the compounds. In addition, pH, dissolved oxygen, conductivity, nitrogen, and temperature were measured.

In 2011, the same sites were used and analysis was for the same compounds.

PROCEDURES

The sampling sites, compounds, and procedures have been described previously (Mattice et al., 2011). Briefly, the four sites on the Cache River ranged from near Jonesboro in the north to below Interstate 40 in the south, a minimum of 75 miles based on distance between Geographical Positioning System (GPS) coordinates for each site. Three tributary sites are located near the most upstream site on the Cache (QM), one near the second most upstream site (RM), and two near the third most upstream site (SM). Geographical Positioning System values for the sites are given in Mattice et al. (2011) reference.

RESULTS AND DISCUSSION

Flooding

There was extensive flooding in eastern Arkansas during the spring and early summer of 2011. Site RM on the main Cache was inaccessible for the first two sampling periods because the access road was under water. Stream flow data at the Cotton Plant gauging site was unavailable for all of May through 16 June, because the gauge had been washed out (pers. comm. William Baldwin, USGS).

The Arkansas harvest is estimated to be 1.160 million acres, 35% below the previous year and the smallest since 1989/1990. Some rice that was planted was lost due to flooding, and other areas could not be planted. Some growers had planned to switch to alternative crops due to stronger relative returns (Anon., 2011). The flooding and the reduced acreage would be expected to influence our results. Pesticides that were applied early could have been flushed off the fields during the flood, and because they were washed off early, they would not have been available to enter stream water later in the season. Also, low concentrations that would normally have been detected may have been diluted below detection limits. Fields that were not planted at all or were planted to alternative crops would have had no rice pesticides applied to them unless these compounds were used on those crops.

Distribution of Pesticides in Water Between 2010 and 2011

Water concentrations for each pesticide and total nitrogen (TN) for 2011 are given in Table 1. In 2011 there were fewer total detections, and fewer detections ≥2 ng/mL compared to 2010 (Table 2). A concentration of 2 ng/mL was the minimum reported in years prior to 2010, and this value should be used to compare current results to results for years prior to 2010.

A variety of ways of interpreting the data all show the effect of early season flooding and reduced acreage on the results. In the main channel there were more detections for four of the five compounds in 2010 compared to 2011 (Table 3). The number of detections of clomazone each year was the same, although site RA was inaccessible due to flooding for the first two sampling periods in 2011. The number of detections of all five compounds in the tributaries was higher in 2010 than in 2011.

The mean concentrations in the main channel for all samples were higher for all five compounds in 2010 than in 2011 (Table 3). When only samples containing detectable concentrations were considered, three of the five mean concentrations were higher in 2010. For all tributary samples the mean concentration for four of the five compounds was higher in 2010. Considering only samples with detections, there were higher mean concentrations for three of the five compounds in 2010.

In 2010, there were 268 detections out of a total of 400 possible detections (80 samples × 5 compounds/sample) for a detection frequency of 67% (Table 3). In 2011 there were 187 detections out of 390 possible (one site was inaccessible for two sampling periods due to flooding) for a 48% detection frequency.

All the above results are consistent with flooding diluting samples to give lower concentrations, diluting low concentrations to levels below detection limits, washing compounds off fields during early flooding, and reduced total acreage planted with a corresponding smaller amount of pesticide being applied.

Distribution of Pesticides Between Tributaries and Main Channel for 2010 and 2011

Although the mean concentrations in the tributaries were typically 2 to 3 times higher than in the main channel for each year, the detection frequency for each year was almost the same for tributaries versus main channel (Table 3). In 2010 the frequency for the main channel was 68.1%, and for the tributaries it was 66.3%. In 2011 for the main channel it was 47.3% and for the tributaries it was 48.8%. The detection frequency in 2011 may have been lower than in 2010 due to flooding and lower acreage, but neither of these causes discriminated among frequency of detection on tributaries versus main channel.

Highest Concentrations

In 2011 the five highest concentrations and seven of the highest ten were for quinclorac (Table 1). This is consistent with our findings in previous years. The highest concentration of 32.1 ng/mL was in the sample taken on 7 June at site RA and the second highest was 26.9 ng/mL at the same site on 14 June. The next three highest were all in samples taken from site QC, 22.4 ng/mL on 8 June, 19.9 ng/mL on 21 June, and 19.4 ng/mL on 7 July. On 14 June the concentration at this site was 10.5 ng/mL which was the tenth highest concentration found. The ninth highest concentration was 11.7 ng/mL for quinclorac from the sample taken at site QA on 22 June.

The sixth, seventh, and eighth highest concentrations were all for clomazone, 14.8 ng/mL on 25 May at site RA, 12.3 ng/mL at site SB on 1 June, and 12.1 ng/mL at site QA on 25 May (Table 1). All of these sites with the ten highest concentrations were on tributaries. The highest concentration found on the main Cache was 10.1 ng/mL for clomazone in the sample taken at site QM on 28 June.

Specific Conductance

The same trend was seen in 2011 as in 2010, but the values in 2011 were lower. Beginning in early June, the values at RA and QA spiked and remained high for the rest of the samples. The highest concentration in 2011 was 0.835 mS/cm on 14 June at site RA and in 2010 it was 1.21 mS/cm on 2 June, also at site RA. These values should not damage paddy rice (Ayers and Westcot, 1976).

Total Nitrogen

The USEPA has recommended concentrations in surface water for the states to use to establish limits consistent with the Clean Water Act (USEPA, 2001). These concentrations were defined as being the 25th percentile of historic concentrations for each ecoregion. By definition, 75% of the concentrations found would be above this level. This says nothing about the effect of these concentrations, but it establishes a concentration against which future results can be measured. Arkansas rice-growing country is in Subecoregion 73 of Ecoregion X which extends along the Mississippi delta from Kentucky to the gulf coast plus most of the area along the Red River in Louisiana. The historic 25th percentile is 0.82 mg/L (calculated) or 0.71 mg/L (reported). The calculated value uses more data from other sources than the reported value and would be used if there weren’t enough reported values to be representative of the area.

For 2010 our total nitrogen results exceeded the 0.71 mg/L level 85.5% of the time and the 0.82 mg/L level 84.1% of the time. In 2011 our results exceeded 0.71 mg/L 84.6% of the time and exceeded 0.82 mg/L 78.2% of the time. If nothing had changed from data collected 10 to 20 years ago and reported in the USEPA document in December, 2001, and if data from the Cache watershed represented the entire Subecoregion 73, we would expect to exceed the benchmark value 75% of the time. Our results show that the benchmark was exceeded between 78.2% and 85.5% of the time, depending on which benchmark was used. The largest average value for TN for any of our sites was 3.0 mg/L for tributary site QC (Fig. 1).

Although the percent exceedance was comparable to historic data, there were individual samples with concentrations higher than the historic high (Table 1). The highest value for TN in Subecoregion 73 reported in the EPA document was 2.68 mg/L. For 2010 and 2011 we found 22 out of a total of 155 samples (14.2%) that had values above this level (Fig. 1). Eighteen of those 22 (81.8%) were from tributaries. The highest value was 9.01 mg/L from site QC on 2 June 2010. Of the remaining four samples, three were at site QM (6.11 mg/L and 2.88 mg/L in 2011, and 2.69 mg/L in 2010), the furthest upstream on the main channel, and one was at site RM, the next site downstream (3.34 mg/L in 2010). The average concentration of 1.75 mg/L in 2010 was not significantly different than 1.65 mg/L in 2011.

Sediment

There were no detectable concentrations of pesticides in sediment when compared to the Upper Confidence Level of the Minimum Detectable Level (MDL) as determined by the EPA method used to determine the MDL (USEPA Federal Register, 1991). In 2010 there were 25 detections out of a possible 400 if all compounds had been found in all samples. All detections were low. The absence of detections in sediment in 2011 may be related to lower amounts of pesticides being applied to fewer acres being planted, to flooding disturbing sediment in river or tributaries, or to introducing new sediment that contained either no pesticides or very low levels of pesticides.

SIGNIFICANCE OF FINDINGS

Virtually all parameters were lower in 2011 compared to 2010. This was likely due to early flooding and reduced acreage. There were no detectable concentrations of pesticides in sediment in 2011 and in 2010 there were only 25 detections out of a possible 400, all at low levels. Results from both years indicate that sediment is not acting as a sink for these pesticides which might then be released later. Although there are two years worth of data for these sites, the unusual weather conditions in 2011 mean that differences may not reflect normal variability. It is also possible that what is normal may be beginning to change. However, the results can show an effect of early flooding and reduced acreage planted.

The USEPA has recommended concentrations in surface water for the states to use to establish limits consistent with the Clean Water Act. These concentrations were defined as being the 25th percentile of historic concentrations for each ecoregion. Thus, by definition 75 % of the concentrations found should be above this level. Our results show that the benchmark was exceeded between 78.2% and 85.5% of the time, depending on which benchmark was used. Although the percent exceedance was comparable to historic data, there were individual samples with concentrations higher than the historic high.

ACKNOWLEDGMENTS

We would like to acknowledge the Arkansas Rice Research and Promotion Board for funding this project.

LITERATURE CITED

Anon. 2011. U.S. Rice production outlook 2011/12, ERS USDA. Available at http://www.agricommodityprices.com/futures_prices.php?id=779. Accessed 11 November, 2011.

Ayres, R.S. and D.W. Westcot. 1976. Water quality for agriculture. Irrigation and drainage paper No. 29. Food and Agriculture Organization of the United Nations. Rome.

Mattice, J.D., B.W. Skulman, and R.J. Norman. 2010. Environmental implications of pesticides in rice production. *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 581:123-132. Fayetteville.

Mattice, J.D., A. Smartt, S. Teubl, T. Scott, and R.J. Norman. 2011. Environmental implications of pesticides in rice production. *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 591:141-153. Fayetteville.

USEPA. (United States Environmental Protection Agency). 1991. Federal Register. 40 CFR Ch. 1 (7-1-91 Edition) Pt 136 App B.

USEPA. United States Environmental Protection Agency. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Nutrient Ecoregion X Office of Water 4304. EPA 822-B-01-016. December 2001.

Table 1. Water concentrations of pesticides and total nitrogen for all samples in 2011.

				Pesticide			
Site	Date	Clomazone	3,4-DCA	Imazethapyr	Propanil	Quinclorac	Total nitrogen
				(µg/L)			(mg/L)
QM	5/18/11	1.0	0.0	0.0	0.0	0.0	0.88
QA	5/18/11	3.8	1.1	0.0	0.0	3.4	1.19
QB	5/18/11	1.2	0.0	0.0	1.0	0.0	0.90
QC	5/18/11	1.4	0.0	1.5	0.0	0.0	0.96
RM	flooded						
RA	5/17/11	1.5	0.0	0.0	4.7	0.0	0.59
SM	5/17/11	0.7	0.0	0.0	0.0	0.0	0.30
SA	5/17/11	0.0	0.0	0.0	0.0	0.0	0.25
SB	5/17/11	0.3	0.0	0.0	1.0	0.0	1.55
TM	5/17/11	1.8	0.0	0.0	0.0	0.0	0.36
QM	5/24/11	5.0	1.3	0.6	0.0	1.3	1.10
QA	5/25/11	12.1	0.0	0.0	0.0	3.3	1.83
QB	5/25/11	4.5	0.9	0.0	0.0	0.0	1.23
QC	5/25/11	8.8	2.4	0.0	0.0	3.8	2.93
RM	flooded						
RA	5/24/11	14.8	1.3	0.0	0.5	0.0	0.95
SM	5/24/11	1.0	0.0	0.0	0.0	0.0	1.30
SA	5/24/11	0.2	0.0	0.0	0.0	0.0	0.61
SB	5/24/11	4.5	0.0	0.0	0.0	0.0	2.85
TM	5/24/11	0.5	0.0	0.0	0.0	0.0	0.58
QM	6/1/2011	1.6	0.0	0.0	0.0	0.0	1.44
QA	6/2/2011	5.5	0.0	0.0	0.4	2.0	2.49
QB	6/2/2011	1.2	0.0	0.0	0.0	0.0	0.81
QC	6/2/2011	5.0	1.1	0.5	0.6	3.7	4.62
RM	6/1/2011	1.5	0.0	0.0	0.0	0.6	0.95
RA	6/1/2011	2.9	1.6	0.0	0.0	1.2	2.43
SM	6/1/2011	1.8	0.0	0.0	0.0	0.0	0.69
SA	6/1/2011	0.0	0.0	0.0	0.0	0.0	0.40
SB	6/1/2011	12.3	0.0	1.7	0.0	0.0	1.22
TM	6/1/2011	0.8	0.0	0.0	0.0	0.0	0.46
QM	6/7/11	4.3	1.1	0.0	0.0	0.0	0.82
QA	6/8/11	8.9	0.0	0.0	0.0	0.7	1.50
QB	6/8/11	0.8	0.0	0.0	0.0	0.0	1.66
QC	6/8/11	1.2	5.2	0.0	1.2	22.4	1.35
RM	6/7/11	1.0	0.0	0.0	0.0	0.0	1.05
RA	6/7/11	2.9	1.1	0.0	1.5	32.1	5.98
SM	6/7/11	1.3	0.0	0.0	0.0	0.0	2.12
SA	6/7/11	0.0	0.0	0.0	0.0	0.0	0.71
SB	6/7/11	0.2	0.0	0.0	0.0	0.0	1.38
TM	6/7/11	2.0	0.0	0.0	0.0	0.0	0.47
QM	6/14/11	2.6	2.3	0.9	0.0	3.1	6.11
QA	6/15/11	3.1	1.2	0.0	0.0	3.4	1.64
QB	6/15/11	3.1	2.0	0.8	0.0	4.1	4.67
QC	6/14/11	2.6	4.2	4.4	0.0	10.5	3.14

continued

Table 1. Continued.

Site	Date	Pesticide					Total nitrogen
		Clomazone	3,4-DCA	Imazethapyr	Propanil	Quinclorac	
		-------------------------------------(µg/L)------------------------------------					(mg/L)
RM	6/14/11	1.6	0.0	0.0	0.0	1.3	1.16
RA	6/14/11	0.0	10.0	0.0	0.6	26.9	1.97
SM	6/14/11	1.4	0.0	0.0	0.0	1.0	0.98
SA	6/14/11	0.0	0.0	0.0	0.0	0.0	0.87
SB	6/14/11	0.3	0.0	0.0	0.0	0.0	1.88
TM	6/14/11	1.3	0.0	0.0	0.0	0.0	1.58
QM	6/21/11	3.5	1.1	1.7	0.0	7.7	2.88
QA	6/22/11	1.2	0.0	0.0	0.0	11.7	2.09
QB	6/22/11	4.8	0.8	1.5	0.0	5.8	1.85
QC	6/21/11	2.7	1.0	2.0	0.0	19.9	0.92
RM	6/21/11	3.7	1.1	1.2	0.5	5.9	1.82
RA	6/21/11	6.9	1.0	0.0	1.1	6.5	2.92
SM	6/21/11	2.4	0.0	0.7	0.0	3.9	1.51
SA	6/21/11	0.0	0.0	0.0	0.0	0.0	0.67
SB	6/21/11	1.3	0.8	0.3	0.0	0.0	0.87
TM	6/21/11	0.8	0.0	1.0	0.0	0.3	1.11
QM	6/28/11	2.2	2.5	1.2	0.0	10.1	1.21
QA	6/29/11	0.4	1.8	1.0	0.0	5.8	1.90
QB	6/29/11	1.1	2.1	0.9	0.0	3.4	4.62
QC	6/28/11	0.8	0.0	1.6	0.0	7.9	1.33
RM	6/28/11	1.9	1.7	0.4	1.5	4.8	1.33
RA	6/28/11	1.4	1.5	1.0	3.0	10.1	3.14
SM	6/28/11	2.7	0.0	0.9	0.0	6.4	1.39
SA	6/28/11	0.0	0.0	1.2	0.0	5.2	3.59
SB	6/28/11	1.5	0.0	1.0	0.5	2.9	0.76
TM	6/28/11	1.3	0.0	0.0	0.0	2.1	0.95
QM	7/7/11	0.8	0.7	1.4	0.0	7.5	1.94
QA	7/6/11	0.0	0.0	0.0	0.0	2.2	0.84
QB	7/6/11	0.5	1.3	0.0	0.0	6.4	1.45
QC	7/7/11	0.6	0.0	1.0	0.0	19.4	3.93
RM	7/6/11	1.2	1.5	1.0	0.0	5.4	1.39
RA	7/6/11	1.1	0.0	0.3	1.9	0.3	0.82
SM	7/6/11	0.9	0.0	0.8	0.0	4.0	1.28
SA	7/6/11	0.0	0.0	0.0	0.0	0.0	1.90
SB	7/6/11	1.1	0.0	0.0	0.0	1.2	0.64
TM	7/6/11	0.8	0.9	0.0	0.0	2.8	0.91
Total detections		69.0	29.0	28.0	15.0	45.0	
%		88.0	37.0	36.0	19.0	58.0	

Table 2. Number of detections, percent detections, and number of detections ≥ 2 µg/L for each compound in 2010 and 2011. There were 80 samples in 2010 and 78 in 2011 due to inaccessibility of site RM for two weeks in 2011 due to flooding.

Year		Clomazone	3-4DCA	Imazethapyr	Propanil	Quinclorac
2010	No. of detections	75	42	58	24	69
	Percent detections	94	53	73	26	86
	No. ≥ 2 ng/mL	40	15	25	2	60
2011	No. of detections	69	30	28	15	45
	Percent detections	88	37	36	19	58
	No. ≥ 2 ng/mL	27	8	2	2	36

Table 3. Number of detections, percent detections, and mean and median water concentrations (µg/L) of each pesticide in the main channel or tributaries for 2010 and 2011. There were a possible 32 detections per compound on the main channel in 2010 and only 30 in 2011, because site RM was inaccessible for two sampling periods due to flooding in 2011.

	2010					2011				
	clom[a]	3-4D	imaz	propan	quinc	clom	3-4D	imaz	propan	quinc
Number of detections										
Main channel	30	14	26	7	32	30	10	12	2	17
	94%	44%	81%	22%	100%	100%	33%	40%	7%	57%
Tributaries	45	28	32	17	37	40	20	16	13	28
	94%	58%	67%	35%	77%	83%	42%	33%	27%	58%
All main channel samples										
Median ng/mL	1.6	0	1.2	0	3.1	1.4	0	0	0	0.6
Mean ng/mL	2.3	0.7	1.3	0.2	3.8	1.8	0.4	0.4	0.1	2.1
Only main channel samples with detections										
Mean ng/mL	2.4	1.6	1.6	0.7	3.8	1.8	1.4	1.0	1.0	4.0
All tributary samples										
Median ng/mL	1.9	0.9	0.7	0	4.9	1.2	0	0	0	1.2
Mean ng/mL	6.1	3.4	2.5	0.3	6.9	2.7	0.9	0.4	0.4	4.7
Only tributary samples with detections										
Mean ng/mL	6.5	5.9	3.7	0.7	9.0	3.2	2.1	1.3	1.4	8.1
Percent detections										
Main channel	68.1	47.3								
Tributaries	66.3	48.8								

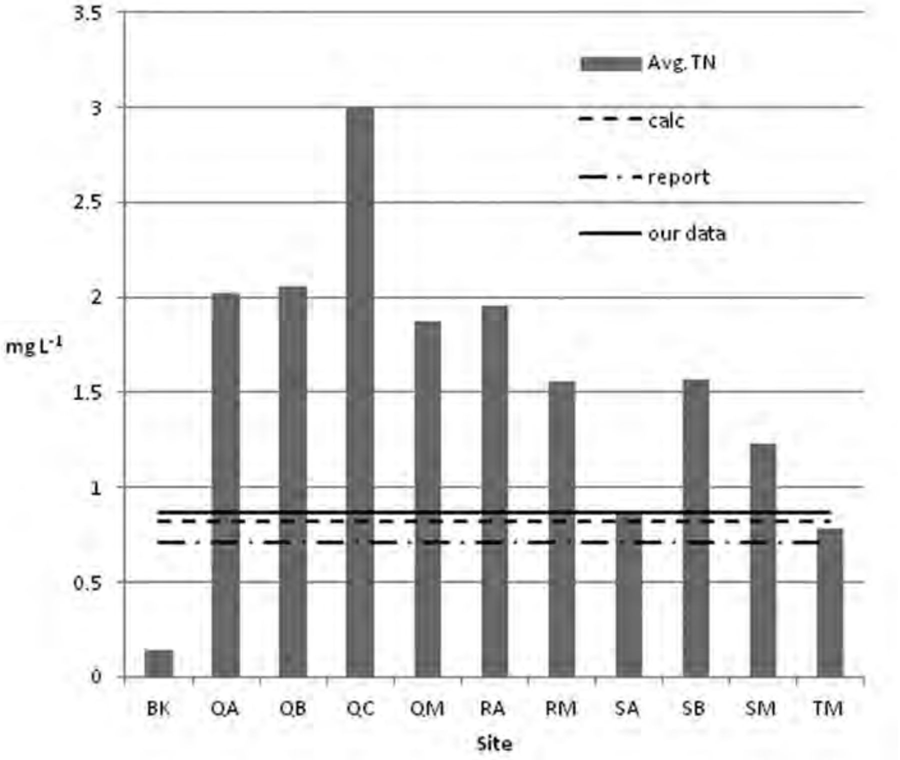


Fig. 1. Average total nitrogen (TN) and 25th percentile for our 2010 and 2011 data and the reported and calculated 25th percentile from the historical EPA Ecoregion 73 data. BK is a blank from a nearby forested, non-agricultural area.

Propanil Plus Thiobencarb Combinations with Imazethapyr for Improved Red Rice (*Oryza rufipogon*) and Barnyardgrass (*Echinochloa crus-galli*) Control in Imidazolinone-Tolerant Rice (*Oryza sativa*)

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

ABSTRACT

Field studies were conducted in 2010 and 2011 to evaluate barnyardgrass (*Echinochloa crus-galli*) and red rice (*Oryza sativa*) control in imidazolinone-tolerant (IT) rice (*Oryza sativa*) with propanil plus thiobencarb in combination with imazethapyr at various application timings. The addition of propanil plus thiobencarb to the first application of imazethapyr increased control of red rice and barnyardgrass at the preflood rice growth stage compared to imazethapyr alone, but the addition of propanil plus thiobencarb to the second imazethapyr application did not improve control of red rice or barnyardgrass compared to two applications of imazethapyr alone. By two weeks after permanent flood, there were no differences in red rice or barnyardgrass control among treatments. The addition of propanil plus thiobencarb to the first application of imazethapyr provided greater control of red rice and barnyardgrass earlier in the season, thus reducing early competition. The addition of another herbicide with a different mode of action provided greater control of weeds earlier, and is also a best management practice to reduce the probability of resistance.

INTRODUCTION

Red rice is a common and very troublesome weed in Arkansas rice production. Red rice has been considered a weed of commercial rice for nearly 160 years and was first recorded as a weed in North Carolina and South Carolina in the mid-1800s. Most red rice populations can be classified as two groups called brownhull and strawhull, but other ecotypes such as brown-, gray-, and gold-hulled have been reported (Constantin, 1960). Red rice is usually taller than most conventional rice cultivars, which makes it more competitive, and it can produce more biomass than rice earlier in the season (Kwon et al., 1992). Diarra et al. (1985) reported that red rice densities of 5, 108, and 215 plants/m^2 in a cultivated rice density of 195 plants/m^2 reduced grain yield by 22%, 77%, and 82%, and reduced straw dry weight by 18%, 66%, and 68%. Although red rice was considered the most troublesome weed of rice in Arkansas for many years, barnyardgrass has surpassed red rice as the most troublesome weed in the opinion of many consultants (Norsworthy et al., 2007). Barnyardgrass is extremely competitive and can grow well in drill- or water-seeded rice culture (Talbert and Burgos, 2007), and barnyardgrass infestations have been shown to be capable of removing 60% to 80% of the available nitrogen from the soil (Holm et al., 1991). The competition for nutrients, moisture, space, and sunlight can cause great losses in food crop yields (Khanh et al., 2007). Smith (1988) reported that rice yield losses of 70% occurred from season-long interference of barnyardgrass in drill-seeded rice, and Stauber et al. (1991) found that just one barnyardgrass plant placed 40 cm from a rice plant reduced the rice yield by 27%. Imidazolinone-tolerant rice offers producers an option to effectively control red rice with little or no effects on the crop itself. Tolerance of IT rice to imidazolinone herbicides was developed from a single rice plant that survived a chemically induced mutation (Sanders et al., 1998). Imazethapyr is used in IT rice systems for control of red rice, as well as other grass weed species common to rice production (White and Hackworth, 1999). Steele et al. (2002) reported that sequential imazethapyr treatments provided up to 98% control of red rice. Increased control of red rice has been observed with the addition of propanil to either the first or second imazethapyr application (Carlson et al., 2011). Smith and Khodayari (1985) reported that propanil plus thiobencarb controlled barnyardgrass greater than propanil alone. The purpose of this research was to examine if the addition of propanil plus thiobencarb to applications of imazethapyr at various timings would increase barnyardgrass and red rice control.

PROCEDURES

Trials were conducted in 2010 and 2011 at the Southeast Research and Extension Center near Rohwer, Ark., to evaluate barnyardgrass and red rice control in IT rice. A randomized complete block design with four replications was used in all trials. The cultivar CL131 was used in 2010 and CL142AR was used in 2011. Both cultivars were drill-seeded into a Sharkey clay soil at 90 lb/acre, and barnyardgrass and red rice was broadcast-seeded after planting. Treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 12 gal/acre. Imazethapyr (NewPath® 2AS, 240 g ai/L, BASF Corporation, Research Triangle Park, N.C.) was applied at 4 oz/acre alone and in combination with propanil plus thiobencarb (RiceBeaux® 6EC, 720 g ai/L, RiceCo LLC, Memphis, Tenn.) at 128 oz/acre to rice at the 1-, 2-, and 5-leaf growth stage. Barnyardgrass and red rice 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 ANOVA and means were separated using Fisher's Protected Least Significant Difference (LSD) test ($P = 0.05$).

RESULTS AND DISCUSSION

In 2010, barnyardgrass control evaluated preflood increased when propanil plus thiobencarb was added to the first application of imazethapyr applied to rice at either the 1- or 2-lf growth stage compared to imazethapyr alone (Table 1). Red rice control at the preflood rice stage also increased from the addition of propanil plus thiobencarb to imazethapyr applied at the 1- and 2-lf growth stage compared to two applications of imazethapyr alone. The addition of propanil plus thiobencarb to imazethapyr at the 5-lf rice application did not improve control of red rice or barnyardgrass preflood compared to applications of propanil plus thiobencarb in combination with imazethapyr at the 1- or 2-lf rice growth stage or two applications of imazethapyr alone. By two weeks after permanent flood, there were no differences among treatments in red rice or barnyardgrass control. Similar results were observed in 2011. Again, the addition of propanil plus thiobencarb to the first application of imazethapyr applied at the 2-lf growth stage increased control of red rice and barnyardgrass compared to two applications of imazethapyr alone when evaluated prior to permanent flood (Table 2). As with the previous year, there were no differences in red rice or barnyardgrass control by two weeks after permanent flood. In both years, the benefit of propanil plus thiobencarb plus imazethapyr was observed from improved control of red rice and barnyardgrass following applications to rice at the earlier growth stages which reduced early season weed competition. Although complete control of barnyardgrass and red rice can be achieved from two applications of imazethapyr alone, early season weed competition can be avoided. The potential for weed control with herbicides diminishes as weed size increases as well as the likeliness of weed escapes. Increased weed pressure, even over a short period of time can reduce rice yield; therefore, producers should treat weed problems early, and use practices that improve control.

SIGNIFICANCE OF FINDINGS

The results of these studies are similar to results observed in previous research (Smith and Khodayari, 1985; Carlson et al., 2011). The addition of propanil plus thiobencarb to the first application of imazethapyr increased control of red rice and barnyardgrass compared to imazethapyr alone. The addition of another herbicide with a different mode of action not only provided greater control of weeds earlier in the season and prevented early season competition, but is also a best management practice to reduce the probability of resistance.

ACKNOWLEDGMENTS

Special appreciation is extended to the Rice Research and Promotion Board for providing funding and support for these projects.

LITERATURE CITED

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 Tech. 25:204-211.

Constantin, M.J. 1960. Characteristics of red rice in Louisiana. Ph.D. dissertation. Louisiana State University, Baton Rouge, La.

Diarra, A., R.J. Smith Jr., and R.E. Talbert. 1985. Interference of red rice (*Oryza sativa*) with rice (*O. sativa*). Weed Sci. 33:644-649.

Holm, G.L., D.L. Plucknett, J.V. Pancho, and J.P. Herber. 1991. The World's Worst Weeds – Distribution and Ecology. Kieger, Malabar, Fla.

Khahn, T.D., A.A. Elzaawely, I.M. Chung, J.K. Ahn, S. Tawata, and T.D. Xuan. 2007. Role of allelochemicals for weed management in rice. Allelopathy J. 19:85-96.

Kwon, S.L., R.J. Smith Jr., and R.E. Talbert. 1992. Comparative growth and development of red rice (*Oryza sativa*) and rice (*O. sativa*). Weed Sci. 40:57-62.

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.

Sanders, D.E., R.E. Strahan, S.D. Linscombe, and T.P. Croughan. 1998. Control of red rice (*Oryza sativa*) in imidazolinone tolerant rice. Proc. South. Weed Sci. Soc. 51:36-37.

Smith, R.J., Jr. 1988. Weed thresholds in southern U.S. rice, *Oryza sativa.* Weed Tech. 2:232-241.

Smith, R.J. Jr. and K. Khodayari. 1985. Herbicide treatments for control of weeds in dry-seeded rice (*Oryza sativa*). Weed Sci. 33:686-692.

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.

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

Talbert, R.E. and N.R. Burgos. 2007. History and management of herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas rice. Weed Tech. 21:324-331.

White, R.H. and H.M. Hackworth. 1999. Weed control with imidazolinone-tolerant rice. Proc. South. Weed Sci. Soc. 52:185.

Table 1. Barnyardgrass and red rice control using imazethapyr alone and in combination with propanil plus thiobencarb, Rohwer, 2010.

			Preflood		2 Weeks Postflood	
Treatment	Rice growth stage	Rate	ECHCG[a]	ORYRU	ECHCG	ORYRU
		(oz/acre)	------------------(% control)------------------			
Imazethapyr fb	1-lf	4				
imazethapyr	5-lf	4	90	91	100	100
Imazethapyr fb	2-lf	4				
imazethapyr	5-lf	4	89	84	100	100
Imazethapyr +	1-lf	4				
propanil + thiobencarb fb	1-lf	128				
imazethapyr	5-lf	4	99	93	100	100
Imazethapyr +	2-lf	4				
propanil + thiobencarb fb	2-lf	128				
imazethapyr	5-lf	4	96	93	100	100
Imazethapyr fb	1-lf	4				
imazethapyr +	5-lf	4				
propanil + thiobencarb	5-lf	128	94	88	100	100
Imazethapyr fb	2-lf	4				
imazethapyr +	5-lf	4				
propanil + thiobencarb	5-lf	128	93	86	100	100
LSD (0.05)			6	8	NS	NS

[a] Abbreviations: ECHCG = barnyardgrass; ORYRU = red rice; NS = not significant.

Table 2. Barnyardgrass and red rice control using imazethapyr alone and in combination with propanil plus thiobencarb, Rohwer, 2011.

			Preflood		2 Weeks Postflood	
Treatment	Rice growth stage	Rate	ECHCG[a]	ORYRU	ECHCG	ORYRU
		(oz/acre)	------------------(% control)------------------			
Imazethapyr fb	1-lf	4				
imazethapyr	5-lf	4	96	91	100	100
Imazethapyr fb	2-lf	4				
imazethapyr	5-lf	4	95	91	100	100
Imazethapyr +	1-lf	4				
propanil + thiobencarb fb	1-lf	128				
imazethapyr	5-lf	4	99	94	100	100
Imazethapyr +	2-lf	4				
propanil + thiobencarb fb	2-lf	128				
imazethapyr	5-lf	4	100	96	100	100
Imazethapyr fb	1-lf	4				
imazethapyr +	5-lf	4				
propanil + thiobencarb	5-lf	128	96	91	100	100
Imazethapyr fb	2-lf	4				
imazethapyr +	5-lf	4				
propanil + thiobencarb	5-lf	128	96	90	100	100
LSD (0.05)			4	3	NS	NS

[a] Abbreviations: ECHCG = barnyardgrass; ORYRU = red rice; NS = not significant.

Acetolactate Synthase-Inhibiting Herbicide Resistance in Two Barnyardgrass (*Echinochloa crus-galli*) Biotypes of Arkansas

D.S. Riar, J.K. Norsworthy, M.T. Bararpour,
M.J. Wilson, R.C. Scott, and V. Srivastava

ABSTRACT

Barnyardgrass (*Echinochloa crus-galli* L.) is the most important weed of rice in Arkansas. Recently, two barnyardgrass biotypes with putative resistance to the acetolactate synthase (ALS)-inhibiting herbicides were collected from Arkansas (herein referred to as AR1 and AR2). Experiments were conducted to confirm and characterize cross-resistance to ALS-inhibiting herbicides and determine the resistance mechanism in these barnyardgrass biotypes. Cross-resistance experiments revealed that the AR1 biotype has evolved cross-resistance to the field rate applications of bispyribac (Regiment), imazamox (Beyond), imazethapyr (Newpath), and penoxsulam (Grasp). The AR2 biotype has also evolved cross-resistance to all these herbicides except bispyribac. Dose-response experiments revealed that AR1 and AR2 biotypes were >94 times more resistant to imazamox; >94 and 30 times, respectively, more resistant to penoxsulam; and 15 and 0.89 times, respectively, more resistant to bispyribac compared to susceptible biotypes based on the lethal dose needed to kill 50% of plants (LD_{50}). Addition of malathion (Prentox) at 0.89 lb ai/acre to penoxsulam reduced dry weight of AR1 and AR2 biotypes by 40% and 94%, respectively, at 21 days after treatment (DAT) compared to penoxsulam applied alone. However, addition of malathion to imazethapyr had no effect on dry weight or mortality of resistant biotypes at 21 DAT. Addition of malathion to bispyribac did not reduce dry weight; however, it increased mortality of the AR1 biotype by 30%. Malathion inhibits the activity of cytochrome P450 monooxygenase, an enzyme known to metabolize various herbicides. Reduction in dry weight after addition of malathion confirms that cytochrome P450 monooxygenase is imparting resistance to penoxsulam. Partial ALS gene coding sequence (CDS, 1701 bp) of AR1 and AR2 biotypes was sequenced and analyzed, which revealed that there is alanine_{122} to valine substitution in the AR1 biotype and alanine_{122} to threonine substitution in the AR2 biotype. Mutation at this position usually imparts a high level of resistance to imidazolinone herbicides (e.g., imazamox and imazethapyr) as seen in our experiments. These experiments show that different resistance mechanisms are involved in imparting cross-resistance to ALS-inhibiting herbicides in these resistant barnyardgrass biotypes.

INTRODUCTION

Barnyardgrass (*Echinochloa crus-galli* L.) is a troublesome weed in rice fields of North America and is ranked as the most important weed of Arkansas rice (Norsworthy et al., 2007). 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 each of these herbicides (Baltazar and Smith, 1994; Lovelace et al., 2002; Norsworthy et al., 2009).

To tackle the menace of propanil-, quinclorac-, and clomazone-resistant barnyardgrass, ACCase-inhibitor (fenoxaprop and cyhalofop) and ALS-inhibitor herbicides (bispyribac and penoxsulam for conventional rice and imazethapyr and imazamox for imidazolinone-resistant rice) were included in herbicide programs for rice (Talbert and Burgos, 2007). Extensive use of ALS-inhibiting herbicides, especially imazethapyr and imazamox, after commercialization of imidazolinone-resistant (Clearfield®) rice in 2002 has led to the evolution of ALS-resistant barnyardgrass biotypes. Imazethapyr-resistant barnyardgrass biotypes, AR1 and AR2, were found in rice fields from northeast Arkansas in 2008 and 2009, respectively, and were confirmed resistant to recommended field application rates of imazethapyr (0.062 lb/acre) in greenhouse trials conducted at the University of Arkansas, Fayetteville, Ark. (Wilson et al., 2010).

Frequency of occurrence of resistance to ALS-inhibiting herbicides is very high in weeds. At present, 112 weed species across 35 countries have been confirmed resistant to one or more ALS inhibitors (Heap, 2012). The mechanism of resistance to ALS-inhibiting herbicides in almost all of the known resistant weeds species is either increased metabolism of the active herbicide or alteration in the ALS gene (reviewed by Tranel and Wright, 2002). Non-target-site resistance in several weed species, because of increased metabolism of ALS-inhibiting herbicides by cytochrome P450 monooxygenases (CPM) has been reviewed by Yuan et al. (2007).

Experiments were conducted with objectives to (a) confirm and characterize cross-resistance to ALS-inhibiting herbicides, bispyribac, imazamox, imazethapyr, and penoxsulam; and (b) determine if increased metabolism of ALS-inhibiting herbicides by CPM or mutation in the ALS gene is the mechanism of resistance in AR1 and AR2 biotypes.

PROCEDURES

Confirmation and Characterization of Cross-Resistance

Plants of AR1, AR2, and a known susceptible biotype were treated with recommended field rates (1X) of bispyribac (0.027 lb ai/acre), imazamox (0.031 lb ai/acre), imazethapyr (0.062 lb ai/acre), and penoxsulam (0.031 lb ai/acre) at the 4- to 5-lf stage. A nontreated control was also included. Adjuvants were added as recommended by herbicide labels. Control of resistant and susceptible biotypes was visually evaluated 21 days after treatment (DAT). Data were subjected to ANOVA using the Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Cary, N.C.). Means were separated using Fisher's Protected Least Significant Difference (LSD) test at $\alpha = 0.05$.

Based on the response in the cross-resistance experiment, plants of all three biotypes at the 4- to 5-lf stage were treated with eight rates (including 1X rate, and rates above and below 1X rate) each of bispyribac, imazamox, and penoxsulam. The 1X rate of all herbicides were similar to the rates in the cross-resistance experiment, except for bispyribac being applied at 0.02 instead of 0.027 lb/acre. A nontreated control was included, and adjuvants were added to each treatment as in the cross-resistance experiment. For the susceptible biotype rates for all herbicide treatments ranged from 1/64 to 2X. Bispyribac rates for AR1 and AR2 ranged from 1/16 to 8X and 1/32 to 4X, respectively. Imazamox and penoxsulam rates for AR1 and AR2 biotypes ranged from 1/4 to 32X. Plant mortality data were recorded 21 DAT and subjected to PROBIT analyses to determine the lethal dose of these herbicides required to kill 50% of the treated plants (LD_{50}) of AR1, AR2, and susceptible biotypes.

Mechanism(s) of Resistance

To find if increased herbicide metabolism by CPM is the mechanism of resistance, AR1, AR2, and susceptible biotypes were treated with bispyribac, imazethapyr, and penoxsulam at 0.020, 0.094, and 0.031 lb/acre, respectively, alone or in combination with malathion (a known CPM inhibitor) at 0.89 lb ai/acre. Malathion alone and nontreated were the control treatments. Plant dry weight and mortality were recorded 21 DAT. Data for dry weight were subjected to ANOVA, means were separated using Fisher's Protected LSD ($\alpha = 0.05$), and *t*-tests ($\alpha = 0.05$) were conducted to determine difference between treatments with herbicides alone and in combination with malathion. Additionally, chi-square analysis was performed on mortality data to determine if there are differences between herbicide treatments with and without malathion.

To determine if altered target site is the mechanism of resistance, partial ALS gene coding sequence (CDS, 1701 bp) of AR1, AR2, and susceptible biotypes were sequenced using primers designed from the conserved regions of the Italian ryegrass (*Lolium multiflorum* Lam.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), and wheat (*Triticum aestivum* L.) ALS gene. The partial CDS of AR1, AR2, and susceptible biotype was blasted against the known *Arabidopsis thaliana* ALS amino acid sequence, and aligned with each other to determine if amino acid substitution in the ALS gene is the mechanism of resistance.

RESULTS AND DISCUSSION

Confirmation and Characterization of Cross-Resistance

Control of AR1 and AR2 biotypes was 57% and 6%, respectively, with imazethapyr; 59% and 6%, respectively, with imazamox; 26% and 51%, respectively, with penoxsulam; and 15% and 98%, respectively, with bispyribac (Table 1). In contrast, control of the susceptible biotype was ≥98% with each herbicide treatment, which confirms that AR1 biotype has evolved cross-resistance to all of the tested ALS-inhibiting herbicides, and AR2 has evolved cross-resistance to imazamox, imazethapyr, and penoxsulam. Dose-response experiments revealed that, compared to the susceptible biotype, the AR1 biotype was >94 times more resistant to imazamox and penoxsulam, and 15 times more resistant to bispyribac (Table 2). The AR2 biotype was >94 and 30 times more resistant to imazamox and penoxsulam, respectively, but was susceptible to bispyribac.

Mechanism of Resistance

Addition of malathion to the field application rate of penoxsulam in comparison to penoxsulam applied alone reduced dry weight by 40% and 94% and increased mortality by 15% and 75% of AR1 and AR2 biotypes, respectively (Table 3). Addition of malathion to imazethapyr had no effect on dry weight and mortality of both resistant biotypes. Addition of malathion to bispyribac had no effect on dry weight, but increased mortality of the AR1 biotype by 30%. Malathion inhibits the activity of CPM, an enzyme known to metabolize various herbicides. Therefore, increased metabolism of penoxsulam (and probably bispyribac) by CPM appears to be the partial mechanism of resistance to penoxsulam in these biotypes.

The sequencing and analyses of the partial coding sequence of the ALS gene of resistant and susceptible biotypes revealed that a mutation in the conserved region of the ALS gene of AR1 and AR2 biotypes resulted in the substitution of alanine$_{122}$ to valine and threonine, respectively. Mutation at alanine$_{122}$ is known to confer a high level of resistance to imidazolinone herbicides (Tranel et al., 2012), as was observed in AR1 and AR2 biotypes. These experiments confirm that multiple mechanisms of resistance are involved in imparting cross-resistance to ALS-inhibiting herbicides in these resistant barnyardgrass biotypes.

SIGNIFICANCE OF FINDINGS

This research confirmed and characterized the level of cross-resistance to ALS-inhibiting herbicides in barnyardgrass biotypes from Arkansas. In the present era of Clearfield® rice technology, evolution of cross-resistance to ALS-inhibiting herbicides in one of the most important weeds of rice will have great impact on rice management practices. The target-site-based resistance to imazamox and imazethapyr in these biotypes justifies the high level of resistance to imidazolinone herbicides. The metabolism-based resistance to penoxsulam hints toward cross- and multiple-resistance to other herbicides, especially ALS and acetyl-coenzyme A carboxylase (ACC) –inhibiting herbicides, because CPM metabolizes a wide range of herbicides. Further experiments are needed to evaluate multiple herbicide resistance in these biotypes.

ACKNOWLEDGMENTS

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

LITERATURE CITED

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.

Heap, I. 2012. The international survey of herbicide resistant weeds. http://www.weedscience.com. Accessed: 2 February 2012.

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

Talbert, R.E. and N.R. Burgos. 2007. History and management of herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas rice. Weed Tech. 21:324-331.

Tranel, P.J. and T.R. Wright. 2002. Resistance of weeds to ALS-inhibiting herbicides: what have we learned? Weed Sci. 50:700-712.

Tranel, P.J., Wright, T.R, and Heap, I.M. 2012. ALS mutations from herbicide-resistant weeds. http://www.weedscience.com. Accessed: 13 February 2012.

Wilson, M.J., J.K. Norsworthy, D.B. Johnson, E.K. McCallister, J.D. DeVore, G.M. Griffitth, S.K. Bangarwa, R.C. Scott, and K.L. Smith. 2010. Use of imazosulfuron in Arkansas Rice. *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 581:153-157. Fayetteville.

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. Control of barnyardgrass biotypes at 21 days after treatment with various acetolactate synthase -inhibiting herbicides.[¶,†]

Herbicide	Rate	Control		
		Susceptible	AR1	AR2
	(lb ai/acre)	(%)		
Imazethapyr	0.062	100 aA	57 bA	6 cC
Imazamox	0.031	100 aA	59 bA	6 cC
Penoxsulam	0.031	99 aAB	26 cB	51 bB
Bispyribac	0.030	98 aB	15 bC	98 aA

[¶] Means for each biotype within a column followed by the same uppercase letters and means for each herbicide within a row followed by the same lowercase letters are not significantly different according to Fisher's protected LSD test (α = 0.05).

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

Table 2. Imazamox, penoxsulam, and bispyribac dose required to kill 50% of plants (LD_{50}) of barnyardgrass biotypes.[¶,†]

Herbicide	Biotype	LD_{50}	(95% CI)	R/S ratio
		(lb ai/acre)		
Imazamox	AR1	>1		>94
	AR2	>1		>94
	Susceptible	0.011	(0.009 to 0.013)	
Penoxsulam	AR1	>1		>94
	AR2	0.320	(0.265 to 0.390)	30
	Susceptible	0.011	(0.009 to 0.013)	
Bispyribac	AR1	0.044	(0.038 to 0.050)	15
	AR2	0.003	(0.002 to 0.004)	0.89
	Susceptible	0.003	(0.002 to 0.004)	

[¶] LD_{50} was determined by conducting PROBIT analysis in SAS.

[†] R/S ratio was calculated by dividing the LD_{50} dose of resistant biotype by the LD_{50} dose of susceptible biotype.

Table 3. Percent dry weight (with percent mortality in parenthesis) of resistant biotypes compared to susceptible barnyardgrass biotype at 21 days after treatment with different acetolactate synthase-inhibiting herbicides applied alone or in combination with malathion.[¶,†]

		Dry weight	
Treatment	Rate	AR1	AR2
	(lb ai/acre)	---- (% of control) --	
Malathion	0.892	92 A (0)	137 A (0)
Imazethapyr	0.094	23 D (0)	92 B (0)
Imazethapyr + malathion	0.094 + 0.892	33 CD (0)	87 B (0)
Penoxsulam	0.031	71 B (0)	51 C (0)
Penoxsulam + malathion	0.031 + 0.892	43[ß] C (15)[§]	3[ß] D (75)[§]
Bispyribac	0.020 + 0.892	4 E (70)	0 D (100)
Bispyribac + malathion	0.020 + 0.892	0 E (100)[§]	0 D (100)

[¶] Means for each biotype within a column followed by the same letters are not different according to Fisher's protected LSD test (α = 0.05).

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

[ß] Represents reduced dry weight with addition of malathion to a particular herbicide treatment based on *t*-test (α = 0.05).

[§] Represents increased mortality with addition of malathion to a particular herbicide treatment based on chi-square test (α = 0.05).

RICE CULTURE

Growing Rice with Less Water

M.M. Anders, K.B. Watkins, L.L. Nalley, T.J. Siebenmorgen, and K.R. Brye

ABSTRACT

Farmers throughout much of the rice production areas of Arkansas are facing diminishing water resources. In order for rice production to continue at its current levels, or increase, it will be necessary to develop management strategies that will allow farmers to continue rice production while using less water. A study was initiated in 2011 that evaluates the potential of row-watered and intermittently-flooded rice production. Results showed that rice grain yields from intermittently-flooded plots were similar to those of flooded plots, while row-watered rice grain yields were significantly reduced. Grain yields from flooded plots averaged 216 bu/acre, while those from plots using intermittent flooding ranged from 201 to 210 bu/acre. Grain yields from row-watered plots were significantly lower at 142 to 150 bu/acre. Yield-scaled water use indicated that flooded rice required 4,536 gallons of water to produce a bushel of grain while the intermittent-flood treatments averaged 1,993 gallons. Our results indicate farmers can significantly reduce irrigation water use without large yield losses.

INTRODUCTION

Over 99% of rice acres in Arkansas are irrigated using flood irrigation (Wilson and Branson, 2006). It is estimated that almost 70% of the total water volume applied to all crops in the rice-growing region of Arkansas is used on rice (Scott et al., 1998). Most irrigation water is supplied by wells tapping into the Mississippi River Valley alluvial aquifer which underlies nearly all of eastern Arkansas (Schrader, 2006). Large water withdraws are placing strong downward pressure on this groundwater source (Czarnecki et al., 2002) and it is estimated that over 100 square miles of the alluvial aquifer could be depleted by 2009 if pumping remains at levels observed in 1997 (Freiwald, 2005).

While that has not happened, receding groundwater levels have prompted the Arkansas Natural Resources Commission to designate significant areas of eastern Arkansas's rice-production region as critical groundwater areas (Arkansas Natural Resources Commission, 2011). It is estimated that rice production in some of these areas will need to be reduced by as much as 50% in order to recharge the alluvial aquifer. This reduction in water use can be achieved by either not growing rice or growing rice with less water. Two irrigation management approaches that have been shown to reduce the volume of water needed to grow rice are row-watering (row rice) and intermittent flooding.

Row rice (RR) was studied in the early 1990s in southeast Missouri (Hefner and Tracy, 1991a, b) which led to the publication of production guidelines for that region (Tracy et al., 1993), and northeast Arkansas (Vories et al., 2002). Decreased water use was the primary benefit cited in this work, but other potential benefits mentioned but not quantified were: 1) elimination of energy, labor, and equipment costs related to levee construction; 2) greater flexibility in making pesticide and fertilizer applications with ground equipment; 3) increased harvest efficiency; and 4) less soil work required after harvest. Only one study attempted to evaluate the costs and returns of row rice (Laughlin and Mehrle, 1996). The results of this study were based on a limited number of field observations and the authors strongly cautioned against forming general conclusions about row rice profitability based on their results.

Intermittent flooding, referred to as alternate wetting drying (AWD) throughout much of the world's rice growing areas, is described as flooding the field to a given depth and allowing the water to evaporate and the field to dry to a specific point; then flooding the field and repeating the drying cycle. This results in wetting and drying cycles throughout the season. Little information is available on this system. It is reported as being successful and is now being used on farms in Mississippi (J. Massey, pers. comm., 2011). Studies conducted in Asia (Cabangon et al., 2004; Belder et al., 2004; Lampayan et al., 2005; Tabbal et al., 2002) indicate, that if used properly, AWD can significantly reduce water use and not result in yield losses.

This study was initiated to evaluate grain yield and irrigation water use for two rice hybrids under six irrigation treatments. Our specific objectives included developing a measurable soil moisture threshold that could be used as a water management tool that resulted in minimum grain yield losses and significant water savings using RR and AWD irrigation management.

PROCEDURES

Irrigation treatments were as follows: 1) flood, 2) RR (40%), 3) RR (60%), 4) AWD (40%), 5) AWD (60%), 6) AWD (40%)-flood. Percentages following irrigation method represent soil moisture content at the time irrigation water was applied. For the AWD treatments, fields were pumped to a 4-in. water level and left with no additional water added until the soil moisture reached the designated percentage. For the AWD flood treatment, the change in irrigation management was made at the green-ring growth stage. Two hybrids were used; CLXL745 and XL723, with four replications. All plots were 14 ft × 100 ft in size with rice planted into 7.5-in. rows at a rate of 30 lb/acre. Plots that were RR treatments were bedded into 30-in. beds and watered through the furrows between beds. All other treatments were flat planted. Fertilizer phosphorus (P) and potassium (K) were added prior to tilling the field at a rate of 60 lb P_2O_5/acre and 80 lb K_2O/acre. Nitrogen (N) was applied to all plots as urea at a rate of 120 lb N/acre as a single pre-flood application at the V4 to V5 development stage.

One plot of each irrigation treatment was equipped with a flow meter to measure irrigation water. Soil moisture sensors were placed in one plot of each treatment. To determine N, three replications of the AWD and flood treatments were equipped with metal rings that were fertilized with ^{15}N labeled urea at the same rate as the plot. Samples were collected from the rings at: 1) two weeks following N application, 2) green ring, 3) flowering, and 4) harvest. These samples will be sent to Dan C. Olk at the USDA/ARS National Laboratory for Agriculture and the Environment, Ames, Iowa, where they will be analyzed. During each drying cycle, soil moisture was measured on a daily basis using a theta probe to determine when the plots would be flooded. Data on evapotranspiration were collected later in the season. Water flow meters were placed on one replication of the AWD and flood treatments and used to determine total irrigation water use for each treatment.

The plots were planted on 12 May 2011. Plant stands were sparse in some treatments but sufficient for the hybrids used. Weed control consisted of a single Command plus Facet application shortly after sowing. Harvest was completed on 14 September 2011.

The experimental design was a randomized split block with irrigation treatments as the main plot and varieties as the split plot. There were four replications. Harvest weights were collected from a 10-ft strip down the center of the plot. Data were analyzed using the GLM procedure in Systat 12 (Systat Software, Inc., Chicago, Ill.). Means comparisons were determined using Tukey's test at a $P < 0.01$ level.

RESULTS AND DISCUSSION

Irrigation treatments were significantly different for all field parameters we measured in this study (Table 1). Both main effects and their interaction were significantly different for days to heading and harvest moisture. Despite our late planting date, grain yields were acceptable and reflect treatment differences (Table 2). There were no significant differences in grain yield between AWD and the flooded treatment, with the RR treatments significantly lower (Table 2). These results indicate intermittent flooding did not result in significant grain yield losses.

Water efficiencies were calculated for each treatment combination using the amount of irrigation water applied and crop grain yields (Table 3). For each RR treatment, more water was required to produce a bushel of grain than for the flooded treatment (Table 3). Recovering 30% of the irrigation water reduced the water requirements to less than those for the flooded treatment. There was a significant reduction in the amount of irrigation water needed to produce a bushel of grain for all AWD treatments when compared to all other treatments (Table 3). This was primarily because there was little loss in grain yield with these treatments. We were able to capture all rainfall during the growing season and needed only three irrigations for the AWD treatments. These results suggest this strategy would allow farmers to maintain acceptable grain yield levels and significantly reduce water use.

SIGNIFICANCE OF FINDINGS

This study indicates there is good potential to reduce water use in rice production without significantly reducing grain yields. There is a potential to use AWD over larger acreage than RR because it does not require additional infrastructure.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Arkansas Rice Research and Promotion Board for their financial support of this work. Additional funding was provided by RiceTec. We would like to thank Shelly Kerr, Terry Sells, David Hendrix, and Tara Moss for their assistance.

LITERATURE CITED

Arkansas Natural Resources Commission. 2011. Arkansas Ground-Water Protection and Management Report for 2010. Arkansas Natural Resources Commission, Little Rock, Ark.

Belder P., B.A.M. Bouman, J.H.J. Spiertz, R. Cabangon, L. Guoan, E.J.P. Quilang, Y. Li, and T.P. Tuong. 2004. Effect of water and nitrogen management on water use and yield of irrigated rice. Agric. Water Manage. 65:193-210.

Cabangon R.J., T.P. Tuong, E.G. Castillo, L.Z. Bao, G.H. Lu, G, Wang, B.A.M. Bouman, Y. Li, C. Chongde, and W. Jianzhang. 2004. Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiencies in typical lowland rice conditions in China. Rice Field Water Environ. 2:195-206.

Czarnecki, J.B., P.D. Hays, and P.W. McKee. 2002. The Mississippi River Valley alluvial aquifer in Arkansas: a sustainable water resource? U.S. Department of the Interior, U.S. Geological Survey, Fact Sheet FS-041-2, August 2002.

Freiwald, D.A. 2005. Ground-water models of the Alluvial and Sparta aquifers: management tools for a sustainable resource. U.S. Department of the Interior, U.S. Geological Survey, Fact Sheet 2005-3008, April 2005.

Hefner, S.G. and P.W. Tracy. 1991a. Effects of nitrogen source, application timing, and dicyandiamide on furrow-irrigated rice. Production Agri. 4(4):536-550.

Hefner, S.G. and P.W. Tracy. 1991b. The effect of nitrogen quantity and application timing on furrow-irrigated rice. Production Agri. 4(4):541-546.

Lampayan, R.M., B.A.M. Bouman, J.L. De Dios, A.T. Lactaoen, A.J. Espiritu, T.M. Norte, E.J.P. Quilang, D.F. Tabbal, L.P. Llorca, J.B. Soriano, A.A. Corpuz, R.B.

Malasa, and V.R. Vicmudo. 2005. Transfer of water saving technologies in rice production in the Philippines. *In*: T.M. Thiyagarajan, H. Hengsdijk, and P. Bindraban (eds.). Transitions in agriculture for enhancing water productivity. Proc. International Symposium on Transitions in Agriculture for Enhancing Water Productivity, 23-25 September 2003, Kilikulam, Tamil Nadu Agricultural University, Tamil Nadu, India. pp 111-132.

Laughlin, D.H. and R.K. Mehrle. 1996. An economic evaluation: straight versus contour levees rice production practices in Mississippi. Mississippi Agricultural and Forestry Experiment Station Bulletin 1063, December 1996.

Schrader, T.P. 2006. Status of water levels and selected water-quality conditions in the Mississippi River Valley alluvial aquifer in eastern Arkansas, 2004. U.S. Department of the interior, U.S. Geological Survey, Scientific Investigations Report 2006-5128.

Scott, H.D., J.A. Ferguson, L. Hanson, T. Fugitt, and E. Smith. 1998. Agricultural water management in the Mississippi Delta region of Arkansas. Arkansas Agricultural Experiment Station, Research Bulletin 959, August 1998.

Tabbal D.F., B.A.M. Bouman, S.I. Bhuiyan, E.B. Sibayan, and M.A. Sattar. 2002. On-farm strategies for reducing water input in irrigated rice: case studies in the Philippines. Agric. Water Manage. 56:93-112.

Tracy, P., B.D. Sims, S.G. Hefner, and J.P. Cairns. 1993. Guidelines for producing rice using furrow irrigation. University of Missouri Cooperative Extension Service, Agricultural Publication G4361, October 1993.

Vories, E.D., P.A. Counce, and T.C. Keisling. 2002. Comparison of flooded and furrow-irrigated rice on clay. Irrigation Sci. 21:139-144.

Wells, B.R., D. Kamputa, R.J. Norman, E.C. Vories, and R. Baser. 1991. Fluid fertilizer management of furrow irrigated rice. J. Fert. Issues 8(7):14-19.

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.

Table 1. Summary of analysis of variance probability values for grain yield, days to 50% heading, days under irrigation, plant height, and harvest moisture percent for the rice with less water study in 2011.

Measurement	Treatment	*P*-value
Grain yield	Irrigation	**0.0000**[¶]
	Variety	0.6036
	Irrigation x variety	0.4739
Days to heading	Irrigation	**0.0009**
	Variety	**0.0000**
	Irrigation x variety	**0.0127**
Days under irrigation	Irrigation	**0.0041**
	Variety	**0.0000**
	Irrigation x variety	0.4955
Plant height	Irrigation	**0.0000**
	Variety	**0.0011**
	Irrigation x variety	0.3059
Harvest moisture	Irrigation	**0.0004**
	Variety	**0.0160**
	Irrigation x variety	**0.0330**

[¶] Those values bolded are considered significantly different.

Table 2. Tukey mean square grain yield values and associated grouping for the rice with less water study in 2011.

Irrigation treatment	Grain yield
	(bu/acre)
Flood	216 A[¶]
AWD[†] 40% – Flood	210 A
AWD 60%	207 A
AWD 40%	201 A
RR[§] 60%	150 B
RR 40%	142 B

[¶] Values followed by the same letter are similar at the *P* = (0.05) level.

[†] AWD = alternate wetting drying.

[§] RR = row watered rice.

Table 3. Summary of irrigation water applied to each treatment and irrigation efficiency as gallons of irrigation water applied for each bushel of grain for the rice with less water study in 2011.

Treatment [¶]	Hybrid	Yield	Efficiency[†]	Irrigation
		(bu/acre)		(acre-in.)
Flood	CLXL745	212	4610 A[§]	36
Flood	XL723	219	4463 A	
AWD - 40	CLXL745	205	1722 D	13
AWD – 40	XL723	197	1792 D	
AWD– 40 - Flood	CLXL745	207	2623 C	20
AWD – 40 - Flood	XL723	213	2549 C	
AWD – 60	CLXL745	209	2208 C	17
AWD – 60	XL723	205	2251 C	
RR – 40	CLXL745	149	5102	28
RR – 40	XL723	135	5631	
RR – 40[£]	CLXL745	149	3644 B	20
RR – 40[£]	XL723	135	4022 B	
RR – 60	CLXL745	140	5430	28
RR – 60	XL723	142	5354	
RR – 60[£]	CLXL745	140	3878 B	20
RR – 60[£]	XL723	142	3824 B	

[¶] AWD = alternate wetting drying; RR = row watered rice.

[†] Efficiency represents the gallons of water needed for each bushel of grain.

[§] Values followed by the same letter are similar at the P = (0.05) level.

[£] Calculated with 30% of irrigation water captured at the bottom of the field.

Development of Nitrogen Soil Test for Rice Correlation and Fertilizer Calibration Curves for Rice Grown on Clayey Soils

A.M. Fulford, T.L. Roberts, R.J. Norman, N.A. Slaton,
C.E. Wilson Jr., D.L. Frizzell, J.D. Branson, M. Duren, and C.W. Rogers

ABSTRACT

An accurate representation of native soil nitrogen (N) fertility across a wide array of growing conditions is needed to avoid costly mismanagement of N fertilizer sources. The successful use of the N-Soil Test for Rice (N-ST*R) on silt loam soils has led to an interest in developing N-ST*R for clayey soils. The objective of this study was to correlate the quantity of alkaline hydrolyzable-N (AH-N), as determined using N-ST*R or the Illinois Soil-N Test (ISNT), to percent relative grain yield (RGY). The second objective was to develop ISNT and N-ST*R 95% RGY N fertilizer rate calibration curves. Previous analysis indicated that an 18-in. sampling depth was needed to properly develop a N fertilizer rate calibration curve using N-ST*R, while a 12-in. sampling depth was required for ISNT calibration on clayey soils. The inconsistency between the two methods, in regard to proper sampling depth, led to a re-evaluation of depth averaged ISNT and N-ST*R soil test values. Further analysis indicated that the strongest correlation for both ISNT ($R^2 = 0.77$) and N-ST*R ($R^2 = 0.79$) to %RGY occurred at the 0- to 12-in. depth. Also, the 0- to 12-in. depth provided the best prediction of the 95% RGY N fertilizer rate based on R^2 values of 0.84 and 0.83 for the ISNT and N-ST*R methods, respectively.

INTRODUCTION

Soil organic nitrogen (SON) as a component of total nitrogen (N) represents up to 90% of the N in surface soils and is located within soil organic matter (SOM; Olk,

2008) and the components of SON have been studied in depth using acid or alkaline hydrolysis (Greenfield, 2001). One component of SON (i.e., amino sugar-N) is derived mainly from microbial biomass and along with ammonium (NH_4-N) determines the concentration of alkaline hydrolyzable-N (AH-N) quantified using the Illinois Soil-N Test (ISNT; Kahn et al., 2001). The successful application of ISNT requires that conditions are suitable for mineralization of SON (Mulvaney et al., 2006). This indicates that ISNT provides an index of potentially mineralizable-N; and if conditions in the field are not conducive to SON mineralization, ISNT will inaccurately predict crop response to N fertilization. Therefore, evaluations of soil-based N tests should identify environmental factors that can potentially limit plant utilization of available-N to achieve an accurate representation of N availability under field conditions.

The N-Soil Test for Rice (N-ST*R) is an AH-N soil test method that has been developed for use on silt loam soils in the state of Arkansas (Roberts et al., 2011a). After establishing a soil sampling protocol based specifically on rice (*Oryza sativa* L.) rooting depth, it became possible to develop N-ST*R correlation and fertilizer calibration curves (Roberts et al., 2011b). Successful field validation trials on silt loam soils across Arkansas have demonstrated that yield maximizing site-specific N fertilizer rates can be predicted using N-ST*R soil test values (Roberts et al., 2011a). Establishing an N-ST*R N fertilizer calibration curve for clayey soils could expand the rice acreage utilizing N-ST*R as a routine soil test procedure. However, rice grown on clayey soils in Arkansas typically requires an additional 30 lb N/acre compared to rice grown on silt loam soils in order to achieve maximum yield (Wilson et al., 2001). Consequently, clayey soils will require a different N fertilizer calibration curve and may require a different N soil test compared to silt loam soils. The objectives of this project were: (1) to evaluate the correlation of ISNT and N-ST*R depth averaged (i.e., 0- to 6-, 0- to 12-, 0- to 18- and 0- to 24-in.) soil test values to %RGY; and (2) develop 95% RGY N fertilizer rate calibration curves using depth averaged ISNT and N-ST*R soil test values.

PROCEDURES

Nitrogen rate trials were conducted at eleven site-years from 2007 to 2010 in order to evaluate growth and yield of rice in response to the addition of N fertilizer across Arkansas. Trials were located on clayey soils in producer and experiment station fields; and at each location, N fertilizer was applied at rates of 0, 90, 120, 150, 180 and 210 lb N/acre. At each location a delayed-flood, direct-seeded cultural system was utilized for stand establishment prior to the installation of N fertilizer rate trials. Individual plots were nine rows wide (7-in. row spacing) by 20 ft in length. At all locations, rice was grown as an upland crop until the 4- to 5-lf stage at which point urea-N (46% N) was broadcast by hand using a two-way split application. The majority of N fertilizer was applied preflood directly to a dry soil surface and the second application occurred at approximately mid-season (MS; i.e., beginning internode elongation). Following preflood N application, a flood was established within 2 days on station fields and within 7 days on production fields and maintained until physiological maturity. Following maturity, four center rows from each plot were harvested and yield was adjusted to 12% moisture to account for differences in grain moisture.

Soil samples were taken from four individual depths (i.e., 0- to 6-, 6- to 12-, 12- to 18- and 18- to 24-in.) and mean soil AH-N concentrations that represented the 0- to 12-, 0- to 18- and 0- to 24-in. depths were determined by summing the concentrations from each individual depth and dividing by the number of depths used in summation. For example, mean soil AH-N concentrations from the 0- to 12-in. sampling depth represent the sum of eight soil AH-N concentrations divided by two depths. Soil cores were obtained from each control (0 lb N/acre) plot by sampling to a 24-in. depth in 6-in. increments using a Dutch Augur (AMS Inc., American Falls, Idaho). Samples were analyzed for inorganic-N (NH_4-N and NO_3-N; Mulvaney, 1996) as well as Mehlich-3 extractable nutrients (Mehlich, 1984). Alkaline hydrolyzable-N was determined by ISNT (Khan et al., 2001) and N-ST*R (Roberts et al., 2011b).

The concentration of AH-N determined using ISNT or N-ST*R was correlated to %RGY using depth averaged (i.e., 0- to 6-, 0- to 12-, 0- to 18- and 0- to 24-in.) soil test values. Percent RGY was calculated as the yield of the control plot divided by the maximum yield at that location multiplied by 100. The N rate required to achieve 95% RGY was regressed against ISNT or N-ST*R soil test value in order to generate a calibration curve used to predict the N rate needed to obtain 95% RGY for each depth averaged increment. Eleven site-years of N fertilizer rate trials were incorporated into the development of ISNT and N-ST*R correlation and fertilizer calibration curves using depth averaged soil test values and linear relationships were modeled using PROC REG in SAS version 9.2 (SAS Institute, Cary, N.C.); significance of the regression equation was determined using $P < 0.05$.

RESULTS AND DISCUSSION

The depth averaged correlation equations generated using ISNT soil test values revealed that the coefficients of determination (R^2) had a range of 0.62 to 0.77 (Table 1). In order to develop an accurate correlation between AH-N and %RGY it is important to evaluate the soil depth over which the rice plant can utilize available-N. Restricting ISNT analysis to the surface 0- to 6-in. would have produced a linear regression equation that would not have been able to describe as much of the variability in %RGY as a linear regression equation developed using the 0- to 12-in. depth. This is apparent from the increased R^2 value as sample depth increased from 0- to 6-in. to 0- to 12-in. indicating that averaging ISNT soil test values over a 12-in. depth improved the accuracy of the correlation curve. The ISNT R^2 values then decreased as soil depth increased to 0- to 18-in. and then 0- to 24-in. indicating the best correlation curve was at the 0- to 12-in. soil depth.

Nitrogen Soil Test for Rice regression analysis indicated that the linear regression equations describing the correlation between N-ST*R and %RGY were improved compared to surface soil (0- to 6-in.) analysis by using depth averaged soil test values, with the exception of the 0- to 24-in. depth (Table 2). The identification of a significant linear relationship ($P = 0.0003$) with an R^2 of 0.79 indicated that the 0- to 12-in. depth provided the most accurate representation of AH-N available for plant uptake based on N-ST*R analysis. In comparison to the trend exhibited by ISNT, the N-ST*R R^2 values also increased as soil depth increased from 0- to 6-in. to 0- to 12-in. and then decreased as depth increased to 0- to 24-in. Previous analysis indicated a discrepancy between the two methods in response to sampling depth. While ISNT required a 0- to 12-in., depth averaged soil test value to achieve the strongest correlation to %RGY, N-ST*R required an 18-in., depth averaged soil test value. This inconsistency between the two methods was resolved by a re-evaluation of the depth averaged ISNT and N-ST*R soil test values. Further analysis indicated that the 0- to 12-in. soil depth could be used to properly correlate either ISNT or N-ST*R soil test values to %RGY for rice grown on clayey soils.

Regression analysis indicated that there was a significant linear relationship between ISNT and the N fertilizer rate required to achieve 95%RGY for clayey soils sampled to a 24-in. depth (Table 3). The trend among depth averaged ISNT regression equations indicated that as sampling depth increased from 0- to 6-in. to 0- to 12-in. the predictive ability of the ISNT fertilizer calibration curve improved. The N fertilizer calibration curves developed for the 0- to 18- and the 0- to 24-in. depths were also capable of describing the linear relationship between ISNT and 95%RGY N fertilizer rate. However, the identification of a significant ($P < 0.0001$; $R^2 = 0.84$) regression equation at the 0- to 12-in. depth indicated that ISNT analysis of soil sampled to a 12-in. depth provided the most accurate prediction of the 95 %RGY N fertilizer rate.

The use of N-ST*R for the development of N fertilizer rate calibration curves produced significant linear regression equations capable of describing the relationship between N-ST*R and 95%RGY N fertilizer rates for clayey soils sampled to a 24-in. depth (Table 4). However, the R^2 values obtained from regression analysis were within a range of 0.60 to 0.83 indicating that differences in N-ST*R soil test values among the four depths evaluated (i.e., 0- to 6-, 6- to 12-, 12- to 18-, and 18- to 24-in.) produced regression equations that were able to explain a different proportion of the variability in the 95%RGY N fertilizer rate. The N-ST*R soil test value obtained using the 0- to 12-in. depth produced a significant ($P = 0.0001$) linear regression equation with an R^2 value of 0.83 which was similar to the R^2 of 0.84 for ISNT at the 0- to 12-in. depth. The trend exhibited among N fertilizer calibration curves across the four depths evaluated indicates that the ability of N-ST*R to predict the 95%RGY N fertilizer rate reached a maximum at the 0- to 12-in. depth, and as sampling depth increased to 24-in. the predictive ability of the N-ST*R fertilizer calibration curve decreased.

The range in soil AH-N concentration as determined by ISNT was 90 to 148 mg N/kg soil (Fig. 1A) while the range in soil AH-N concentration determined using N-ST*R was 111 to 162 mg N/kg soil (Fig. 1B). The range of ISNT soil test values identified using a 0- to 12-in. depth corresponded to 95%RGY N fertilizer rates across an approximate range of 103 to 187 lb N/acre and the range of N-ST*R soil test values obtained from the analysis of the 0- to 12-in. soil depth corresponded to 95%RGY N fertilizer rates across an approximate range of 93 to 186 lb N/acre. Soil analysis using either ISNT or N-ST*R has indicated that AH-N quantified to a 12-in. depth provided the greatest accuracy in predicting the 95%RGY N fertilizer rate over the range of soil test values evaluated.

SIGNIFICANCE OF FINDINGS

The incorporation of N-ST*R in clayey soil rice production systems could expand the total rice acreage utilizing this method as a routine N soil test. However, the successful application of N-ST*R on clayey soils requires the soil test to be indicative of plant available-N across an array of growing conditions and levels of native soil N fertility. Preliminary results suggest that a 12-in. sampling depth can be used for either ISNT or N-ST*R in developing an accurate N fertilizer response correlation curve and N fertilizer calibration curve for rice grown on clayey soils.

ACKNOWLEDGMENTS

This research was supported by Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Greenfield, L.G. 2001. The origin and nature of organic nitrogen in soil as assessed by acidic and alkaline hydrolysis. European J. Soil Sci. 52:575-583.

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple soil test for detecting sites that are nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1751-1760.

Olk, D.C. 2008. Organic forms of soil nitrogen. *In:* J.S. Schepers and W.R. Raun (co-eds.). Nitrogen in Agricultural Systems. Agron. Monogr. 49. Madison, Wis.

Mehlich, A. 1984. Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Commun. Soil Sci. and Plant Anal. 15:1409-1416.

Mulvaney, R.L. 1996. Nitrogen - inorganic forms. *In:* D.L. Sparks et al. (eds.). Methods of Soil Analysis. Part 3. SSSA Book Ser. 5. SSSA. Madison, Wis.

Mulvaney, R.L., S.A. Kahn, and T.R. Ellsworth. 2006. Need for a soil-based approach in managing nitrogen fertilizers for profitable corn production. Soil Sci. Soc. Am. J. 70:172-182.

Roberts, T.L., R.J. Norman, N.A. Slaton, C.E. Wilson Jr., A. Fulford, S. Williamson, J. Branson, and D. Frizzell. 2011a. 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.

Roberts, T.L., W.J. Ross, R.J. Norman, N.A. Slaton, and C.E. Wilson Jr. 2011b. Predicting nitrogen fertilizer needs for rice in Arkansas using alkaline hydrolyzable-nitrogen. Soil Sci. Soc. Am. J. 75:1161-1171.

Wilson, C.E. Jr., N.A. Slaton, R.J. Norman, and D. Miller. 2001. Efficient use of fertilizer. pp. 51-74. *In:* N.A. Slaton (ed.). Rice Production Handbook. University of Arkansas, Division of Agriculture, Cooperative Extension Service MP 192.

Table 1. Regression equations describing the relationship between the depth averaged Illinois Soil-N Test (ISNT) value and percent relative grain yield for clayey soils sampled from 2007 to 2010.

Soil depth	Regression equation	R^2	*P*-value
0- to 6-in.	Y = -47.35 + 0.75x	0.69	0.002
0- to 12-in.	Y = -29.36 + 0.66x	0.77	0.0004
0- to 18-in.	Y = -14.29 + 0.56x	0.72	0.001
0- to 24-in.	Y = -4.07 + 0.50x	0.62	0.004

Table 2. Regression equations describing the relationship between the depth averaged N Soil Test for Rice (N-ST*R) value and percent relative grain yield for clayey soils sampled from 2007 to 2010.

Soil depth	Regression equation	R^2	*P*-value
0- to 6-in.	Y = -60.19 + 0.77x	0.64	0.003
0- to 12-in.	Y = -63.67 + 0.84x	0.79	0.0003
0- to 18-in.	Y = -28.63 + 0.62x	0.70	0.001
0- to 24-in.	Y = -16.35 + 0.55x	0.61	0.005

Table 3. Regression equations describing the relationship between the 95% relative grain yield N fertilizer rate (lb N/acre) and the depth averaged Illinois Soil-N Test (ISNT) value for rice grown on clayey soils in Arkansas.

Soil depth	Regression equation	R^2	*P*-value
0- to 6-in.	Y = 359.58 – 1.68x	0.77	0.0004
0- to 12-in.	Y = 317.47 – 1.45x	0.84	<0.0001
0- to 18-in.	Y = 284.21 – 1.24x	0.78	0.0003
0- to 24-in.	Y = 262.66 – 1.12x	0.68	0.002

Table 4. Regression equations describing the relationship between the 95% relative grain yield N fertilizer rate (lb N/acre) and the depth averaged N Soil Test for Rice (N-ST*R) value for rice grown on clayey soils in Arkansas.

Soil depth	Regression equation	R^2	*P*-value
0- to 6-in.	Y = 367.76 – 1.57x	0.60	0.005
0- to 12-in.	Y = 389.01 – 1.83x	0.83	0.0001
0- to 18-in.	Y = 309.72 – 1.32x	0.71	0.001
0- to 24-in.	Y = 284.84 – 1.18x	0.62	0.004

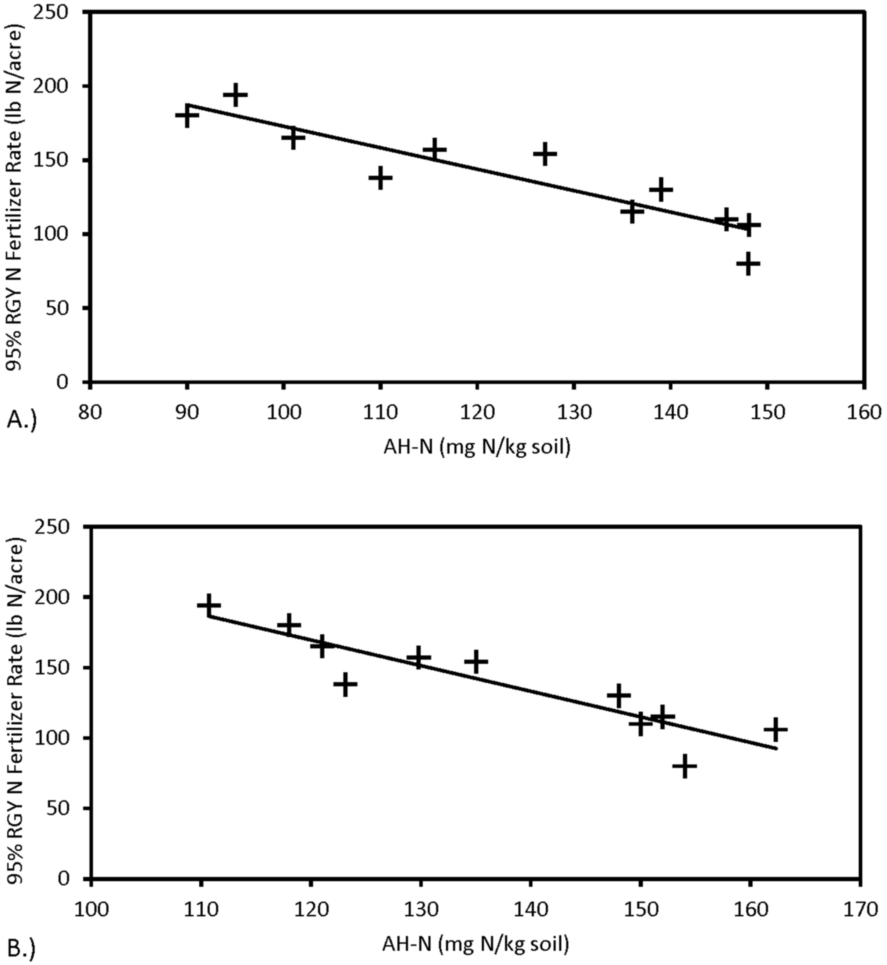


Fig. 1. Nitrogen fertilizer rate (lb N/acre) required to achieve 95% relative grain yield (RGY) versus A) Illinois Soil N Test (ISNT) or B) N-Soil Test for Rice (N-ST*R) soil test value (mg AH-N/kg soil) for clayey soils sampled to a 0- to 12-in. depth.

Soil Surface CO_2 Flux as Affected by Rice-Based Rotation and Tillage

J.M. Motschenbacher, K.R. Brye, M.M. Anders, and E.E. Gbur

ABSTRACT

Carbon dioxide (CO_2) emissions from the soil during the dry period in rice (*Oryza sativa* L.)-based cropping systems are a major component in terrestrial carbon cycling and contribute to the global atmospheric greenhouse gas concentration. This study was conducted in 2010 to evaluate the effect of 10 different rice-based crop rotations and two tillage treatments on soil surface CO_2 flux after 11 years of consistent management. Results showed that soil CO_2 emissions only differed on 4 out of 10 measurement dates among tillage and/or crop rotations; however, few treatment differences were consistent between sampling dates. The only noticeable difference seemed to be related to crop maturity at the time of measurement, whereas CO_2 flux was greater in more mature crops. The lack of consistent treatment effects seems to indicate that over the course of time, the 20 different management combinations appear to have reached some degree of equilibrium for soil surface CO_2 fluxes.

INTRODUCTION

Carbon dioxide (CO_2) emissions from the soil are a byproduct of both root and microorganism respiration (Montgomery et al., 2000). Under oxygen-rich conditions, the microbial decomposition of soil organic matter (SOM) releases carbon in the form of CO_2. Emissions of CO_2 are of little concern during the growing period due to the anoxic soil conditions of flooded rice (*Oryza sativa* L.), which releases methane (CH_4) as opposed to CO_2 due to oxygen-depletion in the soil. However, CO_2 is the primary carbon gas lost during the non-flooded period, which includes pre-flood and post-flood release time periods in years when rice is planted and during the entire year when dry-land crops are produced in rice-based crop rotations.

The loss of CO_2 from the soil is of great concern due to its contribution to the atmospheric CO_2 concentration, as CO_2 is one of the primary greenhouse gases (GHG) that contribute to global warming, along with CH_4, nitrous oxide, and water vapor. Annual emissions of CO_2 have risen by 80% between 1970 and 2004, and CO_2 emissions represent approximately 77% of the total anthropogenic GHG emissions (IPCC, 2007). The world's soils are estimated to contain more C in the organic matter fraction of the soil than that contained in living vegetation and the atmosphere combined (Sundquist, 1993). Agricultural operations can contribute to CO_2 emissions by mechanically disturbing the soil through repetitive tillage and by cultivating fallow land. This disturbance causes the soil to be aerated, which leads to the rapid microbial decomposition of organic matter stored in the soil from crop residues or native vegetation.

One way to counter the loss of CO_2 from the soil is by returning large amounts of crop residues to the soil through conservation practices, such as minimizing or eliminating tillage and the production of high-residue-producing crops. No-tillage management allows crop residues to remain on the soil surface and remain stratified in the near-surface layers of the soil, which leads to greater carbon storage in the soil as opposed to gaseous release into the atmosphere. Furthermore, growing high-residue-producing crops, such as rice (2.9 tons/acre) and corn (3.6 tons/acre), add greater amounts of crop residues to the soil when compared to low-residue-producing crops, such as soybean (1.0 tons/acre) or wheat (1.5 tons/acre). Therefore, the objectives of this study were to evaluate the effects of tillage [conventional tillage (T) and no-tillage (NT)] and rice -based crop rotations [continuous rice (R), rice-soybean (RS), soybean-rice (SR), rice-corn (RC), corn-rice (CR), rice (winter wheat) [R(W)], rice (winter wheat)-soybean (winter wheat) [R(W)S(W)], rice (winter wheat)-soybean (winter wheat) [S(W)R(W)], rice-soybean-corn (RSC) and rice-corn-soybean (RCS)] on soil surface CO_2 flux after 11 years of consistent management. It was hypothesized that soil surface CO_2 flux would be greater in T than NT, greater in rotations with increased frequencies of the high-residue-producing crops, and greater in rotations that are double-cropped with winter wheat compared to rotations that were fallow during the winter.

PROCEDURES

This study was initiated in 1999 on a Dewitt silt loam (fine, smectitic, thermic, Typic Albaqualf) at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark. Prior to 1999, the study area had been fallow for several years due to a lack of irrigation capability. In preparation for this study, the site was land-leveled to a 0.15% grade in fall 1998. This field study consisted of two tillage treatments (T and NT) and 10 rice-based crop rotations (Table 1) arranged in a randomized complete block with four replications of treatment combinations. Each tillage-rotation experimental unit covered an area of 19 ft × 62 ft. The tillage-rotation treatment combinations were treated under an optimal fertility regime (Table 2), and the four replications were located within a 4.7-acre experimental site. The rice was drill-seeded at a rate of 89 lb/acre, soybean at a rate of 50 lb/acre, and wheat at a rate of 60 lb/acre in 7.5-in.

rows. Corn was planted in 30-in. rows at a plant population of 32,000 seeds/acre. Crop management practices closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, irrigation management, weed control, and pest management.

Soil surface CO_2 flux was measured on the tillage-rotation treatment combinations using a portable photosynthesis system (LI-6400XT) equipped with a 4-in. diameter CO_2 flux soil chamber (LI-6400-09; LiCor, Inc., Lincoln, Neb.). Measurements were made 10 times during the 2010 growing season, with the first measurement being made in April and the last measurement being made in November (Fig. 1). For rotations that had rice planted, measurements were made up until the rice was flooded and then again after the flood was released (Table 1), whereas rotations with corn or soybean planted had measurements made throughout the entire growing season. Statistical analyses were conducted separately by measurement date using SAS (version 9.2, SAS Institute, Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level.

RESULTS AND DISCUSSION

During the summer growth period, soil surface CO_2 flux generally increased as atmospheric and soil temperatures increased and decreased in conjunction with temperatures toward the end of the growing season in all tillage-rotation treatment combinations (Fig. 1). However, after 11 years of consistent rotation management and 10 years of T or NT, soil surface CO_2 fluxes did not differ substantially among rotation and/or tillage treatments. When 10 measurement dates in 2010 where evaluated separately (Fig. 1), tillage-rotation treatment combinations only differed on two of the 10 measurement dates (23 June and 15 July). The 23 June ($P = 0.03$) measurement date had a significantly lower soil surface CO_2 flux in the late-season cropping systems [i.e., R(W), R(W)S(W), S(W)R(W)] under both T (0.1 to 1.2 µmol/m^2/s) and NT (0.6 to 1.2 µmol/m^2/s) compared to the other non-flooded crop rotations measured [i.e., RS, RC, R(W), S(W)R(W), RSC, RCS; 3.7 to 8.8 µmol/m^2/s] under T or NT, with the exception of the T/RC (1.5 µmol/m^2/s) combination (Fig. 1). Since root respiration is affected by photosynthetic rates, which increase as the crop matures, and is estimated to make up 40% to 60% of the CO_2 emitted from the soil (Raich and Schlesinger, 1992), this outcome may be explained by the maturity of the crops during the time of sampling. The 15 July ($P < 0.01$) measurement date had significantly greater soil surface CO_2 fluxes from the T/RS (6.9 µmol/m^2/s), T/RC (9.1 µmol/m^2/s), T/RCS (6.7 µmol/m^2/s), and NT/RSC (7.3 µmol/m^2/s) than all other non-flooded crop rotations measured [i.e., RS, RC, R(W), S(W)R(W), RSC, RCS; 3.1 to 5.5 µmol/m^2/s] under T and/or NT (Fig. 1). Results for the RS, RC, and RCS rotations were similar to past studies that showed tilled soil as having a greater soil surface CO_2 flux than reduced and NT treatments (Brye et al, 2005; Reicosky and Lindstrom, 1993); however, soil surface CO_2 fluxes from the R(W), S(W)R(W), and RSC did not follow the expected pattern of greater CO_2 fluxes in the tilled soil.

When averaged across rotation treatments, there were no differences in soil surface CO_2 flux between tillage treatments on any measurement date (Fig. 1). When averaged across tillage treatments, only 2 out of the 10 measurement dates (16 April and 1 July) had differences in soil surface CO_2 flux among crop rotations (Fig. 1). The 16 April ($P = 0.02$) measurement date had a greater CO_2 flux from the R(W)S(W) (3.4 µmol/m^2/s) and R(W) (3.0 µmol/m^2/s) than the R, RS, SR, RC, RSC, and RCS rotations (1.0 to 1.7 µmol/m^2/s; Fig. 1). The significantly greater soil surface CO_2 flux from two of three rotations that included winter wheat was expected from the increased root respiration associated with the wheat crop being in the ground during the time measurements were made, whereas all other rotations were fallow. However, during the 1 July ($P < 0.01$) measurement date, early-season rotations with soybean [i.e., RCS (8.4 µmol/m^2/s) and RS (7.4 µmol/m^2/s)] had significantly greater CO_2 fluxes than late-season rotations that included wheat [i.e., R(W), R(W)S(W), S(W)R(W); 2.6 to 3.1 µmol/m^2/s; Fig. 1], but there were no differences among the RCS, RS, RSC (5.90 µmol/m^2/s), and RC (5.82 µmol/m^2/s) rotations (Fig. 1). Similar to the 23 June measurement date, differences in CO_2 fluxes in late-season rotations on the 1 July measurement date may have also been associated with differences in photosynthetic rates based on differences in crop maturity (Raich and Schlesinger, 1992).

SIGNIFICANCE OF FINDINGS

This study demonstrated that soil surface CO_2 flux was not substantially affected by tillage and rice-based crop rotations after 11 years of consistent management had occurred. Only 4 of the 10 measurement dates in 2010 had any significant differences due to tillage and/or rotation, which appeared to be more related to crop maturity than the tillage and/or rotation treatment combination. Overall, there were no consistent patterns in tillage and/or rotation effects across any of the individual measurement dates. However, the apparent lack of consistent significant differences is in itself significant because the results appear to indicate that, over the course of time, the cropping systems have reached a state of equilibrium. While NT, combined with the production of high-residue-producing crops, may have the ability to sequester an overall greater amount of carbon in the soil overtime, results from this study suggest that increased soil carbon concentrations might not increase the emission rates of CO_2 from the soil during the summer growing period if management procedures have been conducted over a longer period of time.

ACKNOWLEDGMENTS

This research was partially funded by the Arkansas Rice Research and Promotion Board. Field assistance provided by Terry Sells and Daniel McCarty is gratefully acknowledged.

LITERATURE CITED

Brye, K.R., D.E. Longer, and E.E. Gbur. 2005. Impact of tillage and residue burning on carbon dioxide flux in wheat-soybean production system. Soil Sci. Soc. Am. J. 70:1145-1154.

IPCC. Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Synthesis report [online]. Core Writing Team, R.K. Pachauri, and A. Reisinger (eds.) Available at http:www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (verified 1 December 2009).

Montgomery, D.R., D. Zabowski, F.C. Ugolini, R.O. Hallberg, and H. Spaltenstein. 2000. Soils, watershed processes, and marine sediments. pp. 159-194. *In:* M.C. Jacobson, R.J. Charlson, H. Rodhe, and G.H. Orians. (eds.). Earth system science: From biogeochemical cycles to global change. Academic Press, San Diego, Calif.

Raich, J.W. and W.H. Schlesinger. 1992. The global carbon dioxide flux in soil respiration and relationship to vegetation and climate. Tellus Ser. B 44:81-99.

Reicosky, D.C. and M.J. Lindstrom. 1993. Fall tillage method: Effect on short-term carbon dioxide flux from the soil. Agron. J. 85:1237-1248.

Sundquist, E.T. 1993. The global carbon budget. Science 259:934-941.

Table 1. Summary of the crop rotations and dates of planting, rice flooding, flood release, and harvest during the 2010 study period at the Rice Research and Extension Center near Stuttgart, Ark. Crop management dates are summarized for the crops grown during the summer growing period.

	2010 annual crop management dates			
Rotation[a]	Planting	Flooding[b]	Flood release	Harvest
R	14 Apr.	26 May	10 Aug.	25 Aug.
RS	23 Apr.	-	-	26 Aug.
SR	14 Apr.	26 May	10 Aug.	25 Aug.
RC	21 Apr.	-	-	04 Oct.
CR	14 Apr.	26 May	10 Aug.	25 Aug.
R(W)[c]	18 June	12 July	20 Sep.	15 Oct.
R(W)S(W)[c]	24 June	-	-	28 Oct.
S(W)R(W)[c]	18 June	12 July	20 Sep.	15 Oct.
RSC	21 Apr.	-	-	04 Oct.
RCS	23 Apr.	-	-	26 Aug.

[a] R = rice, S = soybean, C = corn, and W = winter wheat.

[b] Flooding dates listed are approximate; rotations with flooding and flood-release dates represent rotations that had rice planted during the growing season

[c] Rotations that include wheat were harvested on 16 June 2009 and planted on 28 October 2010, crops in parentheses were grown during the winter.

Table 2. Summary of the annual nitrogen (N), phosphorous (P_2O_5), and potassium (K_2O) added to corn, soybean, rice, and wheat to comprise the optimal soil fertility treatments in a long-term, rice-based rotation study at the Rice Research and Extension Center near Stuttgart, Ark., on a silt-loam soil.

	Soil amendment		
Crop	N	P_2O_5	K_2O
	(lb/acre)		
Corn	300	80	150
Soybean	0	60	120
Rice	150	60	90
Wheat	150	60	60

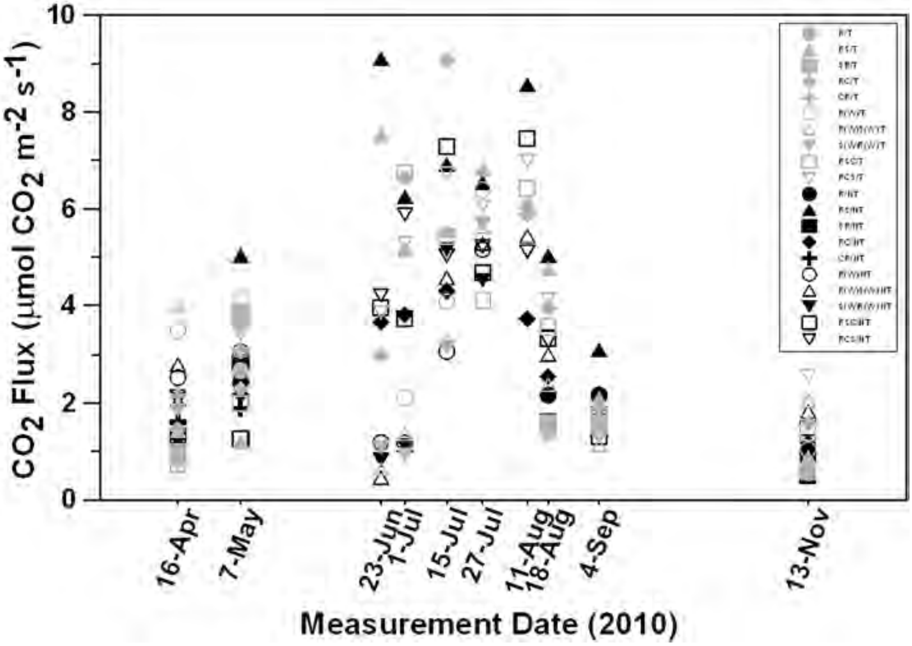


Fig. 1. Soil surface carbon dioxide (CO_2) fluxes during the 2010 growing season under different tillage regimes and rice (R) based crop rotations. Tillage treatments included conventional tillage (T) and no-tillage (NT). Rice was rotated with soybean (S), corn (C), and/or winter wheat (W).

Water-Stable Soil Aggregation in Rice-Based Crop Rotations

J.M. Motschenbacher, K.R. Brye, M.M. Anders, and E.E. Gbur

ABSTRACT

Rice (*Oryza sativa* L.)-based cropping systems are different from other row crops due to the frequent cycling between anaerobic (i.e., flooded) and aerobic (i.e., non-flooded) conditions. These different flood-irrigation regimes can influence the quantity of aggregated soil, which is a key component to optimal soil structure. This study was conducted in 2009 to access the effects of six rice-based crop rotations [continuous rice (R), rice-soybean (RS), rice-corn (RC), rice (winter wheat) [R(W)], rice (winter wheat)-soybean (winter wheat) [R(W)S(W)], and rice-corn-soybean (RCS)], two tillage treatments [conventional tillage (T) and no-tillage (NT)], and two soil depths (0- to 4-in. and 4- to 8-in.) on concentration of water-stable soil macroaggregates (i.e., > 0.25-mm in diameter) after 10 years of consistent management. The total percentage of soil that formed macroaggregates was 1.2 to 4 times greater under NT in the top 4 in. than in the other tillage-depth treatment combinations within all six crop rotations, and the percentage of water-stable soil aggregates in the NT/0- to 4-in. treatment combination was significantly greater in the continuous rice and rice rotations including corn than rotations that included wheat. Results from this study indicate that soil aggregation is positively correlated with increased inputs from high-residue-producing crops and decreased soil disturbance from tillage.

INTRODUCTION

Soil aggregates play an important role in maintaining soil aeration, water infiltration, soil structural stability, and provide the primary physical protection for soil organic matter (SOM) storage (Oades and Waters, 1991). Water-stable aggregation, which is the ability of an aggregate to maintain its structure in the presence of wet conditions, of agriculturally managed soil is directly affected by tillage practices, crop rotation, fertilization treatments, and irrigation regimes. Decreased tillage practices have been reported to increase the concentration and stability of soil aggregates (Franzluebbers, 2004). Furthermore, the degree of soil aggregation in an agricultural crop rotation is highly dependent on the amount of organic material that is returned to the soil from crop residues, which can be increased with optimal fertilization (Angers and Carter, 1996). Aggregate formation increases because of the overall increase in the SOM content in response to decreased soil disturbance from tillage and/or increased biomass input. In rotations that include rice (*Oryza sativa* L.), the maintenance of a flood on the soil surface during the cropping period can affect aggregate formation and stability. This stability of the structure can be compromised because saturated soil conditions influence the rate of SOM decomposition and alter the bonds between SOM and soil particles which hold the aggregate together.

Since the nature of soil physical properties is generally of little concern during a rice-crop growing season due to the flooded-soil conditions, relatively few studies have examined the potential effects of rice rotations on soil physical properties. Therefore, the objective of this study was to evaluate the long-term effects of rice-based crop rotations [continuous rice (R), rice-soybean (RS), rice-corn (RC), rice (winter wheat) [R(W)], rice (winter wheat)-soybean (winter wheat) [R(W)S(W)], and rice-corn-soybean (RCS)], tillage [conventional tillage (T) and (NT)], and soil depth (0- to 4-in. and 4- to 8-in.) after 10 years of consistent management on water-stable soil aggregates (WSA) > 0.25-mm in diameter. It was hypothesized that the percentage of aggregated soil would be greater under NT than under T, greater in rotations with increased frequencies of high-residue-producing crops, and greater in the top 4 in. than in the 4- to 8-in. depth.

PROCEDURES

This study was conducted at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Ark. The study was initiated in 1999 on a Dewitt silt loam soil (fine, smectitic, thermic, Typic Albaqualf). The 4.7-acre study area had been fallow for several years prior to 1999 due to a lack of irrigation capability. In preparation for this study, the site was land-leveled to a 0.15% grade in fall 1998. The field study consisted of two tillage treatments (T and NT), six rice-based crop rotations (Table 1), and two soil depths (0- to 4- and 4- to 8-in.) arranged in a randomized complete block with four replications of treatment combinations. Each tillage-rotation experimental unit covered an area of 19 ft × 62 ft. All crop rotations were treated under an optimal fertility regime (Table 2). Rice was drill-seeded at a rate of 89 lb/acre, soybean at a rate of 50 lb/acre, and wheat at a rate of 60 lb/acre in 7.5-in. rows. Corn was planted in 30-in. rows at a plant population of 32,000 seeds/acre. Crop management practices closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, irrigation management, weed control, and pest management.

In the T treatment, crop residues were burned and then incorporated into the soil generally one to two months following harvest by disking twice. Prior to planting in the spring, plots were tilled by disking once to a typical depth of approximately 4 in., followed by multiple passes with a light field cultivator (i.e., Triple-K) to achieve the desired seedbed for rice planting. In the NT treatment, crop residues were left on the surface after harvest and were not manipulated by any means prior to planting in the spring. A 4- to 8-in. deep flood was established about one month after emergence in rice and was maintained annually until the rice reached physiological maturity. Corn was furrow-irrigated and soybean was flood irrigated on an as-needed basis approximately three to four times annually. Winter wheat was rain-fed only without irrigation.

Soil aggregate samples were collected in mid-March 2009 from the 0- to 4- and 4- to 8-in. depth intervals using a 4-in. diameter stainless steel core chamber. Two core samples were collected from each plot and combined into one composite sample for each depth (0- to 4- and 4- to 8-in.). Following collection, samples were manually broken up into pieces that were small enough to pass through a 6-mm sieve and air-dried for seven days at an approximate temperature of 72 °F. Sub-samples of 150 g of air-dry soil were separated into aggregated soil (> 0.25-mm in diameter) by wet sieving for 5 min at approximately 130 cycles per min (Yoder, 1936). Following wet-sieving, all samples were oven-dried for 24 h at 160 °F and the separated aggregates retained on the sieves were weighed to determine the total concentration of WSA based on the mass of the air-dried sample corrected for a 1.4% moisture difference from the oven-dried mass. Statistical analyses were conducted using SAS (version 9.2, SAS Institute, Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level.

RESULTS AND DISCUSSION

After 10 years of consistent rotation management and 9 years of tillage or NT, the percentage of soil that was aggregated (i.e., > 0.25-mm in diameter) was significantly affected by tillage, rotation, and soil depth ($P = 0.02$). The total percentage of WSA was two to four times greater under NT in the top 4 in. than in the other tillage-depth treatment combinations within all six crop rotations (Fig. 1). A smaller percentage of WSA in the near-surface layer of soil under tillage compared with NT is similar to what other studies reported between these management practices in agricultural systems (Six et al., 2000; Franzluebbers, 2004). The increased quantities of WSA can be explained by the reduced soil disturbance and greater retention of organic matter.

Although there was a considerable difference in the percentage of aggregated soil between tillage treatments in the top 4 in. (NT > T) within all crop rotations, ranging from two times greater in R(W)S(W) to four times greater in RCS, there were no differences in tillage-depth combinations in the 4- to 8-in. depth within any crop rotation (Fig. 1). Similar results in WSA quantities were observed by Anders et al. (2012) at the same experimental site in 2005. This study took place after six years of consistent management (1999 to 2005) in rice-based crop rotations under sub-optimal fertility, as opposed to optimal fertility and a 10 year period (1999 to 2009) of management. The Anders et al. (2012) study showed a greater percentage of WSA in the NT/0- to 4-in.

tillage-depth combination compared to the NT/4- to 8-in. and the T treatment in both the 0- to 4-in. and 4- to 8-in. depths. Another study in a R(W) rotation reported that tillage decreased the percentage of macroaggregates (> 0.25-mm in diameter) in the top 6 in. when compared to NT (Gathala et al., 2011).

The percentage of aggregated soil (i.e., > 0.25-mm in diameter) under tillage in the top 4 in. did not differ between crop rotations (Fig. 1). However, in the top 4 in. under NT, the R, RC, and RCS rotations had significantly greater percentages of WSA. This may be attributed to the increased frequency of high-residue producing crops of rice (2.9 tons/acre/year) and corn (3.6 tons/acre/year) compared rice rotations that were only rotated with soybean (1.0 tons/acre/year; Table 1). Results also suggest that the inclusion of wheat (1.5 tons/acre/year) into double-cropped rice rotations do not necessarily increase the quantity of WSA as much as mono-cropped continuous rice, despite the increase of annual inputs of crop residues. Under NT, continuous rice had a significantly greater percentage of WSA between depths, whereas the 4- to 8-in. depth (5.6%) had an 81% greater concentration of aggregated soil than the top 4 in. (3.1%; Fig. 1). Furthermore, the continuous rice rotation showed a 13% to 67% greater concentration of WSA in the 4- to 8-in. depth under both T and NT treatments when compared to the same tillage-depth combinations in R(W)S(W) and RCS.

SIGNIFICANCE OF FINDINGS

This study demonstrated that after 10 years of consistent soil and crop management, the concentration of aggregated soil was affected by tillage treatment, rice-based crop rotation, and soil depth. In contrast to that expected, only the NT treatment showed a greater percentage of WSA in the top 4 in., whereas the 4- to 8-in. depth under tillage often showed a greater percentage of WSA than in the top 4 in. within the same rotation. Also as expected, rotations that included corn and increased frequencies of rice, with the exception of the R(W) rotation, had a greater WSA concentration in the top 4 in. under NT compared with the other crop rotations, whereas no differences were observed in the 4- to 8-in. depth. This long-term study indicates that inputs from high-residue producing crops and soil manipulation from tillage affect soil aggregation, which subsequently affects soil structure. However, there was no strong evidence to suggest the frequency of periodic saturation of agronomic soils greatly affects the quantity of soil aggregates compared to crop rotations that were flooded less frequently (i.e., 2- and 3- year rice rotations versus continuous annual rice). The results obtained from this study can help highlight the impacts that the commonly used rice management practices of tillage, crop rotation, and flood-irrigation have on soil structural properties.

ACKNOWLEDGMENTS

This research was partially funded by the Arkansas Rice Research and Promotion Board. Field assistance provided by Terry Sells and Daniel McCarty is gratefully acknowledged.

LITERATURE CITED

Anders, M.M., K.R. Brye, D.C. Olk, and B.T. Schmid. 2012. Rice rotation and tillage effects on soil aggregation and aggregate carbon and nitrogen dynamics. Soil Sci. Soc. Am. J. Accepted, *in press*.

Angers, D.A. and M.R. Carter. 1996. Aggregation and organic matter storage in cool, humid agricultural soils. pp. 193-211. *In:* M.R. Carter and B.A. Stewart. Structure and organic matter storage in agricultural soils. CRC Press, Baton Raton, Fla.

Franzluebbers, A.J. 2004. Tillage and residue management effects on soil organic matter. pp. 227-268. *In:* F. Magdoff and R.R. Weil (eds.). Soil Organic Matter in Sustainable Agriculture. CRC Press, Boca Raton, Fla.

Gathala, M.K., J.K. Ladha, Y.S. Saharawat, V. Kumar, V. Kumar, and P.K. Sharma. 2011. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under 7-year rice-wheat rotation. Soil Sci. Soc. Am. J. 75:1851-1862.

Oades, J.M. and A.G. Waters. 1991. Aggregate hierarchy in soils. Aust. J. Soil Res. 29:815-828.

Six, J., E.T. Elliott, and K. Paustain. 2000. Soil microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32:2099-2103.

Yoder, R.E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of 5 erosion losses. J. Amer. Soc. Agron. 28:337-351.

Table 1. Summary of the crop rotations and the number of crops grown in the respective rotations during the 10-yr study period (1999 to 2009) at the Rice Research and Extension Center near Stuttgart, Ark., on a silt-loam soil.

	Number of crops			
Rotation[a]	Rice	Corn	Soybean	Wheat
Continuous Rice	10	-	-	-
Rice-Soybean	5	-	5	-
Rice-Corn	5	5	-	-
Rice-(Wheat)	10	-	-	10
Rice-(Wheat)-Soybean-(Wheat)	5	-	5	10
Rice-Corn-Soybean	4	3	3	-

[a] Crops in parentheses were grown during the winter.

Table 2. Summary of the annual nitrogen (N), phosphorous (P_2O_5), and potassium (K_2O) added to corn, soybean, rice, and wheat to comprise the optimal soil fertility treatments in a long-term, rice-based rotation study at the Rice Research and Extension Center near Stuttgart, Ark., on a Dewitt silt-loam soil.

	Soil amendment		
Crop	N	P_2O_5	K_2O
	(lb/acre)		
Corn	300	80	150
Soybean	0	60	120
Rice	150	60	90
Wheat	150	60	60

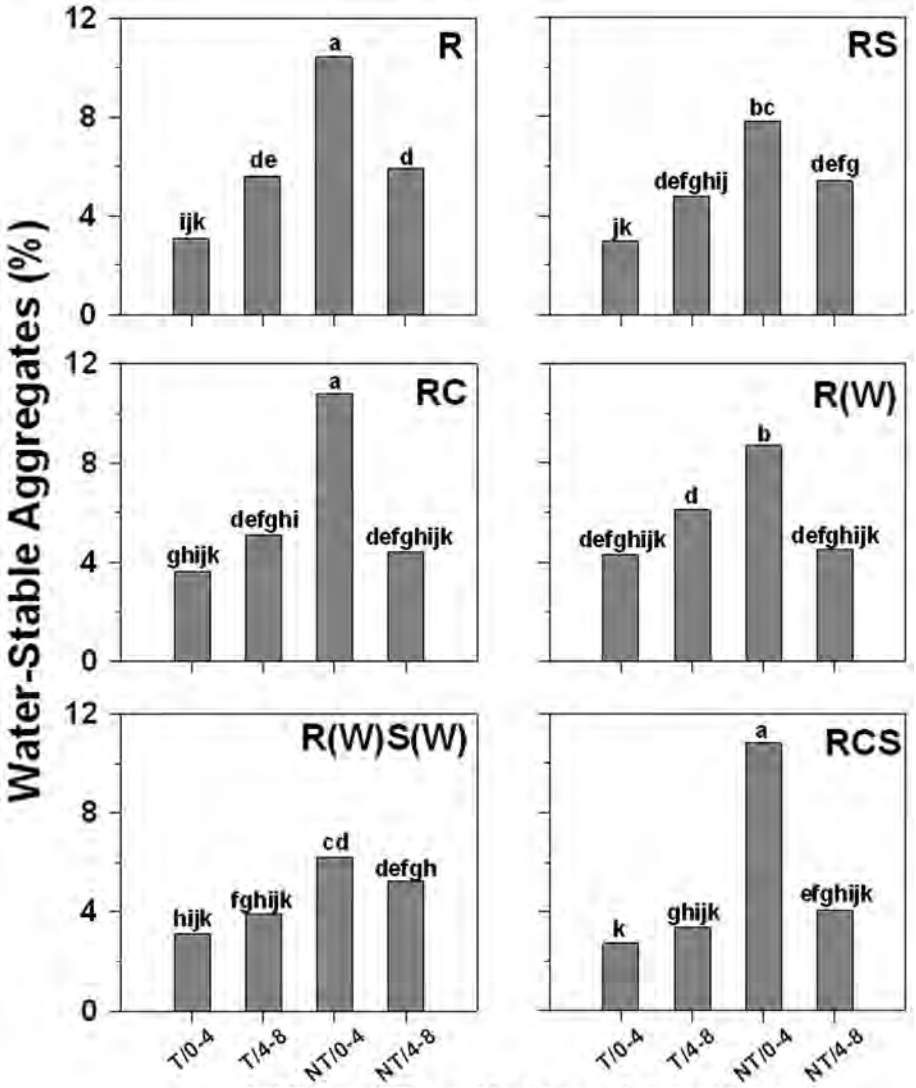


Fig. 1. Tillage [conventional tillage (T) and no-tillage (NT)], rotation [rice (R), soybean (S), wheat (W), and corn (C)], and soil depth (0- to 4- and 4- to 8-in.) effects on the percentage of water-stable aggregates (WSA; > 0.25-mm in diameter) in the bulk soil. Different letters on each bar across all crop rotations are significantly different at the 0.05 level.

RICE CULTURE

Response of Two Rice Varieties to Midseason Nitrogen Fertilizer Application Timing

R.J. Norman, T.L Roberts, D.L. Frizzell,
N.A. Slaton, C.E. Wilson Jr., and J.D. Branson

ABSTRACT

A study was initiated in 2010 to examine the influence of midseason nitrogen (N) application timing on the grain yield of two conventional pure line rice (*Oryza sativa* L.) varieties from Louisiana and Arkansas. The two conventional rice varieties chosen for the study were the Louisiana long-grain, semidwarf Cheniere and the Arkansas long-grain, short stature Taggart. The first year the midseason N was applied at 0.5-in. internode elongation (IE), 0.5-in. IE + 7 days, or 0.5-in. IE + 14 days and the second year the midseason N was applied at beginning IE (BIE), BIE + 7 days, or BIE + 14 days. The first year results showed rice grain yield increased for both varieties when the midseason N application was delayed from 0.5-in. IE until 0.5-in. IE + 7 or 14 days, but not when it was delayed from 0.5-in. IE + 7 days until 0.5-in. IE + 14 days. The second year results indicated the midseason N could be applied from BIE to BIE + 14 days and have a positive influence on rice grain yield. More studies need to be conducted on the response to midseason N application timing of these new rice varieties to clarify the proper midseason N application time.

INTRODUCTION

Nitrogen (N) fertilizer is applied to dry-seeded, delayed-flood rice in two split applications for conventional, inbred 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 beginning internode elongation (BIE) and 0.5-in. internode elongation (IE). The preflood N application is the larger of the two and ranges from 75 to 105 lb N/acre, depending on the variety (Wilson, 2011). The midseason N application is 45 lb N/acre for all conventional rice varieties.

It has been over 10 years since the grain yield response to N application timing at midseason was last studied (Wilson et al., 1998). Consequently, a study was initiated in 2010 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 2010 and 2011 at the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a DeWitt silt loam and in 2011 at the Pine Tree Branch Station (PTBS), near Colt, Ark., on a Calhoun silt loam. The two conventional rice varieties chosen for the study were the Louisiana long-grain, semidwarf Cheniere and the Arkansas long-grain, short stature Taggart. Two preflood N rates of 45 and 90 lb N/acre were utilized along with three midseason N application timings. In 2010, the midseason N rate was 45 lb N/acre and was applied at 0.5-in. IE, 0.5-in. IE + 7 days, or 0.5-in. IE + 14 days. In 2011, there was a check or no midseason N application and a 45 lb N/acre midseason N application at BIE, BIE + 7 days, or BIE + 14 days. There is usually about 5 to 7 days difference between BIE and 0.5-in. IE, thus BIE + 7 days and 0.5-in. IE are comparable growth stages of rice. We changed to BIE as the starting point for midseason N applications in 2011 because our current recommendations say to apply midseason N between BIE and 0.5-in. IE. 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 80 lb/acre in plots 9 rows wide (row spacing of 7 in.), 15 ft in length. In 2010, the rice was seeded 19 April, emerged 29 April, and the preflood N applied 25 May at the RREC. In 2011 at the RREC, the rice was seeded 17 May, emerged 25 May, and the preflood N applied 14 June; and at the PTBS in 2011 the rice was seeded 10 May, emerged 21 May, and the preflood N applied 12 June. The permanent flood was established 1 to 2 days after the preflood N was applied in both years at both 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) × 3 (midseason N application time) factorial design with four replications and a no midseason N application (control) in 2010 and 2011, except there was not a no midseason N application (control) in 2010. Analysis of variance was performed on the grain yield data utilizing SAS 9.1 (SAS Institute, Cary, N.C.). Differences among means were compared using Fisher's protected least significance difference (LSD) procedure at a $P = 0.05$ probability level.

RESULTS AND DISCUSSION

2010

There was no significant three-way interaction between variety × preflood N rate × midseason N application timing for grain yield of rice in 2010. However, for rice grain yield there were two-way interactions of variety × preflood N rate (*P* = 0.0292) and variety × midseason N application timing (*P* = 0.0071). Rice grain yield increased for both varieties when the preflood N rate was increased from 45 to 90 lb N/acre (Table 1). Taggart had a significantly higher grain yield compared to Cheniere at both preflood N application rates. Rice grain yield also increased for both varieties when the midseason N application was delayed from 0.5-in. IE until 0.5-in. IE + 7 days (Table 2). This is somewhat contrary to results obtained by Wilson et al. (1998) which reported no difference between rice grain yields when the midseason N was applied at beginning IE compared to at 0.5-in. IE. However, in the study reported here midseason N was not applied earlier than 0.5-in. IE. Thus, future studies should have an additional treatment where midseason N is applied at beginning IE and also include a no midseason N application to fully measure the grain yield response to midseason N. When the midseason N was delayed from 0.5-in. IE until 0.5-in. IE + 14 days there also was a significant grain yield increase for both varieties, but not when the midseason N was delayed from 0.5-in. IE + 7 days until 0.5-in. IE + 14 days.

2011

There was no significant four-way nor any three-way interactions between the parameters variety × preflood N rate × midseason N application timing × midseason N application rate for grain yield of rice at either location in 2011. However, there was one two-way interaction for rice grain yield of preflood N rate × midseason N rate at RREC (*P* = 0.0003) and PTBS (*P* = 0.0330) and a main effect of variety on grain yield at RREC (*P* = 0.0154) and PTBS (*P* = 0.0247). Similar to 2010, Taggart obtained a higher grain yield compared to Cheniere in 2011 at the RREC and PTBS (Table 3). Rice grain yield increased for both varieties when the preflood N rate was increased from 45 to 90 lb N/acre (Table 4). Contrary to 2010, midseason N application time had no significant influence on grain yield in 2011 at either location for either variety. There was a significant grain yield increase when 45 lb N/acre was applied at midseason for both varieties at both locations, but only when the preflood N rate was 45 lb N/acre not when 90 lb N/acre was applied at preflood. Consequently, the nonsignificance of midseason N application time coupled with the response to midseason N at the 45 lb N/acre preflood N rate indicates the midseason N application window extended from BIE to BIE + 14 days (or 0.5-in. IE + 7 days) in 2011 at PTBS and RREC for both varieties. The no response to midseason N when 90 lb N/acre was applied preflood suggests midseason N is not required when a preflood N rate typical of our rice varieties is applied.

SIGNIFICANCE OF FINDINGS

The first year results indicated the midseason N application may need to be delayed from 0.5-in. IE until 0.5-in. IE + 7 or 14 days to maximize the impact of midseason N on rice grain yield. The second year results indicated the midseason N could be applied from BIE to BIE + 14 days and have a positive influence on rice grain yield. More studies need to be conducted on the response to midseason N application timing of these new rice varieties to clarify the proper midseason N application time.

ACKNOWLEDGMENTS

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

LITERATURE CITED

Wilson, C.E. Jr. 2011. Recommended nitrogen rates and distribution for rice varieties in Arkansas. Fact Sheet. University of Arkansas Division of Agriculture Cooperative Extension Service.

Wilson, C.E. Jr., 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 Division of Agriculture Cooperative Extension Service MP192.

Table 1. Influence of variety and preflood nitrogen (N) application rate, averaged across midseason N application time, on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

	Grain yield	
Cultivar	45 lb N/acre	90 lb N/acre
	---------------------(bu/acre)---------------------	
Cheniere	87	93
Taggart	113	132
LSD$_{(\alpha=0.05)}$	6.6	

Table 2. Influence of variety and midseason nitrogen (N) application time, averaged across preflood N rate, on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

	Grain yield		
Cultivar	0.5-in. IE[a]	0.5-in. IE + 7 days	0.5-in. IE + 14 days
	(bu/acre)		
Cheniere	84	92	94
Taggart	114	127	128
LSD$_{(\alpha = 0.05)}$		8.1	

[a] IE = internode elongation

Table 3. Influence of cultivar, averaged across preflood and midseason N rates and application time, on rice grain yield at the Rice Research and Extension Center (RREC), Stuttgart, Ark., and the Pine Tree Branch Station (PTBS), Colt, Ark., during 2011.

	Grain yield	
Cultivar	RREC	PTBS
	(bu/acre)	
Cheniere	141	167
Taggart	146	172
LSD$_{(\alpha = 0.05)}$	4.6	4.5

Table 4. Influence of preflood nitrogen (N) rate, and mid-season N rate, averaged across application time, on rice grain yield at the Rice Research and Extension Center (RREC), Stuttgart, Ark., and the Pine Tree Branch Station (PTBS), Colt, Ark., during 2011.

	Grain yield			
	RREC		PTBS	
Preflood N rate	0 lb N/acre	45 lb N/acre	0 lb N/acre	45 lb N/acre
(lb N/acre)	(bu/acre)			
45	125	143	153	168
90	151	148	171	176
LSD $_{(\alpha = 0.05)}$	5.3		5.2	

Grain Yield Response of Twelve New Rice Cultivars to Nitrogen Fertilization

R.J. Norman, T.L Roberts, C.E. Wilson Jr., N.A. Slaton,
K.A.K. Moldenhauer, D.L. Frizzell, J.D. Branson, and M.W. Duren

ABSTRACT

The Variety x 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 twelve rice varieties studied in 2011 were: Caffey; JazzMan; Jazzman2; Rex; RoyJ; Bayer hybrid ArizeQM1003; and Horizon AG's Clearfield CL111, CL142AR, CL152; CL162MS, CL181AR, and CL261. Grain yields at all locations were lower than normal due to the atypically hot summer and late planting due to frequent spring rains that kept us out of the field in much of late April and May. Caffey, JazzMan2, CL152, and CL162MS were in the Variety x Nitrogen (N) Fertilizer Rate Study for the first time and thus there is not enough data to give a recommendation at this time. The remaining eight varieties have been in the study for multiple years and a recommendation can be made. The most prudent N fertilizer recommendation for ArizeQM1003 when grown on silt loam and clay soils would be 60 lb N/acre applied preflood followed by 30 lb N/acre applied at booting. JazzMan, RoyJ, CL142, and CL181AR should maximize yield on most silt loam soils when 135 to 150 lb N/acre is applied in a two-way split application of 90 to105 lb N/acre at preflood followed by 45 lb N/acre at midseason. Rex, CL111, and CL261 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 most of the aforementioned varieties should be increased by 30 lb N/acre over the rate recommended for silt loam soils.

INTRODUCTION

The Variety x Nitrogen (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. Twelve rice varieties were studied in 2011 at three locations as follows: Arkansas had the long-grain variety RoyJ; Louisiana had the new semidwarf, medium-grain variety Caffey and the aromatic rice varieties JazzMan and Jazzman2; Mississippi had the new semidwarf, long-grain variety Rex; Bayer reentered their hybrid ArizeQM1003; and Horizon AG entered the Clearfield long-grain varieties CL142AR and CL181AR in cooperation with Arkansas, the semidwarf, long-grain varieties CL111 and CL152 and the semidwarf, medium-grain CL261in cooperation with Louisiana, and the semidwarf, long-grain CL162MS in cooperation with Mississippi. Clearfield rice varieties are tolerant to the broad spectrum herbicide imazethapyr (Newpath).

PROCEDURES

Locations where the Variety x 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 Branch Station (PTBS), 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 was a randomized complete block with four replications at all locations for all the rice varieties studied. A single preflood N fertilizer application was utilized for all varieties, except the Bayer hybrid ArizeQM1003. The preflood N fertilizer was applied as urea on to 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 PTBS 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 hybrid ArizeQM1003 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 ArizeQM1003, were drill-seeded on the silt loams and clay soil at rates of 80 and 110 lb/acre, respectively, in plots nine-rows wide (row spacing of 7 in.), 15 ft in length. ArizeQM1003 was drill-seeded on the silt loams and clay soil at rates of 35 and 45 lb/acre, respectively, in plots nine-rows wide by 15 ft in length. Pertinent agronomic dates at each location in 2011 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 and mean separations were based upon Fisher's protected Least Significant Difference (LSD) 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. The rice varieties typically 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 second split is applied between beginning internode elongation and 0.5-in. internode elongation. Thus if 150 lb N/acre is recommended for a two-way split application, then 120 to 130 lb N/acre is recommended for a single preflood N application. With the rising costs of N fertilizer, growers should consider the single preflood N application.

Pertinent agronomic information such as planting dates and flood dates are shown in Table 1. Grain yields at all locations were lower than normal due to the atypically hot summer. The frequent rains in the spring at the NEREC delayed planting until June and this late planting resulted in low yields for all cultivars in 2011 at this location. Water weevil and stinkbug pressure at PTBS and RREC necessitated two insecticide (Karate) applications.

Caffey 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 soils at the PTBS and RREC (Table 2). Caffey had a maximum grain yield of 153 bu/acre on the clay soil at the NEREC and maintained a yield of 143 to 153 bu/acre when the N rate was increased from 90 to 180 lb N/acre before decreasing when 210 lb N/acre was applied. Caffey achieved a maximum yield of 193 bu/acre on silt loam soil at the PTBS and maintained this yield when up to 120 lb N/acre was applied preflood. Caffey experienced lodging and a decrease in yield when 150 and 180 lb N/acre was applied preflood at the PTBS. Caffey achieve a maximum yield of 146 bu/acre when 150 lb N/acre was applied preflood to the silt loam soil at the RREC and lodged and decreased in yield when 180 lb N/acre was applied preflood. This was the first year Caffey was in the Variety x N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

JazzMan 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 PTBS (Table 3). JazzMan was able to obtain peak yields of 155 and 154 bu/acre at the NEREC and PTBS, respectively. JazzMan obtained a maximum yield of 158 bu/acre and did not significantly increase in yield when more than 120 lb N/acre was applied to the silt loam soil at the RREC. Generally, JazzMan maintained stable grain yields when 90 to 150 lb N/acre was applied at all three locations. Jazzman displayed some lodging when 180 lb N/acre was applied preflood at the RREC, but almost no lodging at any of the locations in 2009 (Norman et al., 2010) or 2010 (Norman et al., 2011). The results from 2009 (Norman et al., 2010), 2010 (Norman et al, 2011), and 2011 indicate JazzMan should require an N rate of 135 to 150 lb N/acre applied in a two-way split application of 90 to 105 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam and clay soils.

JazzMan2 achieved a maximum grain yield of 174 bu/acre on the clay soil at the NEREC when 120 lb N/acre was applied preflood (Table 4). Similarly, JazzMan2 achieved a maximum grain yield of 177 bu/acre on the silt loam soil at the PTBS when 120 lb N/acre was applied preflood. JazzMan2 maintained stable grain yields when 90 to 150 lb N/acre was applied at the NEREC and PTBS in 2011. JazzMan2 did not yield well at the RREC in 2011 where it obtained a peak grain yield of only 135 bu/acre when 150 or 180 lb N/acre was applied preflood. However, JazzMan2 did not significantly increase in yield when more than 120 lb N/acre was applied preflood at the RREC. JazzMan2 displayed no lodging at any of the locations in 2011. This was the first year JazzMan2 was in the Variety x N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

Rex maximized yield at 187 bu/acre and did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood on the clay soil at the NEREC (Table 5). A steady decrease in yield was measured for Rex when 150 lb N/acre or greater was applied at the NEREC. Rex maximized yield at 179 bu/acre when only 90 lb N/acre was applied preflood on the silt loam soil at the PTBS. Rex did not significantly decrease in grain yield at the PTBS when up to 180 lb N/acre was applied, but did display a decreasing trend in yield as the N rate increased above 90 lb N/acre. Rex yielded well (180 to 182 bu/acre) on the silt loam soil at the RREC when 150 or 180 lb N/acre was applied preflood. Rex displayed no lodging in 2011 at any of the locations and virtually no lodging in 2010 (Norman et al., 2011). Also, Rex had good yield stability in 2010 and 2011 when up to 60 lb N/acre more N was applied than what was required to maximize yield. The results from 2010 (Norman et al., 2011) and 2011 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 preflood 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.

RoyJ attained a grain yield of 171 bu/acre and did not significantly increase in yield on the silt loam soil at the PTBS when more than 90 lb N/acre was applied preflood (Table 6). RoyJ displayed good yield stability at PTBS when up to 180 lb N/acre was applied preflood. RoyJ achieved a grain yield of 190 bu/acre on the silt loam soil at the RREC when only 60 lb N/acre was applied preflood and a maximum yield of 198 bu/acre when 150 lb N/acre was applied preflood. RoyJ displayed excellent yield stability over a 90 lb N/acre range at both locations in 2011. RoyJ showed no lodging in 2011 at any of the locations and no lodging in 2010 (Norman et al., 2011). The results from 2010 (Norman et al., 2011) and 2011 indicate RoyJ should require an N rate of 135 to 150 lb N/acre applied in a two-way split application of 90 to 105 lb N/acre at preflood and 45 lb N/acre at midseason to maximize grain yield on most silt loam soils. The preflood N rate for RoyJ when grown on clay soils should be increased by 30 lb N/acre over the N rate recommended for silt loam soils.

ArizeQM1003 reached a maximum grain yield of 171 bu/acre on the clay soil at the NEREC when only 60 lb N/acre was applied preflood (Table 7). As the preflood N rate was increased to 90 lb N/acre and up to 180 lb N/acre the grain yield of ArizeQM1003 decreased steadily at the NEREC. The yield decrease as N rate increased at the NEREC was not due to lodging, there was no lodging of ArizeQM1003 at NEREC. ArizeQM1003 achieved maximum yields of 196 and 183 bu/acre when grown on the silt loam soils at the PTBS and RREC, respectively. Lodging of ArizeQM1003 was a problem on the silt loam soils in 2011 and was probably part of the reason the hybrid peaked in yield at only 60 lb N/acre and could not maintain the yield at both locations when the N rate was increased as it has in past studies (Norman et al., 2009, 2010). The yield decrease as N rate increased at PTBS and RREC was probably associated with lodging since lodging typically increased as N rate increased on the silt loam soils at these two locations. In summary, the ArizeQM1003 hybrid tested in 2008 and 2009 yielded much better compared to the one tested in 2011, but then again the temperatures in 2008 and 2009 were not as hot as in 2011. After three years of testing, the most prudent N fertilizer recommendation for ArizeQM1003 when grown on silt loam and clay soils would be 60 lb N/acre applied preflood followed by 30 lb N/acre applied at booting. Most rice varieties and hybrids typically require at least 30 lb N/acre more to achieve maximum yield when grown on clay soils compared to silt loam soils, but ArizeQM1003 did not respond in that manner.

CL111 did not significantly increase in yield at the NEREC when more than 120 lb N/acre was applied preflood (Table 8). CL111 obtained a peak grain yield of 159 bu/acre on the clay soil at the NEREC when 180 lb N/acre was applied preflood and experienced a significant grain yield decrease when the N rate was increased to 210 lb N/acre. CL111 did not significantly increase in grain yield when more than 120 lb N/acre was applied preflood to the silt loam soil at the PTBS and obtained a peak grain yield of 192 bu/acre when 150 lb N/acre was applied. CL111 maintained this grain yield when the N rate was increased to 180 lb N/acre. There was minimal lodging of CL111 at the RREC in 2011, but not enough to hurt yields, except at the highest N rate of 180 lb N/acre. The 180 lb N/acre rate preflood is just too much N for almost any rice variety on this soil due to its large amount of native soil N. CL111 did not significantly increase in yield at the RREC when more than 120 lb N/acre was applied preflood and obtained a peak grain yield of 154 bu/acre when 150 lb N/acre was applied. CL111 displayed a stable yield with minimal lodging over a wide range of N fertilizer rates in 2010 (Norman et al., 2011) and this was evident in 2011. The two years of data accumulated on CL111 indicate a prudent N rate on silt loam soils would be 150 lb

N/acre applied in a two-way split of 105 lb N/acre applied preflood followed by 45 lb N/acre at midseason. When grown on clay soils the preflood N rate for CL111 should be increased to 135 lb N/acre.

CL142AR attained a maximum grain yield on the clay soil at NEREC when only 90 lb N/acre was applied preflood (Table 9). CL142AR was able to maintain this grain yield when up to at least 150 lb N/acre was applied preflood without any lodging indicating CL142AR had a stable grain yield over a wide range of N rates. A peak grain yield of 188 bu/acre was achieved by CL142AR on the silt loam soil at PTBS when 150 lb N/acre was applied preflood. Although CL142AR did not significantly increase in yield when more than 90 lb N/acre was applied at PTBS, it did display a stable grain yield when 90 to 180 lb N/acre was applied at this location. CL142AR reached a maximum yield of 176 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood. CL142AR did display some lodging at the RREC when 180 lb N/acre was applied preflood and this caused a significant decrease in grain yield. Overall, CL142AR displayed a stable grain yield over a wide range of N fertilizer rates with minimal lodging in 2010 (Norman et al., 2011) and 2011. Thus after two years of testing, the results indicate CL142AR when grown on silt loam soils requires an N fertilizer rate of 135 to 150 lb N/acre applied in a split application of 90 to 105 lb N/acre at preflood followed by 45 lb N/acre at midseason. When grown on clay soils, the preflood N rate for CL142 should be increased by 30 lb N/acre over the rate recommended for silt loam soils.

CL152 obtained a maximum grain yield on the clay soil at the NEREC when only 90 lb N/acre was applied preflood (Table 10). CL152 was able to maintain this grain yield when up to at least 150 lb N/acre was applied preflood without any lodging indicating CL152 had a stable grain yield over a good range of N fertilizer rates. A peak grain yield of 187 bu/acre was achieved by CL152 on the silt loam soil at the PTBS when 120 lb N/acre was applied preflood. Although CL152 did not significantly increase in yield when more than 90 lb N/acre was applied preflood at the PTBS, it did display a stable grain yield when 90 to 150 lb N/acre was applied at this location. CL152 reached a maximum yield of 160 bu/acre on the silt loam soil at the RREC when 150 lb N/acre was applied preflood. CL152 did not display any lodging at the RREC when up to 180 lb N/acre was applied preflood, like some varieties, but there was a significant grain yield decrease when the N rate was increased to 180 lb N/acre. This was the first year CL152 was in the Variety x N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

CL162MS attained a maximum grain yield on the clay soil at the NEREC when only 90 lb N/acre was applied preflood and did not significantly decrease in yield when up to 150 lb N/acre was applied preflood (Table 11). A peak grain yield of 170 bu/acre was achieved by CL162MS on the silt loam soil at the PTBS when 120 lb N/acre was applied preflood. CL162MS was able to maintain a peak yield at the PTBS when an N rate range of 90 to 150 lb N/acre was applied preflood. CL162MS reached a maximum yield of 168 bu/acre on the silt loam soil at the RREC when 120 lb N/acre was applied preflood. When the N rate at the RREC was increased to 150 and 180 lb N/acre, lodging increased and grain yield decreased for CL162MS. CL162MS, like the previously mentioned Clearfield varieties, appears to have a stable grain yield over a 60 to 90 lb N/acre fertilizer range with the only exception being when they were grown at the RREC in 2011. This was the first year CL162MS was in the Variety x N Fertilizer Rate Study and one to two more years of data will be required before an N rate recommendation can be made.

CL181AR did not significantly increase in grain yield above 143 bu/acre when more than 90 lb N/acre was applied preflood to the clay soil at the NEREC (Table 12). The late planting at the NEREC caused the low yields and may have led to most varieties peaking in yield when only 90 lb N/acre was applied preflood at this location. CL181AR reached a maximum grain yield of 184 bu/acre when 120 lb N/acre was applied preflood at the PTBS, but did not significantly increase in yield when more than 90 lb N/acre was applied preflood on this silt loam soil. Yields of CL181AR at the RREC maximized at 172 bu/acre when 120 lb N/acre was applied preflood and did not significantly increase when the N rate was raised above this level. CL181AR displayed stable yields in 2010 and 2011 over a wide range of N fertilizer rates at all three locations without any lodging. After two years of testing, the results indicate CL181AR when grown on silt loam soils requires an N fertilizer rate of 135 to 150 lb N/acre applied in a split application of 90 to 105 lb N/acre at preflood followed by 45 lb N/acre at midseason. When grown on clay soils, the preflood N rate for CL181 should be increased by 30 lb N/acre.

CL261 achieved a grain yield of 135 bu/acre when only 90 lb N/acre was applied to the clay soil at the NEREC (Table 13). Achieving a low grain yield and not significantly increasing when more than 90 lb N/acre was applied at NEREC has to be due to the late planting. CL261 attained a maximum yield of around 165 bu/acre at PTBS when only 90 lb N/acre was applied preflood and maintained this yield when up to 150 lb N/acre was applied. However, there was some lodging when 150 lb N/acre was applied to CL261 at the PTBS; and when the N rate was increased to 180 lb N/acre, lodging increased appreciably and grain yield decreased significantly. CL261 attained a grain yield of 155 bu/acre when 120 lb N/acre was applied preflood on the silt loam soil at RREC and maintained this yield when the N rate was increased to 150 lb N/acre preflood. When the N rate at the RREC was increased to 180 lb N/acre, the lodging of CL261 increased and the grain yield decreased significantly. CL261 did not display grain yield stability over a wide range of N fertilizer rates like it did in 2010 for some reason. The two years of results on CL261 indicate when grown on silt loam soils the variety requires an N fertilizer rate of 135 lb N/acre applied in a split application of 90 lb N/acre at preflood followed by 45 lb N/acre at midseason. When grown on clay soils, the preflood N rate for CL261 should be increased by 30 lb N/acre.

SIGNIFICANCE OF FINDINGS

The Variety x 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 yield when grown commercially on most soils in the Arkansas rice growing region. The twelve rice varieties studied in 2011 were: Caffey; JazzMan; Jazzman2; Rex; Roy J; Bayer hybrid ArizeQM1003; and Horizon AG's Clearfield CL111, CL142AR, CL152; CL162MS, CL181AR, and CL261. 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 Crop Science.

LITERATURE CITED

Norman, R.J., C.E. Wilson Jr., N.A. Slaton, D.L. Frizzell, J.D. Branson, M.W. Duren, K.A.K. Moldenhauer, and J.W. Gibbons. 2009. Grain yield response of thirteen new rice cultivars to nitrogen fertilization. *In:* R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer (eds.). B.R. Wells Rice Research Studies 2008. University of Arkansas Agricultural Experiment Station Research Series 571:224-239. Fayetteville.

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. 2010. Grain yield response of fourteen new rice cultivars to nitrogen fertilization. *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 581:166-180. Fayetteville.

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 591:209-218. Fayetteville.

Table 1. Pertinent agronomic information for the Northeast Research and Extension Center (NEREC), Pine Tree Branch Station (PTBS), and the Rice Research and Extension Center (RREC) during 2011.

Practices	NEREC	PTBS	RREC
Preplant fertilizers	100 DAP/acre	400 lb/A 0-34-30	200 lb/acre 0-20-30 + 30 lb $ZnSO_4$
Planting dates	11 June	10 May	14 April
Emergence dates	16 June	21 May	20 April
Herbicide spray dates	2 June	18 May	29 April
and procedures	1.2 pt/acre Command	3 qt/acre SuperWham + 2 pt/acre Prowl H2O + 0.5 lb/acre Facet	0.5 pt/acre Command + 0.5 lb/acre Facet + 1 oz/acre Permit + 1% COC[a]
Herbicide spray dates	30 June	15 June	27 May
and procedures	4 qt/acre Propanil	4 qt/acre StamWham + 0.25 lb/acre Facet	20 oz/acre RiceStar + 1.5% COC
Herbicide spray dates	11 july	6 July	31 May
and procedures	17 oz/acre RiceStar	15 oz/acre Clincher	0.5 oz/acre Permit + 0.5 lb/acre Facet + 1% COC
Preflood N dates	11 July	20 June	31 May
Flood dates	12 July	21 June	1 June
Insecticide spray dates	---	22 July	29 July
and procedures	---	1.8 oz/acre Karate	3 oz/acre Karate
Insecticide spray dates	---	12 August	26 August
and procedures	---	2 oz/acre Karate	3 oz/acre Karate
Harvest dates	26 October	29 September	31 August

[a] COC = crop oil concentrate.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of Caffey rice at three locations during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC[b]
(lb N/acre)	----------------	(bu/acre)	----------------
0	111	102	86
60	----	167	122
90	153	193	132
120	149	190	142
150	146	174 ^{10}[c]	146
180	143	151 ^{55}	127 ^{42}
210	127	----	-----
LSD$_{(\alpha=0.05)}$	24	14	16
C.V. (%)	11	6	8

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] NOTE: Rep effect was highly significant at this location at Pr > F = 0.0086.

[c] Numbers in superscript to side of the yield are lodging percentages.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of JazzMan rice at three locations during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)	----------------	(bu/acre)	----------------
0	103	89	82
60	----	129	117
90	154	143	139
120	146	151	153
150	146	155	158
180	132	154	150 ^{12}[b]
210	117	---	---
LSD$_{(\alpha=0.05)}$	13	14	9
C.V. (%)	7	7	4

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of JazzMan2 rice at three locations during 2011.

	Grain yield		
N fertilizer rate	NEREC[a,b]	PTBS	RREC
(lb N/acre)	--------	(bu/acre)	--------
0	103	80	71
60	----	145	108
90	165	165	123
120	174	177	127
150	164	170	135
180	162	167	135
210	150	-----	----
LSD$_{(\alpha=0.05)}$	13	14	9
C.V. (%)	3	4	5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] NOTE: Rep effect is significant at this location at Pr > F = 0.0278.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Rex rice at three locations during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)	--------	(bu/acre)	--------
0	147	81	82
60	----	148	131
90	183	179	148
120	187	172	164
150	166	167	180
180	148	165	182
210	138	-----	----
LSD$_{(\alpha=0.05)}$	14	15	10
C.V. (%)	6	7	5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of RoyJ rice at two locations during 2011.

	Grain yield	
N fertilizer rate	PTBS[a]	RREC
(lb N/acre)	(bu/acre)	
0	100	127
60	153	190 ^{8}[b]
90	171	195
120	168	193 ^{20}
150	169	198
180	162	182 ^{12}
LSD$_{(\alpha=0.05)}$	15	24
C.V. (%)	6	9

[a] PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of ArizeQM1003 rice at three locations during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)	(bu/acre)		
0	116	122 ^{32}[b]	122
30 + 30[c]	-----	165 ^{22}	154 ^{25}
60 + 30	171	196 ^{62}	183 ^{75}
90 + 30	145	148 ^{90}	150 ^{62}
120 + 30	109	116 ^{45}	156 ^{100}
150 + 30	84	90 ^{50}	126 ^{75}
180 + 30	52	-----	-----
LSD$_{(\alpha=0.05)}$	24	40	39
C.V. (%)	14	19	17

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

[c] The N fertilizer was applied in a split application at preflood + late boot.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of CL111 at three locations in Arkansas during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)		(bu/acre)	
0	84	74	73
60	----	147	111
90	133	175	130
120	148	181	143
150	150	192	154 [1b]
180	159	185	128 [12]
210	144	----	-----
$LSD_{(\alpha=0.05)}$	13	13	20
C.V. (%)	7	5	11

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of CL142AR at three locations in Arkansas during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)		(bu/acre)	
0	117	93	95
60	----	164	140
90	154	177	157
120	150	183	155
150	148	188	176
180	141	180	137 [28b]
210	125	----	-----
$LSD_{(\alpha=0.05)}$	14	12	26
C.V. (%)	7	5	12

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Table 10. Influence of nitrogen (N) fertilizer rate on the grain yield of CL152 at three locations in Arkansas during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS[b]	RREC
(lb N/acre)	----------------------------------	(bu/acre)	----------------------------------
0	101	88	84
60	----	156	106
90	146	186	133
120	143	187	150
150	137	185	160
180	133	173	145
210	112	----	-----
LSD$_{(\alpha=0.05)}$	1	12	11
C.V. (%)	8	5	5

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] NOTE: Rep effect is significant at this location at Pr > F = 0.0339.

Table 11. Influence of nitrogen (N) fertilizer rate on the grain yield of CL162MS at three locations in Arkansas during 2011.

	Grain yield		
N fertilizer rate	NEREC[a]	PTBS	RREC
(lb N/acre)	----------------------------------	(bu/acre)	----------------------------------
0	29	96	83
60	----	148	130
90	161	166	142
120	159	170	168
150	153	160	115 ^{32}[b]
180	139	136	98 ^{45}
210	134	----	-----
LSD$_{(\alpha=0.05)}$	10	17	19
C.V. (%)	5	8	10

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Table 12. Influence of nitrogen (N) fertilizer rate on the grain yield of CL181AR rice at three locations during 2011.

N fertilizer rate	Grain yield		
	NEREC[a]	PTBS	RREC
(lb N/acre)	----------------	(bu/acre)	----------------
0	105	88	83
60	----	158	144
90	143	169	159
120	141	184	172
150	135	177	156
180	130	171	148
210	110	-----	----
LSD$_{(\alpha=0.05)}$	13	18	9
C.V. (%)	7	8	4

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

Table 13. Influence of nitrogen (N) fertilizer rate on the grain yield of CL261 at three locations in Arkansas during 2011.

N fertilizer rate	Grain yield		
	NEREC[a]	PTBS	RREC
(lb N/acre)	----------------	(bu/acre)	----------------
0	81	87	86
60	----	148	119
90	135	164	136
120	128	164	135
150	104	159 ^{18b}	146
180	106	121 ^{88}	127 ^{42}
210	104	----	-----
LSD$_{(\alpha=0.05)}$	15	16	17
C.V. (%)	9	7	9

[a] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTBS = Pine Tree Branch Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[b] Numbers in superscript to side of the yield are lodging percentages.

Grain Yield Response of the Clearfield Rice Cultivars CL111, CL142AR, CL181AR, and CL261 Compared to Taggart at a High Native Nitrogen Site

T.L. Roberts, R.J. Norman, N.A. Slaton, C.E. Wilson Jr.,
J. Shafer, S.M. Williamson, D.L. Frizzell, and J.D. Branson

ABSTRACT

The recent success of N-ST*R; the nitrogen soil test for rice has resulted in the need for more research regarding the ability of this new soil test to predict N rates for a wide range of rice cultivars. Correlation and calibration of N-ST*R was completed using a standard rice cultivar such as Wells, Francis, or Jupiter which generally require 150 lb N/acre to maximize yield on the majority of silt loam soils in Arkansas. Based on data provided in the Variety by N trials that are conducted each year, different rice cultivars may require different N rates in order to maximize yield due to differences in plant morphology, yield potential, and relative maturity. The purpose of this study was to compare the N rate required to maximize rice yield for four Clearfield varieties, CL 111, CL 142AR, CL 181AR, and CL 261 to a conventional pure line variety Taggart on a very high native N soil in Jackson County, Arkansas. Comparison of yield maximizing N rates for the included Clearfield varieties to the rate required for Taggart will allow adjustments to be made to the current N-ST*R recommendations based on variety. Currently, after a single year of data it appears that the N-ST*R recommendation is valid for CL 111, CL 142AR, CL 181AR, and CL 261 without any additional adjustments.

INTRODUCTION

A major strength of the rice-soil fertility research program has been the delineation of nitrogen (N) fertilizer response curves for promising new rice cultivars. With the recent development and release of N-ST*R (Roberts et al., 2011) more focus has been placed on how this new technology can be adapted to new varieties and a wide range of production practices. Currently in Arkansas, rice produced on silt loam soils generally require either 135 lb N/acre or 150 lb N/acre to maximize yield on silt loam soils following soybean in rotation, indicating that there are differences in N rate required to maximize yield (Norman et al., 2011). Nitrogen requirements of rice are closely tied to plant stature, straw strength, and relative maturity, with short stature stiff-strawed varieties requiring less N per acre than their taller counterparts (Norman et al., 1996). This study measures the influence of N fertilizer rate on grain yield performance and compares it to a standard conventional pure line cultivar to determine whether or not adjustments need to be made prior to implementation of N-ST*R for new varieties. From this data conclusions can be drawn as to whether the standard N-ST*R recommendation can be used or to what extent the N-ST*R rate needs to be increased or decreased to ensure that rice yield is not significantly impacted by over- or under-fertilization with N fertilizer. Promising new rice selections were identified as being important Clearfield releases and included in this study. The 2011 results for Clearfield CL 111, CL 142AR, CL 181AR, and CL 261 are reported here and compared to the standard pure line variety Taggart.

PROCEDURES

The location chosen for this study was the Newport Branch Research Station in Jackson Co. Ark. The soil series at this location was a Forestdale silt loam and has been identified as a high native soil N site using N-ST*R. By comparing varieties at this location, where there is little to no response to N fertilizer, accurate conclusions can be drawn concerning the ability of N-ST*R to predict site-specific N rates for newly released varieties. 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 were: 0, 30, 60, 90, and 120 lb N/acre.

The rice was drill-seeded at a rate of 80 lb seed/acre in plots nine-rows wide (row spacing of 7 in.), 15 ft in length. Plots were established 2 June 2011 and emerged 8 June 2011. Plots were flooded at each location when the rice was at the 4- to 5-lf stage (28 June 2011) 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 five-rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bushel (bu)/acre at 12% moisture (a bushel weighs 45 lb). Statistical analyses were conducted with JMP and mean separations were based upon Fishers protected least significant difference test (LSD; $P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The purpose of this study was to compare the yield maximizing N rates for the Clearfield varieties CL111, CL142AR, CL181AR, and CL261 to the variety Taggart, which has a standard N recommendation of 150 lb N/acre when produced on silt loam soils. The development of N-ST*R was completed using varieties which on average required 150 lb N/acre; and comparison of how new varieties respond to N when compared to a variety like Taggart or Wells will allow scientists to determine whether or not additional corrections need to be made on a variety by variety basis.

Grain yields at this location were above average considering the atypically hot summer and the late planting date. Early in the season, pigweed were prevalent at this location and required some additional management to control, but plots included in this study were not negatively impacted. Yields at this location are generally equal to or higher than other lower native N locations where much higher N rates are required to maximize yield. An important factor that must be considered at this location is the high potential for disease incidence due to excess N, but little disease pressure was documented during the 2011 growing season.

Taggart was chosen as the standard 150 lb N/acre variety due to its high yield potential, similarity to Wells, and recent release for commercial production. Grain yields for Taggart ranged from 180 to 198 bu/acre and yield was maximized when 90 lb N/acre was applied (Table 1). Although grain yield for Taggart was maximized at 90 lb N/acre, the yields were not significantly different than when 30, 60, or 120 lb N/acre were applied suggesting that 30 lb N/acre was sufficient to maximize and optimize yield for this variety on this particular soil.

Grain yield for CL 111 ranged from 175 to 204 bu/acre and was the highest yielding variety at this location. The highest yield for this variety was measured at the 120 lb N/acre rate, but was not statistically different than either the 60 or the 90 lb N/acre rates. There was a significant increase in yield when N rates >30 lb N/acre were applied, suggesting that on this particular soil CL 111 may require slightly more N than the standard variety Taggart. The Optimum preflood N-ST*R recommendation for this location was 50 lb N/acre, and although the yield optimizing N rate was slightly different than Taggart it appears that the N-ST*R recommendation is right on target for CL 111.

CL 142AR and CL 181AR are of particular interest since they were bred and developed by the University of Arkansas rice breeding program. Yield response for CL 142AR was similar to all other varieties, but had the narrowest range in yields from 170 to 185 bu/acre. Like Taggart, CL 142AR yields were maximized with as little as 30 lb N/acre and CL 142AR showed very stable yields when the N rate was increased up to 120 lb N/acre. This variety is similar in height and morphology to Wells and Taggart and it was reassuring to see similar N response characteristics. Seed for this variety will be widely available this year and it appears the N-ST*R recommendation will supply the correct N rate for CL 142AR. Unlike the other varieties, CL 181AR experienced a pretty significant yield decline when N rates greater than 30 lb N/acre were applied. The yields for CL 181AR ranged from 159 to 185 bu/acre, with a 17 bu/acre yield loss when rates of 60, 90, and 120 lb N/acre were applied. Similar to CL 142AR, the yield maximizing rate was 30 lb N/acre and it appears N-ST*R will provide an accurate estimation of N fertilizer needs for this variety on silt loam soils.

The only medium-grain variety included in this study was CL 261, which traditionally has yielded well in other N fertility studies. The yields obtained for CL 261 in this study ranged from 150 to 168 bu/acre and were significantly lower than the yields obtained in similar N response trials for this variety at other locations (PTBS - 191 bu/acre and SEREC - 201 bu/acre). The significant differences in yield may be attributed to the later planting date or other environmental factors that impacted this particular variety at the Newport Branch Station. Yields for CL 261 were maximized at 120 lb N/acre, but were not significantly different than the yields obtained for 30, 60, or 90 lb N/acre. Although this data is similar in nature to what has been observed with the other varieties at this location, the yields are not indicative of CL 216's performance in other N response trials.

Results of this study indicate that the N-ST*R rate recommendation for silt loam soils will provide an accurate estimation of the N needs for the Clearfield varieties CL 111, CL 142AR, CL 181AR, and CL 261. Prior to implementation of N-ST*R for these varieties, at least two more years of data are required. Evaluation of these varieties over several years will ensure that N-ST*R can provide reliable rate recommendations over a wide range of environmental conditions.

SIGNIFICANCE OF FINDINGS

The Arkansas rice industry is facing an unusual period, where competition from other crops such as corn has left producers wondering how to remain profitable and still produce rice. Input costs and commodity prices play a major role in the planting decisions of many producers, but the development and implementation of N-ST*R will give producers more insight as to what their N input costs will be. In order for N-ST*R to be relevant it must be applicable to a wide range of soil and environmental conditions as well as being useful for current and emerging varieties. This research indicates that for the Clearfield varieties CL 111, CL 142AR, CL 181AR, and CL 261, N-ST*R will give an accurate estimate of N fertilizer needs without any additional adjustments. Additional work will be required for each new variety that is released to ensure that producers have the most applicable and efficient N fertilizer management in place to maximize rice yield, optimize inputs and maximize profitability.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board and the U.S. Rice Foundation. Appreciation is also expressed to Horizon Ag 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

Norman, R.J., C.E. Wilson Jr., P.K. Bollich, K.A. Gravois, and B.R. Wells. 1996. Nitrogen uptake of selected rice cultivars. Proc. 26th Rice. Tech. Work. Group 1996:173.

Norman, R.J., Roberts, T.L., 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.

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.

Table 1. Influence of nitrogen (N) fertilizer rate on the grain yield of Clearfield varieties and Taggart at the Newport Branch Station in Jackson Co., Ark., during 2011.

	Grain yield				
N fertilizer rate	CL 111	CL 142AR	CL 181	CL 261	Taggart
(lb N/acre)	----------	----------	(bu/acre)	----------	----------
0	175	170	159	150	180
30	185	185	185	160	194
60	197	183	168	162	196
90	201	186	170	167	198
120	204	182	170	168	195
LSD$_{(\alpha=0.05)}$	9.1	6.2	8.3	8.9	8.6
C.V. (%)	8.23	6.12	9.23	6.54	7.49

Methane Emissions from a Silt-Loam Soil Under Direct-Seeded, Delayed-Flood Rice Management

C.W. Rogers, K.R. Brye, R.J. Norman, T. Gasnier, D. Frizzell, and J. Branson

ABSTRACT

Methane (CH_4) is a potent greenhouse gas with a global warming potential approximately 23 times greater than carbon dioxide (CO_2). Rice (*Oryza sativa* L.) production is unique among agricultural crops in its susceptibility to CH_4 emissions. As a semi-aquatic plant, rice is produced under flooded conditions for the majority of the time it is actively growing. Methane emissions from soil occur when the soil is highly anaerobic and highly reduced. Data concerning flux estimates from Arkansas, the largest rice-producing state, are currently unavailable. Thus, a study was initiated to investigate CH_4 emissions from Arkansas production practices (direct-seeded, delayed-flood) and a soil (DeWitt silt loam) that are typical of a large portion of rice production in the state. The chamber method was used to measure CH_4 fluxes, in replicated plots of nitrogen (N) fertilized rice (150 lb N/acre), unfertilized rice (0 lb N/acre), N fertilized bare soil (150 lb N/acre), and unfertilized bare soil (0 lb N/acre). The maximum flux (22.6 mg CH_4-C/m$^{-2/}$hr) occurred after panicle differentiation 41 days after flooding (DAF) in N fertilized rice and was significantly greater than all other treatments on this date ($P < 0.10$). A second flux peak occurred after 50% heading 62 DAF in N fertilized rice, which was also significantly greater than other treatments ($P < 0.10$). A post-flood release pulse, which accounted for 4% to 14% of total seasonal emissions, was observed with a peak CH_4 flux occurring 6 days after flood release. The total CH_4-C emissions from N fertilized and unfertilized rice were 21.6 and 17.5 g CH_4-C/m^{-2}/growing season, respectively, and 4.3 and 5.2 g CH_4-C/m^{-2}/growing season from N fertilized and unfertilized bare soil. Based on N fertilized-rice fluxes, 215 kg CH_4-C/ha/growing season (193 lb CH_4-C/acre/growing season) were estimated to be emitted in this study. Methane

fluxes measured during this study were within the range of previously published data currently used for the Environmental Protection Agency (EPA) estimates of CH_4 emissions from rice.

INTRODUCTION

Many studies have been conducted concerning CH_4 emissions from rice production. Cicerone and Shetter (1981) initially reported CH_4 fluxes from rice ranging from 2.3 to 9.4 mg CH_4-C/m^{-2} /hr and averaging 5.6 mg CH_4-C/m^{-2}/hr. Based on the average of 5.6 mg CH_4-C/m^{-2}/hr, total CH_4 emissions from rice paddies worldwide were estimated at 59 Tg CH_4/yr using data from N-fertilized rice. Work by Holzapfel-Pschorn et al. (1986) in Italian rice paddies reported a peak flux of 26.5 mg CH_4-C/m^{-2}/hr and reported global emissions in the range of 39 to 94 Tg/yr with the largest emissions coming from Asia where the largest land area of rice is produced. Sass et al. (1990) investigated emissions from N fertilized rice in Texas and reported that the largest fluxes occurred during the grain-fill period and peaked around 14.1 mg CH_4-C/m^{-2}/hr with an average hourly flux during the growing season of 6.5 mg CH_4-C/m^{-2}/hr. Along with these studies, researchers have reported fluxes approaching 100 mg CH_4-C/m^{-2}/hr from a continuous-rice rotation when organic soil amendments, such as swine manure, had been applied (Buendia et al., 1998). Researchers have also reported a post-flood release pulse of CH_4, which accounted for approximately 10% of the CH_4 released from rice from planting to harvest (Denier van der Gon et al., 1996; Bossio et al., 1999).

While a range of data are available from other production areas in the United States and globally, no direct observations of CH_4 fluxes are available from direct-seeded, delayed-flood rice production in Arkansas. Therefore, a study was initiated during the 2011 growing season to measure CH_4 emissions in a silt-loam soil under direct-seeded, delayed-flood rice production in Arkansas to: 1) quantify the CH_4-flux profile from N fertilized rice, unfertilized rice, and open-water above N fertilized and unfertilized bare soil from flooding to flood release, 2) determine if a post-flood release pulse of CH_4 occurs in this production system, and 3) estimate the total CH_4 emissions per area during the growing season. It was hypothesized that CH_4 fluxes would be negligible at the initiation of flooding for all treatments, increase to a maximum with N fertilized rice having the largest flux, and decline thereafter towards the end of the growing season due to the sequential reduction of compounds occurring in the soil and the change of metabolic pathways from aerobic (respiration) to highly anaerobic (methanogenesis). It was also hypothesized that a post-flood release pulse would occur in all treatments due to the removal of the floodwater boundary layer and the decrease in diffusive resistance above the soil and that total CH_4 emissions would be largest from N fertilized rice due to the facilitating nature of the rice plant in CH_4 transport.

PROCEDURES

Research was conducted in 2011 at the University of Arkansas Rice Research and Extension Center 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. The long-grain, conventional rice cultivar Wells (Moldenhauer et al., 2007) was selected for use in the study due to its high-yield potential and widespread use in Arkansas (Norman et al., 2009).

The study consisted of nine field plots with dimensions of 9 rows wide (7 in. spacing) by 15 ft in length (~1.6 m wide by ~5 m long) arranged in a randomized complete block design. Rice was seeded at a rate of 100 lb/acre (112 kg/ha). Nitrogen fertilization [0 lb/acre (0 kg N/ha) and 150 lb/acre (168 kg N/ha)] and vegetation (rice and bare soil) were the studied treatments. Fertilized plots received N in a split application of 105 lb/acre (118 kg N/ha) preflood followed by a 45 lb N/acre (50 kg N/ha) application at mid-season. At the 4- to 5-lf growth stage, a permanent flood was established at a depth of 2 to 4 in. (5 cm to 10 cm) and was maintained until maturity at which time the flood was removed for harvest.

Prior to flooding, a composite soil sample was collected from the top 4 in. (10 cm) from each plot and oven-dried at 40 °C, crushed and sieved through a 2-mm mesh screen. Sub-samples of sieved soil were analyzed for Mehlich-3 extractable nutrients 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 by potassium chloride (KCl) extraction and analyzed colorometrically on a Sans Skalar Wet Chemistry Auto-Analyser (Skalar, Netherlands). Total carbon (TC) and total nitrogen (TN) were determined by combustion on a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). Soil pH was determined using a 1:2 soil to water ratio. Bulk density was also determined in the top 4 in. (10 cm) using a ~2-in. (4.7 cm) diameter stainless steel core chamber with beveled edges to minimize soil compaction. Selected soil properties and chemical characteristics are shown in Table 1.

Enclosure-based chambers were utilized for measuring gas fluxes (Livingston and Hutchinson, 1995). Chambers were constructed of polyvinyl chloride with a diameter of 15.2 cm and heights of 40, 60, and 100 cm to accommodate increasing heights of the rice plants throughout the growing season. Chambers were covered with reflective metal tape to minimize temperature changes within and a small fan was installed in the chambers to circulate air within the headspace. Permanent collars were installed in all plots at a depth of 8 to 10 cm one week before initial sampling to minimize disturbance associated with chamber installation. Collars were established in plots containing N fertilized and unfertilized rice, and in open-water above N fertilized and unfertilized bare soil. Permanent boardwalks were established within each plot to minimize disturbance and the possible impact of foot traffic on resulting CH_4 fluxes.

Gas samples were collected weekly and analyzed by gas chromatography (Agilent 6890N, Agilent Technologies, Santa Clara, Calif.) until field flood release, at which time sampling was increased to every other day. Four samples were collected from each chamber on each sampling date at 0, 15, 20, and 45 min after sealing the chamber. Growing-season emissions were calculated by linear interpolation between measurements and reported for the 103 day period between flooding and harvest. Means and standard errors were calculated using PROC Means in SAS 9.2 (SAS Institute, Inc., Cary, N.C.). An analysis of variance (ANOVA) was conducted using PROC MIXED and means separation performed using Fisher's Protected Least Significant Difference test (LSD). Due to the small number of replications and expected within-field variability, a $P < 0.10$ was used for means separation.

RESULTS AND DISCUSSION

Methane emissions followed a clear pattern from initial flooding until the flood was released (Fig. 1). Results showed that appreciable CH_4 emissions began around 20 days after flooding (DAF). Fluxes peaked after panicle differentiation and midseason N application at 41 DAF for N fertilized rice with a maximum observed flux of 22.6 mg CH_4-C/m^2/hr, which was significantly greater than all other treatments ($P < 0.10$). Nitrogen fertilized bare soil also reached a maximum at 41 DAF. By 48 DAF, unfertilized bare soil reached its maximum flux (11.6 mg CH_4-C/m^2/hr) along with unfertilized rice (13.9 mg CH_4-C/m^2/hr), but there were no significant differences in fluxes ($P < 0.10$) at 48 DAF.

Nitrogen fertilized rice and unfertilized bare soil reached a second flux maximum 62 DAF at 21.8 and 6.7 CH_4-C mg/m^2/hr, respectively, and N fertilized rice was again significantly different from all other treatments ($P < 0.10$; Fig. 1). This pattern of a double maximum of peak fluxes early in reproductive growth and around heading has been previously reported by Sass et al. (1990) in a field near Lake Charles, Texas, by Holzapfel-Pschorn et al. (1986) in Italy, and by Cicerone et al. (1983) in California rice fields. In this study all treatments indicated this double maximum, each occurring within 1 week/sampling interval of each other, except for the unfertilized rice where no clear maximum was reached and fluxes remained numerically similar during periods of maximum CH_4 flux. Fluxes from all treatments in this study, excluding N fertilized bare soil, decreased from 60 DAF until the flood was released at 85 DAF at which time observed fluxes did not differ among treatments.

A post-flood release pulse of CH_4 emissions, as reported by Bossio et al. (1999) and Denier van der Gon and Neue (1995), was apparent in this study (Fig. 2). Bossio et al. (1999) and Denier van der Gon and Neue (1995) reported post-flood release pulses accounting for nearly 10% of total seasonal CH_4 emissions. In this study, a discreetly large flux was measured 6 days after flood release in all treatments except unfertilized bare soil where the flux was 0.17 CH_4-C mg/m^2/hr. Estimates from N fertilized rice in this study were 4.2% of total emissions from initial flooding until harvest in N fertilized rice, 3.9% from unfertilized rice, 6.4% from unfertilized bare soil, and 14.5% from N fertilized bare soil. All treatments except the fertilized bare soil in this study released a lower percentage of their total emissions from their post-flood release pulse than the 10% previously reported by Bossio et al. (1999) and Denier van der Gon et al. (1996). However, it is apparent that a potentially large and variable pulse of CH_4 occurs following flood release. Therefore, it is important for field studies and those making estimates of CH_4 emissions in rice to include this post-flood release pulse.

Growing-season CH_4 emissions estimated from the 103-day-long season were greatest from N fertilized rice at 21.6 g CH_4-C/m^{-2}/growing season followed by unfertilized rice at 17.6 g CH_4-C/m^{-2}/growing season. Bare soil had lower emissions compared to rice where the unfertilized bare soil emitted 5.2 g CH_4-C/m^2/growing season and N fertilized bare soil emitted 4.3 g CH_4-C/m^2/growing season. These estimates are comparable to previously published rates from Cicerone and Shetter (1981) and Cicerone et al. (1983) in fields near Davis, Calif., which ranged from 16.4 to 31.2 g CH_4-C/m^{-2}/yr. Along with these estimates, Schütz et al. (1989) reported emissions from unfertilized rice in Italy averaged 24.8 g CH_4-C/m^2/yr and N fertilized rice ranged from 9.0 to 32.3 g CH_4-C/m^{-2}/yr.

In contrast to the results of this study, prior studies in the United States have reported lower emissions from rice ranging from 3.4 to 12.0 g CH_4-C/m^{-2}/yr in Texas (Sass et al., 1991). Bossio et al. (1999) reported low emissions of 1.9 g CH_4-C/m^{-2}/yr when rice straw residue was burned, reducing the available organic-C, coupled with a temporary midseason field flood release. In contrast, when rice straw was incorporated, 9.2 g CH_4-C/m^{-2}/yr was emitted (Bossio et al., 1999). Thus, it is apparent that residue and water management can play a major role in magnitude of CH_4 fluxes and emissions; however, further research is necessary to determine whether these techniques are feasible based not only on CH_4 emissions, but also from a weed and disease management, water quality, and overall crop productivity standpoint.

SIGNIFICANCE OF FINDINGS

Methane emissions are a direct consequence of the flood-irrigation water management scheme of the rice production system. It is apparent that the CH_4 emissions from a silt-loam soil in a direct-seeded, delayed-flood rice production system in Arkansas are within the range of those previously reported both in the United States and abroad. Rice production in Arkansas represents only a small fraction of the global land area cropped to rice, and thus represents only a small fraction of the global carbon footprint associated with rice production. The highly mechanized nature of the United States production system and the ability to control a multitude of field conditions allows investigations of specific factors and management strategies, which could influence emissions. This study represents a starting point from which to begin further research into the varying factors influencing CH_4 emissions from the direct-seeded, delayed-flood rice production in Arkansas. Further research concerning crop rotation, straw management, water management, and N fertilization effects on CH_4 emissions will be important in understanding which management techniques have the potential to reduce CH_4 emissions, while maintaining high yields and grain quality and avoiding increased susceptibility to both diseases and pests.

ACKNOWLEDGMENTS

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

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.

Buendia, L.V., H.U. Neue, R. Wassmann, R.S. Lantin, A.M. Javellana, J. Arah, Z. Wang, L. Wanfang, A.K. Makarim, T.M. Corton, and N. Charoensilp. 1998. An efficient sampling strategy for estimating methane emission from rice field. Chemosphere 36:395-407.

Cicerone R.J. and J.D. Shetter. 1981 Sources of atmospheric methane: measurements in rice paddies and a discussion. J. Geophys. Res. 86:7203-7209. DOI: 10.1029/JC086iC08p07203.

Cicerone, R.J., J.D. Shetter, and C.C. Delwiche. 1983. Seasonal variation of methane flux from a California rice paddy. J. Geophys. Res. 88:11022-11024.

Denier van der Gon, H.A.C., N. van Breemen, H.U. Neue, R.S. Lantin, J.B. Aduna, M.C.R. Alberto, and R. Wassmann. 1996. Release of entrapped methane from wetland rice fields upon soil drying. Global Biogeochemical Cycles 10:1-7.

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.

Holzapfel-Pschorn, A., R. Conrad, and W. Seiler. 1986. Effects of vegetation on the emission of methane from submerged paddy soil. Plant and Soil 92:223-233. DOI: 10.1007/bf02372636.

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. Harriss (eds.). Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell Sciences Ltd., Osney Mead, Oxford.

Moldenhauer, K.A.K., F.N. Lee, J.L. Bernhardt, R.J. Norman, N.A. Slaton, C.E. Wilson Jr., M.M. Anders, R.D. Cartwright, and M.M. Blocker. 2007. Registration of 'Wells' rice. Crop Sci. 47:442-443.

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. Soil Sci. Soc. Am. J. 73:2184-2190.

Sass, R.L., F.M. Fisher, and P.A. Harcombe. 1990. Methane production and emission in a Texas rice field. Global Biogeochem. Cycles 4:47-68.

Schütz, H., A. Holzapfel-Pschorn, R. Conrad, H. Rennenberg, and W. Seiler. 1989. A 3-year continous record on the influence of daytime, season and fertilizer treatment on methane emission rates from an Italian rice paddy. J. Geophys. Res. 94:16405-16416.

Table 1. Mean soil properties (n = 9) in the top 4 in. (10 cm) associated with methane fluxes from a DeWitt silt loam during the 2011 growing season at the Rice Research and Extension Center near Stuttgart, Ark.

Soil property	Mean (standard error)
pH (1:2)	5.8 (<0.01)
Mehlich-3 extractable nutrients (mg/kg)	
P	26 (1)
K	126 (3)
Ca	841 (9)
Mg	146 (2)
Fe	413 (4)
Na	62 (1)
S	9.2 (0.2)
Cu	0.9 (<0.01)
Zn	7.8 (0.2)
NO_{3-}-N (mg/kg)	5.7 (0.6)
NH_4-N(mg/kg)	3.4 (<0.01)
Total N (%)	0.1 (<0.01)
Total C (%)	0.9 (<0.01)
C:N ratio	9:1 (1)
Organic matter (%)	2 (<0.01)
Bulk density (g cm^{-3})	1.6 (<0.01)

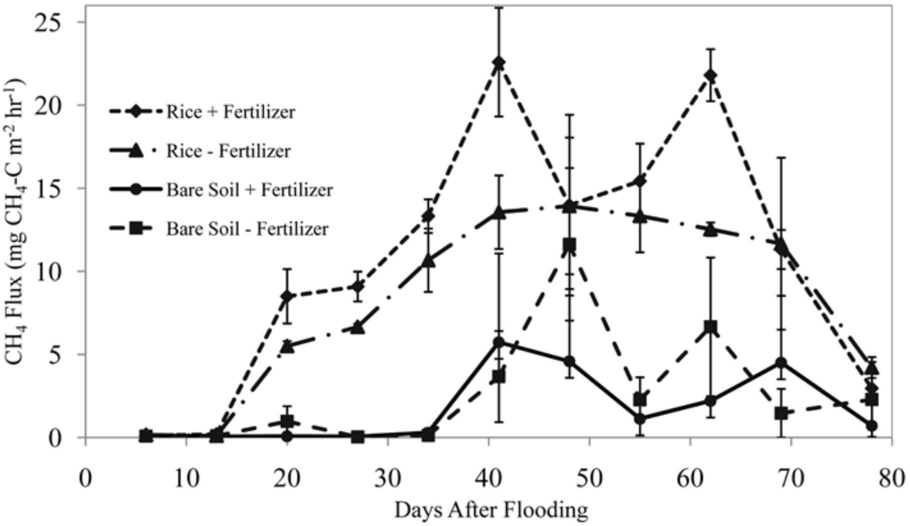


Fig. 1. Growing season profile of methane (CH_4) fluxes from a DeWitt silt loam at the Rice Research and Extension Center near Stuttgart, Ark. (error bars represent standard error of the mean).

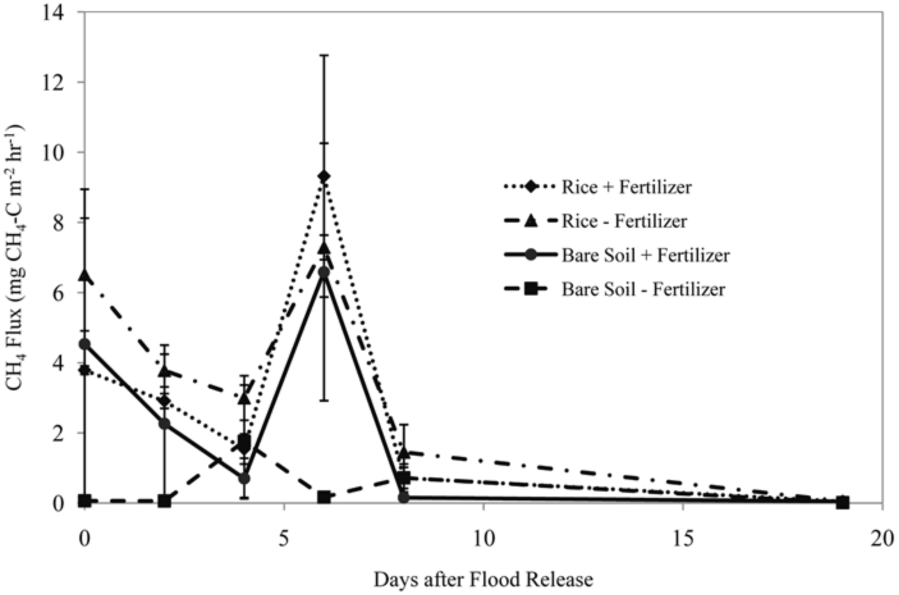


Fig. 2. Post flood release profile of methane (CH_4) emissions from a DeWitt silt loam at the Rice Research and Extension Center near Stuttgart, Ark. (error bars represent standard error of the mean).

RICE CULTURE

Evaluation of Inhibitors to Reduce Ammonia Volatilization for Usage in Directed-Seeded, Delayed-Flood Rice Production

C.W. Rogers, R.J. Norman, T.L. Roberts, N.A. Slaton,
C.E. Wilson Jr., K.R. Brye, A.M. Fulford, D.L. Frizzell, and J.D. Branson

ABSTRACT

Ammonia (NH_3) volatilization of urea fertilizer is an important loss mechanism in direct-seeded, delayed-flood rice (*Oryza sativa* L.) production if fields are not flooded quickly. Consequently, urease inhibitors are often employed as a means of minimizing NH_3volatilization from preflood N applications. Of these inhibitors, [N-(n-butyl) thiophosphorictriamide, NBPT] has been shown effective over a multitude of studies in both rice production and other agricultural production systems. Static diffusion chambers were used in the laboratory in 2010 and 2011 to measure NH_3 volatilization loss of urea treated with different products. In both years, Agrotain and Arborite treated urea lost statistically less nitrogen (N) via NH_3 volatilization across all sampling dates as compared to both urea and Stay-N-treated urea. In 2011 from day 11 on, Arborite-treated urea lost significantly more NH_3 than Agrotain-treated urea. Cumulative N-loss in 2011 from urea and Stay-N treated urea were statistically similar except on day 5 when Stay-N-treated urea lost more N than urea (11.0 and 10.1%, respectively) and day 20 when the cumulative loss was less for Stay-N-treated urea than for urea (27.2% and 28.1%, respectively). From a practical standpoint, Agrotain and Arborite clearly decreased NH_3 volatilization loss from urea. Stay-N appears to have little to no effect in mitigating NH_3volatilization loss from urea and any positive effect on yield associated with Stay-N is not a result of decreased NH_3volatilization from urea.

INTRODUCTION

Nitrogen is the largest fertilizer input in direct-seeded, delayed-flood rice production. Fertilizer recommendations call for the usage of ammonium (NH_{4+}) or NH_{4+} forming fertilizers, of which, urea is the most common and cost effective. Typically, urea is applied in either a single preflood or split (preflood and midseason) application (Wilson et al., 2001). Urea undergoes hydrolysis in the soil in the presence of water and the urease enzyme which converts the urea to NH_3, which raises pH and increases the susceptibility to volatilization. Losses can be minimized by proper fertilizer management where the urea is applied to a dry soil and flooded immediately after fertilizer application. However, environmental and logistical constraints often arise which limit a producers ability to flood the field as quickly as is optimal. Thus, inhibitors have been developed and tested which delay the hydrolysis of urea and increase the producers flooding timeframe, greatly increasing their ability to decrease N-loss from the field to the environment (Griggs et al., 2007; Norman et al., 2009; Roth et al., 2009).

PROCEDURES

Static diffusion chambers were utilized in the laboratory to determine NH_3 volatilization differences among several products sold to decrease NH_3 volatilization loss of urea. Treatments included urea, urea + Agrotain (Agrotain International; St. Louis, Mo.), urea + Arborite (Weyerhaeuser Company, Vanceboro, N.C.), and urea + Stay-N (Loveland Products, Greeley, Colo.). A DeWitt silt loam soil (18% gravimetric water content) which is commonly used for rice production was used for the experiment. Soil (50 g) was added to the glass diffusion chambers to a depth of 2.5 cm. Nitrogen fertilizer was then applied to the surface of the soil at a rate of 180 lb N/acre (202 kg N/ha). To capture the NH_3 volatilized from the soil and urea fertilizer, a 4% boric acid (H_3BO_3) solution was suspended within the chamber. Ammonia volatilization was measured at 25º C from samples collected from the chambers. Three replications of each product were prepared and sampled on the following dates, in 2010 sampled 1, 4, 7, 11, 15, and 21 days after fertilization and in 2011 sampled 1, 3, 5, 7, 11, 15, and 20 days after urea fertilizer application. The studies were analyzed as a split-plot design with product as the whole-plot factor and time as the split-plot factor. Years 2011 and 2012 were analyzed separately, and statistical analysis was performed in SAS 9.2 (SAS Institute, Inc., Cary, N.C.) using an analysis of variance (ANOVA), and mean separations by Fisher's protected least significant difference (LSD) are reported at $P < 0.05$.

RESULTS AND DISCUSSION

Soil nutrient data for the samples used in the two years are presented in Table 1. Shown in Fig. 1 are the cumulative NH_3 volatilization results from the laboratory-incubation study conducted in 2010 for each of the three N sources measured at 1, 4, 7, 11, 15, and 21 days after N fertilizer application. Urea (check) lost the most N via NH_3

volatilization of the products tested with 2.5% by day 4, 15.2% by day 7, 28.6% by day 11, 36.4% by day 15, and 40.4% by day 21. Both Agrotain- and Arborite-treated urea significantly reduced NH_3 volatilization from urea over the 21 day incubation. Agrotain-treated urea and Arborite-treated urea lost little N to NH_3 volatilization over the 21 day incubation, 2.7 and 6.4%, respectively. Agrotain- and Arborite-treated urea lost similar small amounts of N via NH_3volatilization over the first 15 days of incubation; however, while not statistically significant, between day 15 and day 21 the Arborite-treated urea lost numerically more N than Agrotain-treated urea. By day 11, Agrotain- and Arborite-treated urea lost <0.3% of the urea via NH_3 volatilization and by day 15 lost 0.5% and 1.4%, respectively. By day 21, Agrotain and Arborite were losing their effectiveness as indicated by the cumulative NH_3 volatilization of Agrotain-treated urea increasing from 0.52% on day 15 to 2.7% by day 21 and Arborite-treated urea increasing from 1.4% on day 15 to 6.4% by day 21.

In 2011, NH_3volatilization from urea was not measured until 3 days after fertilization for any N-source, at which time urea and Stay-N-treated urea began to volatilize NH_3, Agrotain- and Arborite-treated urea had no significant NH_3volatilization at this time (Fig. 2). By day 5, Stay-N-treated urea lost 11.0% of the applied N via NH_3 ammonia volatilization which was statistically greater than any other N source. Agrotain- and Arborite-treated urea were not statistically different from zero N loss by day 5. While urea and Stay-N-treated urea lost significant amounts of N by day 3, not until day 11 did Agrotain- (0.5%) and Arborite (1.5%) -treated urea lose measurable amounts of N via NH_3 ammonia volatilization. This is consistent with previous research which reported that NBPT can minimize volatilization for at least a week after urea application (Bremner and Chai, 1989). Furthermore, our cumulative losses over 20 days for urea (28.1%) were comparable to those reported by Norman et al. (2009) of 23.4% over a two year study conducted on a Calloway silt loam (a fine-silty, mixed, active, thermic AquicFraglossudalf); and our Agrotain source (6.8%) was lower but still relatively comparable to 10.1% as reported by Norman et al. (2009). Most importantly is the conclusion that NBPT, as found in Agrotain and Arborite, is effective at minimizing NH_3 volatilization when properly used with urea fertilizers.

Although the laboratory incubation method does not exactly mimic NH_3 volatilization in the field, it does allow us to compare products' NH_3 inhibition relative to each other. These NH_3 volatilization results over the first 15 days of the laboratory incubation reflect the results previously reported in the field when we delayed the flood for up to 10 days; that is, over a 10 day period, Arborite and Agrotain inhibit NH_3 volatilization of urea similarly.

SIGNIFICANCE OF FINDINGS

Investigations as to the effectiveness of these products inhibiting NH_3 volatilization in direct-seeded, delayed-flood rice production in Arkansas are important, because Arkansas rice producers invest substantial capital into fertilizers and amendments each year. Our studies indicate that both Agrotain and Arborite (NBPT containing inhibitors) are effective at reducing NH_3 volatilization of urea, Stay-N had little to no effect at reducing NH_3 volatilization. Thus, if Stay-N appears to have a positive effect on yield, it is not a result of decreased NH_3 volatilization loss of urea.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Bremner, J.M. and H.S. Chai. 1989. Effects 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.

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. Soil Sci. Soc. Am. J. 73:2184-2190.

Roth, C.R., T.L. Roberts, and R.J. Norman. 2009. Variable rates of Agrotain on ammonia volatilization loss of urea applied to a DeWitt silt loam. *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 571:240-245. Fayetteville, Ark.

Wilson, C.E., N.A. Slaton, R.J. Norman, and D.M. Miller. 2001. Efficient use of fertilizer. pp. 51-74. *In:* N.A. Slaton (ed.). Rice Production Handbook.University of Arkansas.Divison of Agriculture Cooperative Extension Service MP 192. Fayetteville, Ark.

Table 1. Selected soil chemical property means (*n* = 8) of the soils used in the ammonia volatilization laboratory experiments conducted in 2010 and 2011. The soil is a Dewitt silt loam from the Rice Research Extension Center.

Year	Soil pH	Mehlich-3 extractable nutrients P	K	Ca	Mg	Na	S	Cu	Zn
	(1:2)	(mg/kg)							
2010	6.1	31	172	1064	188	56	9.8	1.2	6.3
2011	6.1	15	140	926	144	66	11.0	1.4	1.7

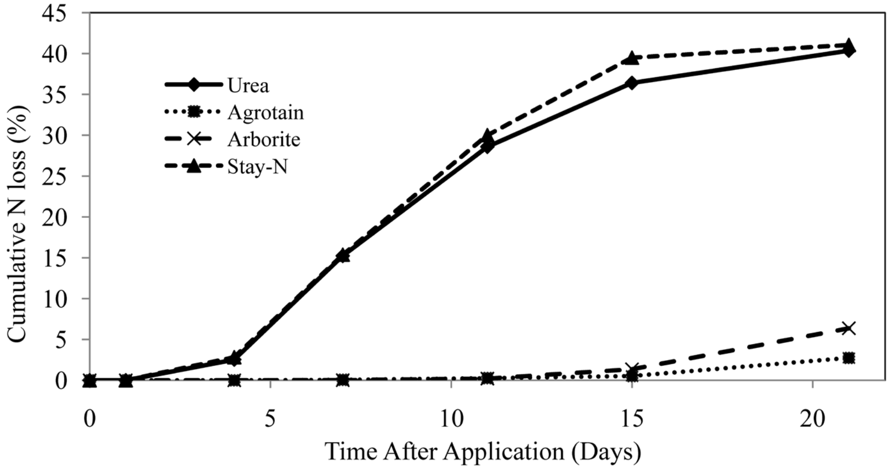


Fig. 1. Cumulative NH_3 volatilization loss from urea, urea + Agrotain, urea + Stay-N, and urea+Arborite applied to a silt loam soil using static diffusion jars (2010).

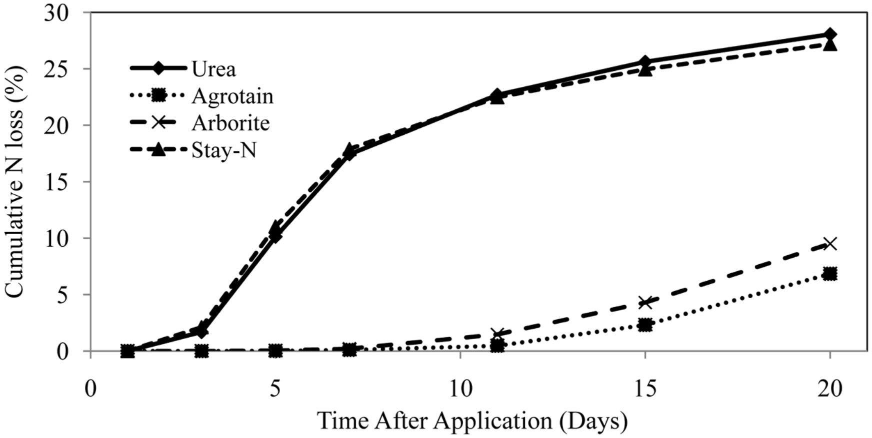


Fig. 2. Cumulative NH_3 volatilization loss from urea, urea + Agrotain, urea + Stay-N, and urea+Arborite applied to a silt loam soil using static diffusion jars (2011).

Rice Grain Yield As Influenced By Nitrogen Source, Nitrogen Rate, and Nitrogen Application Time

C.W. Rogers, R.J. Norman, T.L. Roberts,
C.E. Wilson Jr., N.A. Slaton, D.L. Frizzell, and J.D. Branson

ABSTRACT

Urea is the primary nitrogen (N) source used for the large preflood N application in delayed-flood rice (*Oryza sativa* L.); however, urea is prone to substantial ammonia volatilization losses if the flood is not established soon after application. Most delayed-flood rice fields require five to ten days to flood. Consequently, a study was conducted on a Dewitt silt loam soil at the Rice Research and Extension Center near Stuttgart, Ark., to evaluate the effectiveness of the inhibitors, Agrotain (Agrotain International; St. Louis, Mo.) and Arborite (Weyerhaeuser Company; Vanceboro, N.C.) in 2010 and 2011 and Stay-N (Loveland Products, Greeley, Colo.) in 2011, for minimizing the ammonia volatilization of urea when a flood cannot be applied in a timely manner. Urea, Arborite-treated urea, Agrotain-treated urea, and Stay-N-treated urea were applied 1, 5, and 10 days prior to flooding at rates of 60 and 120 lb N/acre. Arborite-treated urea and Agrotain-treated urea resulted in similar total N uptakes and rice grain yields which were significantly higher than the rice grain yield obtained with untreated urea in 2010. In 2011 ammonia volatilization loss was apparently not substantial enough to result in a N uptake difference between the urea treated with Agrotain, Arborite, and Stay-N compared to urea.

INTRODUCTION

Nitrogen (N) fertilizer must be applied in the proper amounts and times to produce maximum agronomic rice (*Oryza sativa* L.) yield. Currently, the most efficient method of N fertilization for rice grown in the direct-seeded, delayed-flood production system is to apply an ammonium or ammonium-forming N source (e.g., urea) to a dry soil surface near the 5-lf stage of rice growth and incorporate the N quickly by establishing a flood that will be maintained for the duration of the growing season. Norman et al. (2003) reported that rice recovery of properly managed preflood urea-N was 60% to 75% of the total applied N. A second application of N fertilizer (~45 lb N/acre as urea) is generally applied into the floodwater near the panicle differentiation (PD) stage 4 to 5 weeks after the preflood N application. Following the recommended N fertilization guidelines allows for high yields, minimizes environmental N losses, and represents the most cost-efficient means for sufficient N fertilization of flood-irrigated rice.

Urea and ammonium sulfate are the N fertilizers recommended for preflood fertilization of rice in Arkansas (Slaton, 2001); however, urea is the most commonly used N fertilizer for rice due to its high N analysis and relatively low cost. One major disadvantage of surface application of urea-N is the potential for substantial N loss via ammonia volatilization, which is one of the two most prevalent N loss mechanisms in the dry-seeded, delayed-flood production system. The other prevalent loss mechanism is denitrification of soil- or fertilizer-N that has undergone nitrification.

Griggs et al. (2007) showed ammonia volatilization losses ranged from 20% to 30% of the total urea-N applied to a silt loam 14 days before flooding. Ammonia volatilization losses from $(NH_4)_2SO_4$ were lower (<5%) compared with urea. The results of Griggs et al. (2007) shows that a significant proportion of N can be lost via ammonia volatilization even when proper fertilization and water management practices are followed on silt loam soils. Our research objectives in 2010 were to: i) describe the differences in rice grain yield as affected by N rate, and application timing of two urease inhibitors as compared to urea-N application and ii) determine the influence urease inhibitors applied to urea at varying N rates at multiple application times have on aboveground N uptake at the late boot/early heading stage of rice growth and development. In 2011, the research objectives were the same except that the product Stay-N was added to the experiment. Stay-N is marketed as an ammonia volatilization inhibitor, not as a urease inhibitor. The ultimate goals of these experiments were to determine if Agrotain-, Arborite-, and Stay-N-treated urea would increase rice grain yield by effectively limiting ammonia volatilization compared to untreated urea when applied several days in advance of the permanent flood.

PROCEDURES

Description of Experimental Site

Research was conducted in 2010 and 2011 to evaluate the influence of three inhibitors and time of N application on rice grain yield and N uptake.The experiments were established at the Rice Research and Extension Center on a Dewitt silt loam (fine, smectitic, thermic TypicAlbaqualfs), and soybean [*Glycine max* (L.) Merr.] was the previous crop grown in rotation.

Eight composite soil samples (two per bay) were collected from the 0- to 4-in. depth at each site before seeding rice. Each composite sample consisted of eight 1-in. diameter cores. Soil samples were oven-dried, crushed to pass through a 2-mm sieve, extracted with Mehlich-3 (Mehlich, 1984), and extracts were analyzed using inductively coupled plasma atomic emission spectroscopy. Soil water pH was determined in a 1:2 soil weight:water volume ratio using a glass electrode. Total soil N and carbon were determined by combustion (LECO CN2000, St. Joseph, Mich.; Nelson and Sommers, 1996). The mean values of selected soil chemical properties for 2010 and 2011 are listed in Table 1.

Treatments

Individual plots, measuring 6.5-ft wide × 16-ft long, were flagged to establish plot boundaries. Phosphorus (36 lb P_2O_5/acre as triple superphosphate) and potassium (72lb 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 variety Wells was drill-seeded into conventionally tilled seedbeds at 80 lb seed/acre. Each plot contained nine rows of rice spaced 7 in. apart and was surrounded by a 1.5-ft wide alley that contained no rice. Urea, Agrotain-treated urea, Arborite-treated urea, and in 2011, Stay-N-treated urea, were applied at rates equivalent to 60 and 120 lb N/acre. An unfertilized control was also included in the study. Each N source was applied at three timings, 10, 5, and 1 day before flooding (DBF) onto a dry soil surface. Following the 1 day N application, a 2- to 4-in. deep permanent flood was established and maintained until rice reached physiological maturity. The dates of several agronomic events for 2010 and 2011 are listed in Tables 2 and 3, respectively. In general, rice management closely followed the University of Arkansas Cooperative Extension Service recommendations for stand establishment, pest management, and irrigation management (Slaton, 2001).

Crop Measurements

Aboveground plant samples were collected near the late-boot to early-heading (HDG) stage to evaluate N-fertilizer uptake among the N-fertilizer sources. The HDG stage represents maximal N accumulation by rice during the growing season (Guindo et al., 1994). Plant samples were taken from a 3-ft section in the first inside row of each plot. Samples were dried at 60 °C in a forced-draft oven, weighed, and ground to pass through a 1-mm sieve. A 0.20- to 0.30-g subsample was weighed into a tared Elementar macroN crucible (Elementar, Mount Laurel, N.J.) and total N was determined by combustion (ElementarVario Max CN, Mount Laurel, N.J.; Campbell, 1992).

Aboveground N content was calculated by multiplying the whole-plant N concentration by total aboveground dry matter accumulation. Grain yield was determined at physiological maturity by harvesting 65-ft^2 from the middle of each plot with a small plot combine. Grain weights and moisture contents were recorded and grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

Statistical Analysis

In each year, the experiment was a randomized complete block with treatments defined by N sources applied (3 in 2010 and 4 in 2011) at 2 N rates with 3 N application times plus an unfertilized control (0 lb N/acre). Each treatment was replicated four times. Nitrogen uptake and rice grain yield were analyzed using an analysis of variance (ANOVA) and means were separated using Fishers protected least significant difference (LSD) at the $P = 0.05$ and 0.10 significance level when appropriate. All statistical analysis was conducted with PROC MIXED in SAS 9.2 (SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

Rice Grain Yield

2010 Growing Season

Rainfall during the 10 days prior to flooding when the urea fertilizer was either being applied or had been applied was minimal and not sufficient to incorporate the urea fertilizer into the soil (Table 4). In addition, the temperatures during the day were in the high 80s and low 90s °F. Thus, the environment was conducive for ammonia volatilization of urea and well suited for conducting a study to evaluate a urease inhibitor.

There was no three-way nor any two-way interactions between N source, N rate, and/or N application timing on rice grain yield at the $P < 0.05$ or 0.10 levels (Table 5). However, there were significant main effects of N rate ($P < 0.0001$), N application timing ($P < 0.0001$), and N source ($P = 0.0003$) on rice grain yield.

Rice grain yield was significantly affected by N rate when averaged across N sources and N application times (Table 6). Thus, indicating there was a positive response to N fertilizer and the site was appropriate for a N response study. The new N-soil test for rice (i.e., N-ST*R) indicated a rice variety like Wells should require 85 lb N/acre to maximize yield on this soil (Roberts et al., 2011).

Application time of the N fertilizer in reference to establishment of the permanent flood significantly affected rice grain yield when averaged across N rate and N source (Table 7). As the time between N application and flooding was increased from 1 to 5 days there was not a significant decrease in rice grain yield at the $P = 0.05$ nor at the $P = 0.10$ level. However, there was a significant decrease in rice grain yield when the time between N application and flooding was increased from 1 to 10 days and 5 to 10 days at the $P = 0.05$ level. Consequently, the decrease in yield as the time between N application and flooding was increased indicates there was ammonia volatilization loss over the 10 days prior to flooding and the study was suitable for evaluating a urease inhibitor.

Averaged across N rates and N application times, rice grain yield was significantly affected by N source at $P = 0.05$ (Table 8). All N sources resulted in a grain yield higher than the control. Arborite-treated urea and Agrotain-treated urea resulted in similar mean grain yields (136 and 138 bu/acre, respectively) which were significantly higher than the rice grain yield obtained with untreated urea (129 bu/acre). Thus, the grain yield results indicate Arborite was as effective as Agrotain in minimizing ammonia volatilization loss and maintaining grain yield as the time between N fertilizer application and flooding was delayed from 1 to 10 days under the conditions which existed in 2010.

Total Aboveground Nitrogen Uptake

There was no three-way nor any two-way interactions between N source, N rate, and/or N application timing on rice N uptake at the $P = 0.05$ or 0.10 levels; however, there were significant main effects of N rate ($P < 0.0001$), N application timing ($P = 0.0003$), and N source ($P = 0.01$) on total N uptake $P < 0.05$. The total N uptake results mimic very closely the rice grain yield results.

Total N uptake was significantly affected by N rate when averaged across N sources and N application times (Table 9). This indicates there was a positive response to N fertilizer and the site was appropriate for a N response study. As stated earlier, our new N soil test for rice (i.e., N-ST*R) indicated a rice variety like Wells should require 85 lb N/acre to maximize yield on this soil (Roberts et al., 2011).

Application time of the N fertilizer in reference to establishment of the permanent flood significantly affected total N uptake when averaged across N rate and N source (Table 10). As the time between N application and flooding was increased from 1 to 5 days there was not a significant decrease in total N uptake at the $P = 0.05$ nor at the $P = 0.10$ level. However, there was a significant decrease in total N uptake when the time between N application and flooding was increased from 1 to 10 days and 5 to 10 days at the $P = 0.05$. Consequently, the decrease in total N uptake as the time between N application and flooding was increased indicates there was ammonia volatilization loss over the 10 days prior to flooding and the study was suitable for evaluating a urease inhibitor.

Total N uptake was significantly affected by N source at $P = 0.05$ level when averaged across N rates and N application times (Table 11). All N sources resulted in a total N uptake higher than the control. Arborite-treated urea and Agrotain-treated urea resulted in similar mean total N uptakes which were significantly higher than the total N uptake obtained with untreated urea. Thus, the total N uptake results mimic the grain yield results and indicate Arborite was as effective as Agrotain in minimizing ammonia volatilization loss and maximizing total N uptake as the time between N fertilizer applications and flooding was delayed from 1 to 10 days in 2010.

2011 Growing Season

During the 10 days prior to flooding, when the urea fertilizer was either being applied or had been applied, rainfall was virtually nonexistent, except on day 6 (17 June 2011) when 0.04 in. of rain fell which was insufficient to incorporate the N fertilizer into the soil (Table 4). In addition, the temperatures during the day were, as in 2010, in the high 80s to high 90s °F. However, because the soil and air were excessively dry and hot, NH_3 volatilization was apparently minimized to an extent that made yield differences between urea and the NBPT-treated urea non-significant. Thus, during 2011 the soil and environment were not optimal for ammonia volatilization of urea and the evaluation of a urease inhibitor.

There was no three-way nor any two-way interactions between N source, N rate, and/or N application timing on rice grain yield at the $P = 0.05$ or 0.10 levels (Table

5). However, there were significant main effects of N rate (*P* = 0.001), N application timing (*P* = 0.007), and N source (*P* = 0.099) on rice grain yield.

Rice grain yield was significantly affected by N rate when averaged across N sources and N application times (Table 12). Fertilization of 120 lb N/acre resulted in yields of 147 bu/acre as compared to 126 lb/acre when fertilized with 60 lb N/acre. Thus, indicating there was a positive response to N fertilizer and the site was appropriate for a N response study.

Application time of the N fertilizer in reference to establishment of the permanent flood significantly affected rice grain yield when averaged across N rate and N source with similar conclusions as in 2010 (Table 13). As the time between N application and flooding was increased from 1 to 5 days, there was not a significant decrease in rice grain yield at the *P* = 0.05 nor at the *P* = 0.10 level. However, there was a significant decrease in rice grain yield when the time between N application and flooding was increased from 1 to 10 days and 5 to 10 days at the *P* = 0.05. Consequently, the decrease in yield as the time between N application and flooding was increased indicates there was apparently some ammonia volatilization loss and/or nitrification prior to flooding and denitrification after flooding loss to cause the grain yield decrease.

Averaged across N rates and N application times, rice grain yield was significantly affected by N source at *P* = 0.10 level, but not at the *P* = 0.05 level (Table 14). All N sources resulted in a grain yield higher than the control where no N was applied. Arborite-treated urea and Agrotain-treated urea resulted in similar mean grain yields which were significantly higher than the rice grain yield obtained with Stay-N-treated urea, but not with untreated urea. Thus, the numerical grain yield results indicate Arborite was as effective as Agrotain in maintaining grain yield as compared to urea as the time between N fertilizer application and flooding was delayed from 1 to 10 days, but statistically the difference was not large enough to be significant at the *P* = 0.05 or 0.10 levels.

Total Aboveground Nitrogen Uptake

In contrast to 2010, there were no statistically significant treatment interactions or main effects concerning N uptake in 2011.

SIGNIFICANCE OF FINDINGS

In 2010, Arborite- and Agrotain-treated urea were effective urease inhibitors that significantly slowed and minimized the ammonia volatilization of urea. The two products appeared almost identical in their performance in the field. The inhibition of ammonia volatilization of urea by Arborite and Agrotain was substantial enough in the field over the 5 and 10 days prior to flooding to result in a significant increase in total N uptake and grain yield when compared to untreated urea. In 2011, field conditions were not conducive to ammonia volatilization loss and this resulted in no significant difference in total N uptake or grain yield between Agrotain-, Arborite-, or Stay-N-treated urea compared to untreated urea.

ACKNOWLEDGMENTS

This research was supported primarily by the Arkansas Rice Research and Promotion Board and the Weyerhaeuser Company.

LITERATURE CITED

Campbell, C.R. 1992. Determination of total nitrogen in plant tissue by combustion. pp. 20-22. *In:* C. Owen Plank (ed.). Plant analysis reference procedures for the southern U.S. Southern Coop. Ser. Bull. 368. Univ. of Georgia, Athens, Ga.

Griggs, B.R., R.J. Norman, C.E. Wilson Jr., and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake froconvvential and conservation tilled dry-seeded, delayed flood rice. Soil Sci. Soc. Am. J. 71:745-751.

Guindo, D., B.R. Wells, and R.J. Norman. 1994. Cultivar and nitrogen rate influence on nitrogen uptake and portioning in rice. Soil Sci. Soc. Am. J. 58:840-845.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. pp. 961-1010. *In*: D.L. Sparks (ed.). Methods of soil analysis. Part 3.Chemical methods.SSSA Book Series 5.SSSA, Madison, Wis.

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 (ed.). 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. 75:1161-1171.

Slaton, N.A. 2001. Rice production handbook. Misc. Publ. 192. University of Arkansas Cooperative Extension Service, Little Rock.

Table 1. Selected soil chemical property means (n = 8) of research established at the Rice Research Extension Center (RREC) on a Dewitt silt loam in 2010.

Site	Soil pH	Mehlich-3 extractable nutrients							
		P	K	Ca	Mg	Na	S	Cu	Zn
	(1:2)	----------(mg/kg)----------							
2010									
North Bay	6.2	33	167	1086	192	58	9.3	1.1	6.4
South Bay	6.0	29	178	1043	184	54	8.5	1.3	6.2
2011									
North Bay	5.8	23	126	863	147	58	9.0	0.9	8.7
South Bay	5.8	23	116	818	138	56	8.5	0.9	7.7

Table 2. Pertinent agronomic information for the research study at the Rice Research and Extension Center during 2010.

Practices	Dates and rates
Preplant fertilizers	200 lb/acre 0-18-36 + 30 lb/acre $ZnSO_4$
Planting date	16 June
Emergence date	22 June
Herbicide spray and and procedures	28 May = 0.5 pt/acre Command + 0.5 lb/acre Facet 8 July = 24 oz/acre RiceStar HT + 1 oz Permit + 1% COC[a] 14 July = 24 oz/acre RiceStar HT + 1 oz Permit + 1% COC
Insecticide spray dates and procedures	28 July = 3 oz/acre Karate 6 August = 3 oz/acre Karate
Preflood N dates	5 July = 10 days 10 July = 5 days 14 July = 1 day
Flood date	15 July
50% Heading date	NA
Harvest date	18 October

[a] COC = crop oil concentrate.

Table 3. Pertinent agronomic information for the research study at the Rice Research and Extension Center during 2011.

Practices	Dates and rates
Preplant fertilizers	March 31 200 lb/acre 0-20-30 + 30 lb/acre $ZnSO_4$
Planting date	17 May
Emergence date	25 May
Herbicide spray dates and procedures	17 May = 0.5 pt/acre Command + 0.5 lb/acre Facet 20 June = 4 qt propanil + 0.66 oz Permit + 0.25 lb Facet + 1% Crop Oil
Insecticide spray dates and procedures	29 July = 3 oz/acre Karate 12 August = 3 oz/acre Karate 26 August = 3 oz/acre Karate
Preflood N dates	13 June = 10 days 18 June = 5 days 22 June = 1 day
Flood date	23 June
50% Heading date	(average of 14 August) 13 August to 16 August varied by N rate
Harvest date	4 October

Table 4. Soil and air temperatures and rainfall events during the 10 days of nitrogen (N) fertilization prior to flood establishment at the Rice Research and Extension Center in 2010 and 2011.

	Soil		Air		
Date	Max	Min	Max	Min	Rainfall
	-----------------------------	(°F)	-----------------------------		(hundredths)
2010					
5 July	92	81	92	72	0.00
6 July	93	81	94	74	0.00
7 July	91	81	-----	-----	0.03
8 July	89	82	93	74	0.00
9 July	93	80	94	76	0.00
10 July	88	81	90	74	0.00
11 July	90	80	91	75	Trace
12 July	90	83	92	77	Trace
13 July	90	81	95	71	0.26
14 July	89	81	89	72	0.08
15 July	92	82	96	77	0.00
2011					
13 June	106	80	91	69	0.00
14 June	107	83	97	74	0.00
15 June	106	80	97	70	0.00
16 June	107	85	96	77	0.00
17 June	109	80	96	71	0.04
18 June	103	79	65	71	0.00
19 June	105	84	97	78	0.00
20 June	107	86	97	79	0.00
21 June	106	83	95	77	0.00
22 June	91	81	83	72	0.00
23 June	100	80	89	72	0.00

Table 5. 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 in 2010.

Parameter	Value
2010	
N source	0.0003
N rate	<0.0001
N timing	<0.0001
N source*N rate	0.76
N source*N timing	0.23
N source*N rate*N timing	0.55
2011	
N source	0.099
N rate	<0.001
N timing	0.007
N source*N rate	0.71
N source*N timing	0.79
N source*N rate*N timing	0.89

Table 6. Influence of nitrogen (N) rate on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N rate	Grain yield
(lb N/acre)	(bu/acre)
120	141 a[¶]
60	128 b
Control	98

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 7. Influence of nitrogen (N) application timing on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N timing	Grain yield
(dpf[¶])	(bu/acre)
1	139 a[†]
5	135 a
10	128 b

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

[†] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 8. Influence of nitrogen (N) source on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N rate	Grain yield
	(bu/acre)
Agrotain	138 a[¶]
Arborite	136 a
Urea	129 b
Control	98

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 9. Influence of nitrogen (N) rate on total N uptake at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N rate	Total N uptake
(lb N/acre)	(bu/acre)
120	166 a[¶]
60	124 b
Control	91

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 10. Influence of nitrogen (N) application timing on total N uptake at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N timing	Total N uptake
(dpf[¶])	(bu/acre)
1	157 a[†]
5	147 a
10	131 b

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

[†] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 11. Influence of nitrogen (N) source on total N uptake at the Rice Research and Extension Center, Stuttgart, Ark., during 2010.

N source	Grain yield
	(bu/acre)
Agrotain	149 a[¶]
Arborite	150 a
Urea	135 b
Control	91

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 12. Influence of nitrogen (N) rate on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

N rate	Grain yield
(lb N/acre)	(bu/acre)
120	147 a[¶]
60	126 b
Control	105

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 13. Influence of nitrogen (N) application timing on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

N timing	Grain yield
(dpf[¶])	(bu/acre)
1	140 a[†]
5	137 a
10	132 b
Control	105

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

[†] Means followed by the same letter are not statistically different ($P < 0.05$).

Table 14. Influence of nitrogen (N) source on rice grain yield at the Rice Research and Extension Center, Stuttgart, Ark., during 2011.

N rate	Grain yield
	(bu/acre)
Agrotain	138 a[¶]
Arborite	138 a
Urea	135 ab
Stay-N	133 b
Control	105

[¶] Means followed by the same letter are not statistically different ($P < 0.05$).

Rice Growth and Yield Response to CruiserMaxx Seed Treatment and Fertilization

N.A. Slaton, T.L. Roberts, R.J. Norman,

R.E DeLong, C.G. Massey, D.L. Frizzell, S. Clark, and J. Shafer

ABSTRACT

Plant roots serve many purposes with one of the most important being the uptake of mineral nutrients. The objective of this research was to determine the effect of CruiserMaxx and nitrogen (N) and phosphorus (P) fertilizer rate on the growth and yield of rice grown in the delayed-flood, direct-seeded production system. Two trials were established on alkaline silt loam soils at the Pine Tree Research Station. The treatments included two rates of CruiserMaxx® (0 and 7 oz/cwt) and four combinations of two rates of preplant applied MicroEssentials fertilizer (MESZ, 0 and 60 lb P_2O_5/acre) and two rates of preflood urea-N (90 and 130 lb urea-N/acre). Rice fertilized with 150 lb MESZ/acre and 130 lb preflood N produced the greatest dry matter at midtillering and grain yield compared to the other three fertilizer combinations, and rice receiving no MESZ and 90 lb preflood N/acre produced the lowest dry matter and grain yield. The N (18 lb N/acre), P (60 lb P_2O_5/acre), sulfur (S;15 lb S/acre) and/or zinc (Zn;1.5 lb Zn/acre) content in MESZ increased early heading stage dry matter by 14% to 22% and grain yield by 8% to 10% compared to rice fertilized with no MESZ for the 90 and 130 lb N/acre rates, respectively. Rice tissue P and Zn concentrations were not significantly changed by the application of CruiserMaxx, but showed a tendency for both P and Zn to numerically increase in rice that received CruiserMaxx. CruiserMaxx increased rice dry matter by 25% at midtillering, 11% at early heading, and increased grain yield by 6%.

INTRODUCTION

Plant roots serve many purposes with one of the most important being the uptake of mineral nutrients. Soil traits, crop management practices (e.g., in season tillage) or pests may inhibit root development or damage roots to the point that nutrient uptake is reduced and may be severe enough to limit crop growth and yield. Thus, protecting crop root systems from root-damaging pests can be an important component to improving soil and fertilizer nutrient uptake. In the mid-South United States, rice grown in the direct-seeded, delayed-flood production system has at least two common root damaging insects including the grape colaspis and rice water weevil. Both pests may be present in Arkansas rice fields during the early season growth phase when vigorous plant growth and nutrient uptake are important for producing high grain yields. CruiserMaxx® seed treatment contains both insecticides and fungicides to aid in stand establishment and prevention of grape colaspis and rice water weevil damage.

Below et al. (2010) reported that corn (*Zea mayes* L.) hybrids possessing *Bacillus thuringiensis* (Bt) rootworm resistance had greater yield potential and nutrient uptake than hybrid isolines lacking Bt resistance to rootworm. Although our current rice cultivars and hybrids lack genetic insect control, proper use of insecticides that control root-feeding pests may also result in increased root mass and improved nutrient uptake. The primary objective of this preliminary research was to determine the effect of CruiserMaxx and N and P fertilizer rate on nutrient and dry matter accumulation and grain yield of rice grown in the delayed-flood, direct-seeded production system.

PROCEDURES

Two trials were established at the Pine Tree Research Station near Colt, Ark., on soils mapped as Calhoun and Calloway silt loams. Before planting and fertilizer application, one composite soil sample (0- to 4-in. depth) was collected from specific plots within each of four replicates at each site. Soil was oven-dried, ground to pass a 2-mm sieve and analyzed for water pH (1:2 soil:water v/v ratio), Mehlich-3 extractable nutrients and organic matter by weight loss on ignition (Table 1). Potassium fertilizer (0-0-60) was applied to supply the equivalent of 80 lb K_2O/acre to ensure K was not yield limiting.

The conventional rice variety Wells was hand treated with CruiserMaxx® seed treatment (Syngenta, Wilmington, Del.). A 50 lb bag of Wells seed was mixed with a 370 mL slurry that included 103.6 mL CruiiserMaxx®, 6.5 mL color coat blue, and ~259.9 mL tap water. CruiserMaxx® is a premixed combination of insecticide and fungicides including Thiamethoxam (26.4%, insecticide), Fludioxonil (0.28%, insecticide), Azoxystrobin (1.32%, fungicide), Mefenoxam (1.65%, fungicide), and other ingredients (70.35%). A second 50 lb bag of Wells rice from the same seed lot and having no seed treatment (0 mL CruiserMaxx®) was used as a comparison.

Rice was drill-seeded into conventionally tilled seedbeds on 19 April on the Calloway soil and 10 May on the Calhoun soil at a rate of 80 lb seed/acre. Rice emerged to a stand on 30 April and 22 May, respectively. Each plot was nine rows wide (7-in.

drill spacing) and 16 ft long and was separated from adjacent plots by a 21- to 30-in. plant-free border. Pests were controlled by timely applications of the appropriate pesticides following practices recommended by the University of Arkansas Cooperative Extension Service.

The experimental treatments for this trial included the two rates of CruiserMaxx® (0 and 7 oz/cwt), two rates of preplant applied MicroEssentials fertilizer (MESZ, 0 and 150 lb/acre) and two rates of preflood urea-N (90 and 130 lb urea-N/acre). The MESZ (The Mosaic Company, Plymouth, Minn.) fertilizer is 12% N, 40% P_2O_5, 10% S, and 1% Zn, which resulted in application of 18 lb N, 60 lb P_2O_5, 15 lb S, and 1.5 lb Zn/acre. The MESZ was broadcast by hand after the final seedbed was prepared, but before the rice was drill-seeded. The two preflood urea-N rates were used to simulate suboptimal and near optimal N rates, respectively. Urea was broadcast by hand to a dry soil surface on 26 May (Calloway soil) and 15 June (Calhoun soil) and plots were flood irrigated within 48 hours after application.

Plant samples were collected from each plot at the midtillering stage on 15 and 27 June and at the early heading stage 26 July and 3 August for the Calloway and Calhoun soils, respectively. The whole-aboveground portion of all plants within a 3-ft long section in one of the inside rows was cut 1-in. above the soil surface, placed in labeled paper bags, dried in a forced draft oven, ground to pass a 2-mm sieve, and digested in concentrated HNO_3 and 30% H_2O_2. The nutrient concentrations in the digests were determined by inductively coupled plasma atomic emission spectroscopy. At maturity, plots were trimmed, length was measured, and six (Calloway) or eight (Calhoun) of the nine 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 design with 4 by 2 factorial treatment structure and each treatment was replicated four times. Data were analyzed using a split plot treatment structure where site was the whole plot and treated as a random variable. The subplot factor was the factorial arrangement of CruiserMaxx and fertilizer rate combinations (fixed effects). Analysis of variance was performed using PROC MIXED in SAS v9.1. (SAS Institute, Inc., Cary, N.C.). When appropriate, Fisher's Protected Least Significant Difference method was used to separate means at a significance level of 0.10. Correlation analysis was performed on replicate data to determine whether tissue nutrient concentration or dry matter was the greater contributor to total nutrient uptake.

RESULTS AND DISCUSSION

The CruiserMaxx® by fertilizer rate interaction ($P = 0.2337$) did not significantly influence grain yield or rice dry matter accumulation and tissue P and Zn concentrations at the midtillering or early heading stages, but the main effects of CruiserMaxx® and fertilizer rate were often significant (Table 2). Rice fertilized with 60 lb P_2O_5 (150 lb MESZ) plus 130 lb preflood-N/acre produced the greatest dry matter at midtillering and grain yield compared to the other three fertilizer combinations, and rice receiving no P (MESZ) and 90 lb preflood-N/acre produced the lowest dry matter and grain yield (Table 3). The N (18 lb N/acre), P (60 lb P_2O_5/acre), S (15 lb S/acre) and/or Zn (1.5 lb Zn/acre) content in MESZ increased early heading stage dry matter by 14% to 22% and grain yield by 8% to 10% compared to rice fertilized with no MESZ for the 90 and 130 lb/acre, respectively. Tissue P concentrations were equal between the two N rates for rice receiving like rates of MESZ, but rice fertilized with MESZ had greater P concentrations than rice receiving no MESZ. Rice P concentrations at midtillering were deficient and clearly limited early season growth with these early season growth differences continuing to be expressed until early heading. Rice fertilized with 150 lb MESZ plus 130 lb preflood-N/acre produced the greatest dry matter at midtillering and grain yield compared to the other three fertilizer combinations, and rice receiving no MESZ and 90 lb preflood-N/acre produced the lowest dry matter and grain yield. Midtillering rice Zn concentrations were not different among fertilizer combinations, but showed a clear trend for rice receiving MESZ to contain lower Zn concentrations than rice receiving no MESZ. The observed numerical difference is attributed to a dilution effect from increased growth due in large part to enhanced P availability.

The primary reason for conducting this trial was to evaluate whether CruiserMaxx seed treatment would significantly enhance rice growth, nutrient uptake, and grain yield (Table 4). Rice tissue P and Zn concentrations were not significantly changed by the application of CruiserMaxx, but showed a tendency for both P and Zn to numerically increase in rice that received CruiserMaxx. CruiserMaxx increased rice dry matter by 25% at midtillering, 11% at early heading, and increased grain yield by 6%.

The total aboveground uptake of P, Zn, and other nutrients as affected by the treatments were subjected to ANOVA, but are not summarized in this report. Alternatively, we showed that P and N fertilization and/or CruiserMaxx significantly influenced rice growth and nutrient concentrations, which provides strong evidence that total nutrient uptake was enhanced. The correlation among dry matter, nutrient concentrations, and total aboveground uptake within each growth stage was examined to determine whether nutrient concentration or dry matter had the greater influence on total nutrient uptake. Total P uptake at midtillering was highly and positively correlated with both dry matter ($r = 0.95$) and tissue P concentration ($r = 0.91$). Total Zn uptake at the midtillering stage was due primarily to increased dry matter (0.78) rather than increased tissue Zn concentration ($r = 0.32$). By early heading, increased P and Zn uptake were primarily a function of increased dry matter ($r = 0.82$ and 0.75, respectively) more than changes in tissue concentration ($r = 0.56$ and 0.29, respectively).

SIGNIFICANCE OF FINDINGS

This preliminary research showed positive rice growth and yield increases from applying preplant P, 130 lb preflood urea-N/acre (compared to 90 lb urea-N), and CruiserMaxx seed treatment. Increased growth from sufficient rates of N and P fertilizer were expected because of the typical N requirement for this variety and the low soil test P at the two sites. However, specific reasons why rice growth was increased by CruiserMaxx seed treatment were beyond the scope of this study. The results show promise and warrant further investigation to determine by what mechanism(s) the CruiserMaxx is benefiting rice growth and yield.

LITERATURE CITED

Below, F.E., J.W. Haegele, and M.L. Ruffo. 2010. Mineral nutrition of rootworm resistant corn [On-line]. Available at http://frec.cropsci.illinois.edu/2010/report9/. *In:* Illinois Fertilizer Conference Reports: January 2010. University of Illinois Extension, Urbana-Champaign.

Table 1. Selected soil chemical property means of two research areas at the Pine Tree Research Station used to evaluate the effects of CruiserMaxx and P and N fertilizer rates in 2011.

Site	Soil pH[a]	SOM by WLOI[b]	Mehlich-3 extractable soil nutrients					
			P[c]	K[c]	Ca	Mg	S	Zn
		(%)	----------------	----------------	(ppm)	----------------	----------------	----------------
Calhoun	7.6	3.1	11 (1.5)	99 (7)	1855	310	17	2.0
Calloway	7.1	2.7	10 (<1)	86 (5)	1271	262	9	2.6

[a] Soil pH was measured in a 1:2 soil: water volume mixture.

[b] SOM by WLOI = soil organic matter by weight loss on ignition.

[c] Values in parentheses are the standard deviation of mean soil test P and K values.

Table 2. ANOVA *P*-values summarizing the effect of CruiserMaxx rate (CMR), fertilizer rate (FR), and their interaction on crop dry matter accumulation, tissue P and Zn concentration at the midtillering and early heading stages and grain yield.

Source	Midtillering stage			Early heading stage			Grain yield
	TDM	P	Zn	TDM	P	Zn	
FR	0.0138	0.0167	0.4228	0.0830	0.7482	0.2661	0.0499
CMR	0.0296	0.1750	0.2333	0.0971	0.3810	0.8826	0.0413
FR x CMR	0.2045	0.2739	0.8997	0.3681	0.1568	0.2545	0.2337

Table 3. Rice aboveground dry matter (DM) and tissue P and Zn concentration at the midtillering and early heading stages, and grain yield as affected by preplant P and preflood N fertilizer rate, averaged across CruiserMaxx rates and sites, during 2011.

	Midtillering stage			Early heading stage			
P and N fertilizer rate	DM	P	Zn	DM	P	Zn	Grain yield
(lb P_2O_5 & N/acre)	(lb/acre)	(% P)	(ppm Zn)	(lb/acre)	(% P)	(ppm Zn)	(bu/acre)
0 lb P & 90 lb N	1,570	0.103	30.0	10,016	0.219	36.5	150
60 lb P[a] & 90 lb N	2,241	0.152	25.5	12,165	0.238	33.8	161
0 lb P & 130 lb N	1,704	0.102	31.2	11,345	0.245	41.5	165
60 lb P[a] & 130 lb N	2,556	0.157	27.5	12,964	0.235	37.4	181
LSD0.10	340	0.023	NS[b]	1,675	NS	NS	14

[a] 150 lb of MESZ = 60 lb P_2O_5, 15 lb S, and 1.5 lb Zn.

[b] NS, not significant at $P = 0.10$.

Table 4. Rice aboveground dry matter (DM) and tissue P and Zn concentration at the midtillering and early heading stages, and grain yield as affected by CruiserMaxx rate, averaged across preplant P and preflood N fertilizer rate and sites, during 2011.

	Midtillering stage			Early heading stage			
CruiserMaxx rate	DM	P	Zn	DM	P	Zn	Grain yield
(oz/100 lb seed)	(lb/acre)	(% P)	(ppm Zn)	(lb/acre)	(% P)	(ppm Zn)	(bu/acre)
0	1796	0.126	26.9	11,045	0.241	37.1	160
7	2239	0.131	30.2	12,200	0.227	37.5	169
LSD0.10	130	NS[a]	NS	1,121	NS	NS	3

[a] NS, not significant at $P = 0.10$.

RICE CULTURE

Evaluation of Phosphorus, Potassium, and Zinc Fertilization Strategies for Rice

N.A. Slaton, T.L. Roberts, R.J. Norman, R.E. DeLong,
C.G. Massey, J. Shafer, J. Branson, 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 covered in this report include the evaluation of rice growth and yield response to: 1) phosphorus (P) and potassium (K) fertilizer application time (fall, winter, or spring); 2) different P fertilizer sources, 3) tillage, and P and zinc (Zn) fertilization; and 4) long-term P or K fertilization rate. Grain yields of rice were not affected by P, K, and/or Zn fertilizer source, time of fertilizer application, or application rate. Despite the lack of significant grain yield differences, important information was gleaned from these trials. For example, rice uptake of P and K were not affected by fertilizer application time indicating that fertilizer applications can be applied in the fall without sacrificing nutrient availability on many soils. Growers should also select the P fertilizer source that best fits their production and management goals as research shows little or no consistent difference in rice performance among P fertilizers. Results from these trials also add invaluable data for our long-term goal of improving the accuracy of soil-test based fertilizer recommendations.

INTRODUCTION

Phosphorus (P), potassium (K), and zinc (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. 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 broadcasting 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.

Research has shown 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) P and K fertilizer application time (fall, winter, or spring); 2) different P fertilizer sources; 3) tillage, and P and Zn fertilization; and 4) long-term P or K fertilization rate.

PROCEDURES

Phosphorus and Potassium Fertilization Time

Two trials, one for P and one for K, were established on a soil mapped as a Calloway silt loam at the Pine Tree Research Station (PTRS). A field cropped to soybean in 2010 was tilled and floated in October 2010 to prepare a level seedbed. Adjacent research areas were flagged to define individual plot boundaries (7-ft wide × 25-ft long). In April 2011, composite soil samples were collected (0- to 4-in.) from plots that had received no P or K fertilizer in each trial area. Composite soil samples were analyzed for soil pH (1:2 soil: water mixture), Mehlich-3 extractable soil nutrients, and soil organic matter content (Table 1).

Phosphorus- (as triple superphosphate) and K-fertilizer (as muriate of potash) treatments were broadcast applied to the soil surface at rates of 0, 45, and 90 lb K_2O or P_2O_5/acre on 28 October 2010, 2 March 2011, and 7 April 2011. The K research area received 90 lb P_2O_5/acre and the P research area received 90 lb K_2O/acre as muriate of potash on 7 April 2011. Zinc fertilizer (10 lb Zn/acre as $ZnSO_4$) was broadcast onto the soil surface of each research area. CL151 rice (100 lb/acre, 7.5-in. wide rows) was drill-seeded into an undisturbed (i.e., stale) seedbed on 9 April 2011. Ammonium sulfate (100 lb/acre) was applied on 26 May and urea (260 lb N/acre) was broadcast applied on 1 June 2011 and a 4-in. deep flood was established on 2 June. Rice management with respect to irrigation and weed control was performed following University of Arkansas Cooperative Extension Service guidelines.

Rice plant samples were collected from a 3-ft length of the first inside row at the midtillering (15 June) stage in the P trial and the late boot stage (26 July) in the

K trial to evaluate how time and rate of fertilizer application affected rice uptake of P and K fertilizer, respectively. Plant samples were oven dried to a constant weight, weighed for dry matter accumulation, ground to pass a 2-mm sieve, and a subsample was digested to determine tissue nutrient concentrations. Plant tissue analysis for this trial is not yet complete. 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 design with a 2 (fertilizer rate) × 3 (application month) factorial treatment arrangement compared to a no fertilizer (P or K) control. Each treatment was replicated six times and each replicate contained two no fertilizer control plots. All statistical analyses were performed with the GLM model in SAS v9.1 (SAS Institute, Cary, N.C.) with significant differences interpreted when $P < 0.10$ for yield and nutrient concentration data.

Phosphorus Source Trial

An experiment evaluating different P fertilizers and rates was established on a Calhoun silt loam at the PTRS. Soil sampling and analysis were performed as described previously (Table 1). Individual plots were 6.5-ft wide and 16-ft long. The treatments included 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) broadcast applied at 0, 40, 80 and 120 lb P_2O_5/acre. Treatments were applied to a tilled soil surface immediately before drill-seeding CL151 rice (100 lb/acre) at the PTRS on 10 May. 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-in. deep flood was established within 2 days after N application.

At the midtillering growth stage, whole, aboveground rice plants receiving 0 or 80 lb P_2O_5/acre were cut 1 in. above the soil surface, bagged, oven-dried to a constant weight, weighed, ground to pass a 2-mm sieve, and a subsample was digested for nutrient analysis. Harvest at both sites was performed as previously described.

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) × 3 (P source) factorial treatment structure compared to a no P control (No P and 0 lb P_2O_5/acre). Analysis of variance was performed using PROC GLM in SAS (v9.1, 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 was established on a Calhoun silt loam at the PTRS in a field that was cropped to soybean in 2010. 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 mid-April. On 10 May, Wells rice was planted (100 lb seed/acre) into each strip. No additional tillage was performed on the tilled strip resulting in tillage treatments that are best described as stale seedbed and no-tillage. Immediately before rice was planted three different fertilizer treatments were hand applied to the soil surface with like treatments being in adjacent plots with different tillage. The fertilizer treatments were no P or Zn, 10 lb Zn/acre as Zinc-Gro granular $ZnSO_4$ (35.5% Zn), and 10 lb Zn plus 60 lb P_2O_5/acre as triple superphosphate. Each plot was 7-ft wide and 20-ft long and contained 9 rows of rice with 7.5-in. wide row spacing. At the midtillering growth stage, whole, aboveground rice plants from a 3-ft section of an inside rice row were sampled for dry matter and tissue analysis. Harvest at both sites was performed as previously described.

The experiment was a randomized complete block with a strip-plot structure and 6 blocks. Analysis of variance was conducted using PROC MIXED in SAS (v9.1, 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.

Long-Term Phosphorus and Potassium Fertilization

Trials to evaluate how P and K fertilizer rate affects soil properties and crop yields were established on a Dewitt silt loam at the Rice Research Extension Center (RREC) in 2007. Soil samples (0- to 4-in. depth) are taken annually and extracted with Mehlich-3 to evaluate changes in soil fertility levels. In 2011, soil samples were collected on 22 March. Means of selected soil properties from soil receiving no K fertilizer are listed in Table 1. The P trial received 60 lb K_2O/acre and the K trial received 50 lb P_2O_5/acre. The same rates of K_2O and P_2O_5 (0, 40, 80, 120, and 160 lb/acre) have been applied annually to the same plots since 2007 making 2011 the fifth year of fertilization. The rice variety CL151 was drill-seeded on 16 May into an undisturbed (no-till) seedbed following the 2010 soybean crop. Each plot measured 15 ft-wide and 25-ft long. Urea (120 lb N/acre) was broadcast applied to each trial at the 5-lf stage and flooded within 48 hours. At the midtillering stage, whole, aboveground plant samples were collected from the P trial for the 0 and 80 lb P_2O_5/acre treatments. Samples were processed as described previously for determining dry matter and tissue P concentration. Grain yield was measured by harvesting a swath in the area of each plot.

Each trial was a randomized complete block with each treatment replicated six times. Analysis of variance was performed on soil and plant data collected in 2010 using PROC GLM in SAS (v9.1, SAS Institute, Inc., Cary, N.C.). When appropriate, means were separated using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Phosphorus and Potassium Application Time Trial

Phosphorus application time, averaged across P rates, had no significant influence on rice dry matter accumulation at the midtillering growth stage or grain yield, but did influence rice tissue P concentration and lodging at maturity (Table 2). The concentration of P in rice plants was greater for rice that received P compared to rice that received no P. Among the three P application times, the greatest tissue P concentration was from P applied in October 2010, about 7 months before rice emerged. This agrees with results from a previous trial (Slaton et al., 2010). Lodging was greatest when P was applied in October 2010 and April 2011. Lodging affected the grain yield results by introducing variability from the difficulty of harvesting lodged rice. Phosphorus application rate, averaged across application months, did influence dry matter and tissue P concentration. Rice fertilized with 90 lb P_2O_5/acre had the greatest dry matter (1613 lb/acre, LSD0.10 = 137) and P concentration (0.182% P, LSD0.10 = 0.012) compared to the 45 (1438 lb/acre and 0.156% P) and 0 (1315 lb/acre and 0.123% P) lb P_2O_5/acre rates. The effect of P rate on lodging was not quite significant, but showed a strong trend for rice that received 45 (42%) and 90 (59%) lb P_2O_5/acre fertilizer to lodge more than rice that received no P (20%). Increased lodging from P fertilization has been observed before but usually on slightly acidic soils that produce seedlings with sufficient P concentrations. In contrast, rice in this P trial had what would be considered low (<0.20% P) tissue P concentrations.

Rice growth and yield were not affected by the time or rate of K fertilization (Table 3). Rice dry matter accumulation was very uniform among treatments as indicated by the low coefficient of variation (C.V.). Tissue analysis is not yet complete. Lodging was not as extreme in this trial (compared to the P trial) and averaged from 5% to 20% among individual treatments. Lodging had no influence on dry matter accumulation at early heading and K uptake. Results from these measurements indicate no difference among K application times.

Phosphorus Source by Rate Trial

Rice dry matter and whole plant P concentrations at midtillering were significantly affected by P source, which were applied at 80 lb P_2O_5/acre (Table 4). Dry matter was greatest for rice fertilized with TSP, intermediate for MESZ and MAP and least for rice receiving no P. Tissue P concentration was greatest for rice fertilized with MAP, intermediate for rice receiving TSP and MESZ and least for rice that received no P. Rice grain yield was not affected by P source, P rate (*P* = 0.4164) or their interaction (*P* = 0.1408). Unlike the trials from 2010, P fertilizers that contained N showed no significant and consistent benefit on early season rice growth (Slaton et al., 2011).

Tillage Trial

Rice dry matter and whole-plant Zn concentrations, and grain yield were not significantly affected by fertilizer treatment, tillage or their interaction (Table 5). Plant P concentrations were affected only by fertilizer treatment, averaged across tillage systems. Rice receiving P had greater concentrations than rice receiving no P. There were some non-significant trends for yield, dry matter and tissue Zn concentrations to be numerically higher for rice in the stale-seedbed system.

Long-Term Phosphorus and Potassium Fertilization

Soil test P and K have changed after 4 years of applying different P and K fertilizer rates and rice and soybean production (Table 6). On average, soil test P and K have increased by 1 ppm for every 16.7 lb P_2O_5 (ppm P = 0.0598x + 11.6, $R^2 = 0.99$) and 5.5 lb K_2O/acre (ppm K = 0.1825 + 98, $R^2 = 0.97$) applied. In 4-years, cropping and application of the different annual fertilizer rates have changed soil test P levels from 'Low' (16 to 25 ppm) to levels ranging from 'Very Low' (<16 ppm) to 'Above Optimum' (>50 ppm) and soil test K levels from 'Optimum' (131 to 175 ppm) to soil test levels that now range from 'Medium' (91 to 130 ppm) to 'Above Optimum' (>175 ppm).

Rice receiving 80 lb P_2O_5/acre/year produced more dry matter (1563 lb/acre, LSD0.10 = 356) and had a greater mean whole-plant P concentration (0.453% P, LSD0.10 = 0.022) than rice that received 0 lb P_2O_5/acre/year (1159 lb/acre and 0.393% P). However, the tissue P concentration of rice grown on soil that has received no P fertilizer in 5 years would be considered sufficient (>0.20% P). Despite the changes in soil test P and K levels, rice yields have not yet been affected by the different P and K fertilizer rates (Table 6).

SIGNIFICANCE OF FINDINGS

Rice fertilization experiments conducted in 2011 did not show significant grain yield increases from P, K, and Zn fertilization, but important information can be gleaned from the results. First, soil P and K fertility levels are affected by fertilization across time. Soil nutrient availability index values may decrease when P and K fertilizer are withheld, remain fairly constant when moderate rates are applied, or increase when high fertilizer rates are applied annually. There is no doubt crop growth and yield will be affected in these experiments in the near future. Rice uptake of P and K were not significantly affected by the month of fertilizer application suggesting that P and K can be applied from the fall until planting without influencing crop yield. Although numerous P fertilizers are available to growers, there does not appear to be any consistent differences among these sources indicating that growers should purchase the one that best fits their short- and long-term fertilization goals. Results from 2011 also suggest that growers need to use caution when fertilizing lodging-prone cultivars/hybrids with P, as P had a significant influence on lodging of CL151. Finally, 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 stale-seedbed system providing preliminary 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., R.E. DeLong, R.J. Norman, S.D. Clark, and B.R. Golden. 2010. Rice response to phosphorus and potassium fertilization time. *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 581:197-201. Fayetteville.

Slaton, N.A., R.J. Norman, T.L. Roberts, R.E. DeLong, C.G. Massey, S. Clark, and J. Branson. 2011. Evaluation of new fertilizers and different methods of application for rice production. *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 591:266-277. Fayetteville.

Table 1. Selected soil chemical property means (0- to 4-in. depth, n = 4 to 6) of sites used to evaluate crop response to different fertilization strategies at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

			Mehlich-3 extractable soil nutrients					
Site and crop†	Soil¶ OM	pH	P	K	Ca	Mg	S	Zn
	(%)		-------------[ppm (standard deviation)]--------------					
PTRS-KT	6.8	2.0	7	77 (4)	1276	316	8	1.4
PTRS-PT	6.5	1.9	6 (<1)	95	1029	330	14	1.5
PTRS-PS	2.9	7.3	16 (3)	92	1799	357	16	2.8
PTRS-Till	2.6	8.0	22 (4)	133	2679	330	10	2.4
RREC-K	--	5.1	32	101	670	110	10	5.9
RREC-P	--	5.3	13	117	808	121	8	6.9

¶ OM = organic matter by weight loss on ignition. Soil pH measured in a 1:2 soil:water mixture.

† K = potassium; P = phosphorus; T = timing trial; S = source trial; and Till = tillage trial.

Table 2. The effect of P fertilizer application time, averaged across P rates, on rice dry matter and P and K concentration at midtillering and lodging and grain yield at maturity at the Pine Tree Research Station.

Fertilizer application	Dry matter[¶]	Tissue P	Tissue K	Lodging	Grain yield
(month)	(lb/acre)	----------------------	(%)	----------------------	(bu/acre)
No fertilizer	1,315 a	0.123 c	1.90 a	20 b	187 a
October	1,512 a	0.179 a	2.21a	57 a	173 a
March	1,532 a	0.160 b	2.13 a	67 a	186 a
April	1,532 a	0.167 ab	2.09 a	28 b	181 a
Source			*P*-value		
Month of application	0.9704	0.0527	0.5260	0.0120	0.4385
Rate	0.0250	0.0002	0.7947	0.1023	0.7444
Interaction	0.1593	0.8896	0.3700	0.4077	0.7500
C.V., %	15.3	12.1	12.9	72.8	12.9

[¶] Within each column, means followed by different lowercase letters are different at the 0.10 level.

Table 3. The effect of K fertilizer application time, averaged across K rates, on rice dry matter at early heading, and lodging and grain yield at maturity at the Pine Tree Research Station.

Fertilizer application time	Dry matter[¶]	Lodging	Grain yield
(month)	(lb/acre)	(%)	(bu/acre)
No fertilizer	12,009 a	11 a	215 a
October	12,339 a	18 a	211 a
March	12,556 a	12 a	219 a
April	12,723 a	13 a	214 a
Month of application	0.5612	0.4898	0.3262
Rate	0.4110	0.5020	0.7843
Interaction	0.6474	0.1511	0.5005
C.V., %	7.0	111	6.2

[¶] Within each column, means followed by different lowercase letters are different at the 0.10 level.

Table 4. Rice dry matter, tissue P and Zn, and grain yield means of rice as affected by P fertilizer source (averaged across P rate for yield) at the Pine Tree Research Station in 2011.

Fertilizer[¶]	Dry matter[†]	Tissue P	Tissue Zn	Grain yield
	(lb/acre)	(%)	(ppm)	(bu/acre)
No P	902 b	0.218 c	36.7 a	199 a
MAP	1185 b	0.270 a	35.6 a	196 a
MESZ	1354 ab	0.245 b	37.2 a	199 a
TSP	1700 a	0.255 b	38.6 a	199 a
		(*P*-value)		
P source	0.0933	0.0004	0.3904	0.4921
P rate	--	--	--	0.4164
Interaction	--	--	--	0.1408

[¶] MAP, monoammonium phosphate; MESZ, MicroEssentials; and TSP, triple superphosphate. Dry matter and tissue P 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).

[†] Within each column, means followed by different lowercase letters are different at the 0.10 level.

Table 5. Rice dry matter and tissue P and Zn at midtillering; grain yield means of rice as affected by tillage, averaged across fertilizer treatments; and fertilizer treatment, averaged across tillage treatments, at the Pine Tree Research Station in 2011.

Tillage	Dry matter[¶]	Tissue P	Tissue Zn	Grain yield
	(lb/acre)	(%)	(ppm)	(bu/acre)
No till	776 a	0.182 a	33.1 a	166 a
Stale seedbed	824 a	0.178 a	36.0 a	175 a
P-value	0.4009	0.4568	0.3348	0.1164
Fertilizer[†]				
No P and Zn	726 a	0.173 b	31.4 a	168 a
Zn only	839 a	0.176 b	38.5 a	168 a
Zn + P	835 a	0.190 a	33.7 a	174 a
P-value	0.1956	0.0648	0.2917	0.4624
Interaction *P*-value	0.7513	0.8556	0.5762	0.8661

[¶] Within each column, means followed by different lowercase letters are different at the 0.10 level.

[†] Zn only received 10 lb/Zn acre and Zn + P received 10 lb Zn + 60 lb P_2O_5 /acre.

Table 6. Mehlich-3 soil test P and K means for soil samples collected in March 2011 following soybean and rice grain yield as affected by annual P and K fertilizer rate in a long-term trial at the Rice Research Extension Center.

	P trial		K trial	
Annual rate	Soil test P[¶]	Grain yield	Soil test K	Grain yield
(lb K_2O or P_2O_5/acre)	(ppm P)	(bu/acre)	(ppm K)	(bu/acre)
0	13 e	122 a	101 d	144 a
40	20 d	125 a	128 c	148 a
80	31 c	127 a	155 b	149 a
120	39 b	132 a	172 b	146 a
160	51 a	122 a	225 a	144 a
P-value	<0.0001	0.1755	<0.0001	0.5798

[¶] Within each column, means followed by different lowercase letters are different at the 0.10 level.

RICE CULTURE

Rice and Soybean Response to Selected Humic Acid or Biological Enhancing Soil Amendments

N.A. Slaton, R.J. Norman, T.L. Roberts, R.E. DeLong,
C.G. Massey, J. Shafer, J. Branson, and S.D. Clark

ABSTRACT

Unbiased information is lacking regarding the utility of various organic and biological stimulants that are being marketed for use in row crop production. The research objectives were to evaluate rice growth and/or yield as affected by the application of Hydra-Hume DG (HH), Carbon Boost-S, and Titan-Accomplish. Hydra Hume was applied at a rate of 0, 1, 5, and 10 times the manufacturer recommended rate of 40 lb HH/acre. Carbon-Boost-S and Titan-Accomplish 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 treatments involving HH, Carbon Boost-S, or Titan-Accomplish, 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 soybean grown on undisturbed soils.

INTRODUCTION

Organic amendments and biological stimulants are increasingly being marketed for use in row crop production. Manufacturers often claim, among other things, that their products increase soil microbial activity, crop uptake of soil and/or fertilizer nutrients, decomposition rate of crop residues, and/or increase 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 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.) 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) and Rice Research and Extension Center (RREC) to examine crop growth and yield responses to the application of products that claim to enhance nutrient uptake, yield, or both. One trial with soybean was also established at the PTRS. The soil series at all PTRS research sites was a Calhoun silt loam that was cropped to irrigated soybean in 2010. At the RREC, the soil was a Dewitt silt loam following soybean. The research areas were flagged to define plot boundaries and a composite soil sample (0- to 4-in.) was collected from each replicate of each trial 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. For the rice trial, each plot was 16-ft long and 6.5-ft wide allowing for nine, 7.5-in. wide rows in each plot. Treatments included four HH rates designated as 0, 1, 5, and 10×, which corresponded to 0, 40, 200, and 400 lb HH/acre. The HH label suggests an application rate of 40 lb/acre (1×), which can be considered the standard. Each HH rate was broadcast to the soil surface in combination with two rates (0 and 150 lb) of MESZ fertilizer (12-40-0-10S-1Zn, The Mosaic Company, Plymouth, Minn.) before planting and two rates of urea-N (0 and 100 lb N/acre at the PTRS and 0 and 80 lb N/acre at the RREC) applied preflood on 14 June at both sites. A permanent flood was established 1 or 2 days after preflood N was applied at the 5-lf stage. Different preflood N rates were used at the two locations because the soils require different amounts of N to maximize yield. The 150 lb rate of MESZ fertilizer provided 18 lb N and S, 60 lb P_2O_5, and 1.5 lb Zn. The preplant MESZ and preflood urea-N rates will be referred to as fertilizer rates. The preflood N rates were selected to test whether the HH provided significant N to rice supplied with suboptimal N rates. Following MESZ and HH applications onto a tilled soil surface, the plots were drill-seeded with CL131 rice (100 lb/acre) on 10 May at the PTRS and CL151 rice on 11 May at the RREC. The PTRS research area received 60 lb K_2O/acre before planting. Each plot contained 9 rows of rice with the outside rows of each plot separated by a 1.75-ft wide alley that contained no rice. The rice emergence date was 22 May. 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 on 27 June from an inside row of each plot. Plant samples were placed in paper bags, oven-dried 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 at the PTRS on 3 August 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. Five (RREC) or 8 (PTRS) 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 PROC MIXED in SAS (v9.1, 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.

All experiments with CB and TA were seeded with CL151 rice and were established, maintained and harvested using the same procedures and equipment described for the HH rice trial. Treatments for the CB trial included two preflood N rates (70 and 120 lb urea-N/acre at the PTRS and 46 and 92 lb urea-N/acre at the RREC) and six CB treatments. The CB treatments at the PTRS included: i) no CB, ii) 12 oz CB/acre applied preplant, iii) 12 oz CB preplant followed by (fb) 8 oz CB preflood/acre, iv) 8 oz CB preflood fb 8 oz CB midseason/acre, v) 12 oz CB preplant fb 8 oz CB midseason/acre, and vi) 12 oz CB preplant fb 8 oz CB preflood fb 8 oz CB midseason/acre. At the RREC, the same CB treatments were used, but the midseason CB applications were not applied. Thus, for the RREC, only the first four CB treatments will be reported. Carbon Boost-S is a liquid formulation and, based on manufacturer guidelines, was applied directly to granular fertilizers, which served as the CB carrier. 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, 80 lb K_2O/acre as muriate of potash (PTRS only) preplant, the designated preflood urea-N rate treatment (CB-treated or untreated), and midseason applied at 46 lb urea-N/acre (CB-treated or untreated, PTRS only). The preplant, preflood and midseason fertilizer applications were made on 10 May, 8 June, and 7 July at PTRS, respectively and, 11 May (preplant) and 14 June (preflood) at the RREC. The permanent flood was established on 10 June at PTRS and 16 June at RREC. Plant samples were collected from the first CB treatments, weighed for dry matter accumulation, and processed to determine nutrient concentration only at the PTRS at the midtillering stage (27 June). The ingredients of CB are not well defined, but according to the label, it contains 0.5% Zn derived from 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 treatment was the subplot. Data were analyzed by site as described for the HH trial.

The TA material is a mixture of UAN (3% N) and bacteria (*Bacillus* species). The TA trial treatments included two preflood N rates (80 and 140 lb N/acre at the PTRS and 60 and 120 lb N/acre at the RREC) and six TA treatments. The six TA treatments can be summarized as being applied: i) directly to P (preplant) or K (preflood) fertilizer or ii) applied to soil as a spray/solution using a calibrated, CO_2-pressurized backpack sprayer (no P or K fertilizer) and consisted of a) no TA, b) TA applied preplant only, and c) TA applied preplant and preflood. When fertilizer was the carrier, the TA was spray applied to 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. When TA was spray-applied directly to soil, the rates were 246 (preplant) or 251 (preflood) mL TA/acre. The TA experiment was a RCB design that contained four blocks with a split-plot treatment structure where preflood urea-N was the whole plot and TA treatment was the subplot. Data were analyzed by site as described for the HH trial.

The effect of HH on soybean was also evaluated at the PTRS. The soybean trial was a RCB design that examined the same four HH rates described for the rice trials. Soybean (Armor 48-R40) was planted in 15-in. wide rows on 30 May in plots that were 7-ft wide and 20-ft long allowing for five rows per plot. The HH was broadcast to the surface of a freshly tilled soil on 18 May, triple superphosphate (40 lb P_2O_5/acre) and muriate of potash (60 lb K_2O/acre) were broadcast to the research area. 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 RCB design with six blocks. Analysis of variance was conducted using PROC MIXED in SAS v9.1. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Hydra-Hume DG Trials

In general, the Calhoun soil cropped to rice at PTRS was alkaline, had very low (<16 ppm) to medium (26 to 35 ppm) soil test P, near medium soil test K (90 to 130 ppm), and near medium (2.5 to 4.0 ppm) soil test Zn levels and would have received recommendations for nominal to moderate P, K, and Zn fertilizer rates to maintain soil test levels (Table 1). The Dewitt soil at the RREC was slightly acidic and contained very low (<1.6 ppm) soil test Zn, low (16 to 25 ppm) soil test P, and Optimal (>130 ppm) soil test K levels. Despite below optimum soil P and Zn levels, a positive response to fertilization with these elements was not expected due to the slightly acidic pH.

The two-way interaction between NP fertilizer and HH rates was significant ($P < 0.10$) only for midtillering tissue P concentrations ($P = 0.0565$, data not shown) at the PTRS. The main effect of NP fertilizer rate, averaged across HH rates, had a significant effect on all measurements (Table 2). Rice fertilized with 0 or 60 lb P_2O_5/acre preplant plus 100 lb urea-N/acre preflood generally produced greater dry matter, tissue P and Zn concentrations and grain yield than rice fertilized with no N. The major exception to this occurred at the PTRS for rice receiving 100 lb urea-N/acre preflood, in which case rice fertilized with 60 lb P_2O_5/acre as MESZ produced more dry matter at midtillering and grain yield than rice receiving no P. In contrast to the effect of NP fertilization, the main effect of HH rate, averaged across NP fertilizer rates was significant only for grain yield at the RREC (Table 3). There was no consistent benefit from HH as soil amended with 200 lb HH/acre produced greater yields than all other HH rates, which had similar yields. The main effects shown in Tables 2 and 3 effectively highlight the significant interaction that occurred among midtillering P concentrations at the PTRS. Rice receiving 60 lb P_2O_5 and 100 lb urea-N/acre always had the greatest tissue P concentrations ranging from 0.184 to 0.213% P among HH rates. Among the other NP fertilizer and HH rate combinations, tissue P concentration fluctuated from 0.133% to 0.147% for 10 of the 12 NP fertilizer and HH rate combinations. The two remaining treatments were slightly above or below this range (0.129% P for 0 lb HH + 0 lb P_2O_5 + 0 lb urea-N/acre and 0.153% P for 40 lb HH + 60 lb P_2O_5 + 0 lb urea-N/acre).

Soybean yield was not affected by HH rate ($P = 0.1792$) at the PTRS in 2011. The overall mean yield was 66 bu/acre with treatment means ranging from 64 (200 lb HH/acre) to 69 (40 lb HH/acre) bu/acre.

Carbon Boost-S

Plant samples were collected only at the PTRS site for determination of treatment effects on dry matter and nutrient uptake. Dry matter accumulation at the PTRS was the only growth parameter significantly affected by the preflood N by CB interaction ($P = 0.0560$, data not shown). Significant differences among treatments were related to two treatment combinations, 70 or 120 lb Urea-N/acre plus 12 oz CB preplant + 8 oz CB preflood/acre, that produced the lowest (2512 lb/acre) and highest (3509 lb/acre) dry matter. The fact that the same CB treatment produced the lowest and highest dry matter, albeit with different N rates, suggests the differences are likely due to experimental error rather than true treatment effects. Preflood N rate had the most consistent and greatest influence on rice growth and yield (Table 4). At the PTRS, rice P and Zn concentrations at midtillering and grain yield were 16% to 19% greater for rice fertilized with 120 lb urea-N/acre compared to rice receiving 70 lb urea-N/acre. Carbon Boost-S treatments, averaged across preflood N rates, had no significant influence on rice growth or yield (Table 5).

Titan-Accomplish

Plant samples were collected only at the PTRS site for determination of treatment effects on dry matter and nutrient uptake. The two-way interaction between preflood N rate and TA treatment had no significant influence on rice growth, P and K concentration, or yield. Application of the higher preflood N rate (120 or 140 lb urea-N/acre) increased midtillering stage plant P concentrations at the PTRS by 23%, grain yield at the PTRS by 21%, and grain yield at the RREC by 4% (Table 6). Titan-Accomplish treatments influenced only midtillering tissue K concentrations (Table 7), which was a result of the method of TA application. Rice receiving P and K fertilizer, regardless of the addition of TA, had higher whole plant K concentrations.

SIGNIFICANCE OF FINDINGS

Results of several trials conducted during 2011 suggested that Hydra-Hume DG, Carbon Boost-S, and Titan-Accomplish had no significant and consistent benefit on rice growth and yield. The results suggest that fertilization with proper amounts of N, P, K, and Zn have a greater influence on rice growth and yield. The trials conducted in 2011 with Hydra-Hume DG represent the second year of research on undisturbed soils, and no benefit from Hydra-Hume DG has been measured in either year. 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 from 2011 is not sufficient to conclude that these products 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. Research on these and perhaps other products will continue in future years so that more robust conclusions can be made. 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 farmers avoid products that have not been adequately researched by unbiased entities and prefer that they trust only research conducted and published by the University of Arkansas or another peer institution.

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.

Table 1. Selected soil chemical property means (0- to 4-in. depth, n = 4-6) of sites used to evaluate crop response to Hydra Hume DG (HH), Carbon Boost-S (CB), and Titan Accomplish (TA) on a silt loam soils at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

	Soil¶		Mehlich-3 extractable soil nutrients					
Site & Crop	OM	pH	P	K	Ca	Mg	S	Zn
	(%)		----------	----------	---------- (ppm)	----------	----------	----------
Rice								
PTRS-HH	2.8	7.5	10	102	1811	313	17	2.4
PTRS-CB	3.0	7.2	34	87	1656	311	15	2.6
PTRS-TA	2.8	7.1	24	87	1632	325	14	2.5
RREC-HH	2.2	5.6	21	182	763	137	12	0.5
RREC-CB	2.3	5.6	21	181	740	134	12	0.5
RREC-TA	2.3	5.6	20	176	780	139	12	0.5
Soybean								
PTRS-HH	2.9	7.8	23	89	1986	311	6	2.3

¶ 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, at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

Site	Preplant P_2O_5-N[¶] rates	Preflood N rate	Midtillering dry matter	Midtillering tissue concentration		Heading dry matter	Grain yield
				P	Zn		
	(lb/acre)	(lb/acre)	(%)	---------------(ppm)---------------		(lb/acre)	(bu/acre)
PTRS	0-0	0	1662 c[†]	0.135b	19.4 b	4995 b	54 c
	60-18	0	1685 c	0.144 b	18.6 b	--	50 c
	0-0	100	2332 b	0.144 b	30.7 a	8053 a	75 b
	60-18	100	2741 a	0.195 a	28.9 a	--	94 a
		p-value	<0.0001	<0.0001[§]	<0.0001	0.0027	0.0007
RREC	0-0	0	688 b	0.302 c	30.7 c	--	121 b
	60-18	0	644 b	0.329 bc	31.8 b	--	122 b
	0-0	100	1188 a	0.353 ab	40.3 a	--	168 a
	60-18	100	1064 a	0.384 a	39.5 a	--	173 a
		p-value	<0.0001	0.0539	<0.0001	--	0.0002

[¶] Preplant N and P applied as 150 lb MESZ/acre (MESZ 12-40-0-10S-1Zn).

[†] Means within each column followed by different lowercase letters are different at 0.10.

[§] The NP-Fertilizer × Hydra-Hume DG rate interaction was significant 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, at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

Site	HH rate[¶]	Midtillering dry matter	Midtillering tissue concentration P	Midtillering tissue concentration Zn	Heading dry matter	Grain yield
	(lb/acre)	(lb/acre)	(%)	(ppm)	(lb/acre)	(bu/acre)
PTRS	0	2025 a	0.149 a[†]	24.2 a	6685 a	67 a
	40	1953 a	0.155 a	24.2 a	6476 a	69 a
	200	1937 a	0.157 a	24.4 a	6523 a	71 a
	400	1992 a	0.156 a	24.8 a	6412 a	69 a
	p-value	0.7164	0.3323[§]	0.7977	0.8888	0.4793
RREC	0	886 a	0.349 a	38.0 a	--	144 b
	40	878 a	0.345 a	38.3 a	--	144 b
	200	847 a	0.334 a	36.7 a	--	151 a
	400	973 a	0.339 a	36.5 a	--	146 b
	p-value	0.3913	0.7168	0.4883	--	0.0258

[¶] Hydra-Hume DG rates correspond to 0, 1, 5, and 10× the recommended rate of 40 lb/acre.

[†] Means within each column followed by different lowercase letters are different at 0.10.

[§] The NP-Fertilizer × Hydra-Hume-DG rate interaction was significant 0.0565.

Table 4. 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 (PTRS) and Rice Research Extension Center (RREC) in 2011.

	PTRS trial				RREC
Preflood N rate[¶]	Midtillering dry matter	Midtillering tissue concentration P	Midtillering tissue concentration Zn	Grain yield	Grain yield
(lb urea-N/acre)	(lb/acre)	---------- (%) ----------		(ppm)	(bu/acre)
46 or 70	2843 a[†]	0.289 b	25.8 b	155 b	159 a
92 or 120	3206 a	0.346 a	30.0 a	185 a	164 a
p-value	0.1870 [§]	0.0024	0.0440	0.0020	0.2282

[¶] Preflood urea-N rates differed between sites. Preflood N rates of 70 and 120 lb urea-N/acre were applied at PTRS and rates of 46 and 92 lb urea-N/acre were applied at RREC.

[†] Means within each column followed by different lowercase letters are different at 0.10.

[§] The preflood urea-N rate × Carbon Boost-S treatment interaction was significant 0.0560.

Table 5. Rice dry matter and selected nutrient concentration means of whole aboveground rice plants at the midtillering stage as affected by the main effect Carbon Boost (CB) treatment, averaged across preflood N rates, at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

Carbon Boost Application time[¶]			PTRS Trial				RREC Trial
			Midtillering dry matter	Midtillering tissue concentration			
Preplant	Preflood	Midseason		P	Zn	Grain yield	Grain yield
---------------- (oz CB/acre/application)		--------------	(lb/acre)	(%)	(ppm)	------------(bu/acre)	-----------
0	0	0	2818 a[†]	0.332 a	29.1 a	167 a	161 a
12	0	0	3171 a	0.331 a	29.4 a	167 a	162 a
12	8	0	3010 a	0.308 a	26.5 a	172 a	163 a
0	8	8	3097 a	0.299 a	26.8 a	171 a	159 a
12	0	8	--	--	--	170 a	--
12	8	8	--	--	--	173 a	--
		p-value	0.2343 [§]	0.1438	0.1962	0.6895	0.9543

[¶] Carbon Boost-S impregnated on triple superphoshate 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 different lowercase letters are different at 0.10.

[§] The preflood urea-N rate × Carbon Boost-S treatment interaction was significant 0.0560.

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 (PTRS) and Rice Research Extension Center (RREC) in 2011.

		PTRS trial			
		Midtillering tissue concentration			RREC
Preflood N rate[¶]	Midtillering dry matter	P	K	Grain yield	Grain yield
(lb urea-N/acre)	(lb/acre)	---------- (%) ----------		(ppm)	(bu/acre)
60 to 80	3053 a[†]	0.232 b	2.31 a	145 b	145 b
120 to 140	3336 a	0.286 a	2.23 a	176 a	151 a
P-value	0.1930	0.0126	0.5285	0.0011	0.0881

[¶] Preflood urea-N rates differed between sites. Preflood N rates of 80 and 140 lb urea-N/acre were applied at PTRS and rates of 60 and 120 lb urea-N/acre were applied at RREC.

[†] Means within each column followed by different lowercase letters are 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 Titan Accomplish (TA) treatment, averaged across preflood N rates, at the Pine Tree Research Station (PTRS) and Rice Research Extension Center (RREC) in 2011.

			PTRS trial				RREC trial
Titan Accomplish				Midtillering tissue concentration			
Application method[¶]	Preplant TA rate	Preflood TA rate	Midtillering dry matter	P	K	Grain yield	Grain yield
--------------- (oz TA/acre) ----------			(lb/acre)	------ (%) -------		----------- (bu/acre) ----------	
Spray	0	0	3060 a[†]	0.263 a	1.88 b	158 a	145 a
Spray	8.3	0	3082 a	0.276 a	1.97 b	161 a	149 a
Spray	8.3	8.5	3221 a	0.256 a	1.92 b	162 a	147 a
Fertilizer	0	0	3243 a	0.251 a	2.66 a	162 a	148 a
Fertilizer	8.3	0	3218 a	0.259 a	2.65 a	158 a	147 a
Fertilizer	8.3	8.5	3346 a	0.250 a	2.55 a	163 a	155 a
		p-value	0.6881	0.3253	<0.0001	0.8110	0.5429

[¶] Application 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 different at 0.10.

RICE CULTURE

Rice Response to Nitrogen and Potassium Fertilizer Rates

N.A. Slaton, T.L. Roberts, R.J. Norman,
C.G. Massey, R.E. DeLong, J. Shafer, and S.D. Clark

ABSTRACT

Nitrogen (N) and potassium (K) nutrition are critical for producing high yielding rice on silt loam soils. 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. Trials were established using several N and K rate combinations. Rice growth and yield parameters were measured. On soils that had sufficient K availability, little or no benefit occurred from K fertilization and N was the most growth- and yield-limiting nutrient. However when soil K availability was insufficient and little or no K fertilizer was applied, the benefits from N were limited; or when excessive N was applied, it became detrimental to plant yield. 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 necosis 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

Field trials were established at the Pine Tree Research Station (PTRS) and the Rice Research Extension Center (RREC) during 2011. Results from the RREC trial will not be reported due to very high soil test K (190 ppm) and excessive lodging which contributed to highly variable grain yields. Two trials were established at the PTRS, with each site following soybean in the rotation and both sites were mapped as a Calhoun silt loam. The PTRS-short term (ST) trial was located in a field that had been managed and cropped uniformly in previous years. The long-term K fertilization trial (PTRS-LT) was located in an area that was first established in 2002 and has plots that have since received different rates of K fertilizer (Slaton et al., 2011). Before fertilizer treatments were applied to the PTRS-ST, a composite soil sample (0- to 4-in. 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 early March. Soil samples were dried at 50 °C in a forced-draft oven, crushed, soil water pH was determined in a 1:2 soil weight-water volume mixture by electrode, and subsamples of soil were extracted using the Mehlich-3 method. Elemental concentrations of the Mehlich-3 extracts were determined by inductively coupled plasma spectroscopy. 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.

CL151 rice was drill-seeded on 10 May into an untilled seedbed at PTRS-LT and a conventionally tilled seedbed at the PTRS-ST. Management of rice with respect to stand establishment, pest control, irrigation, and other practices closely followed University of Arkansas Cooperative Extension Service guidelines for direct-seeded, delayed-flood rice production. Each plot was 6.5-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 on the same date, but before rice was seeded. 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) since the trial was initiated. For the PTRS-ST, the K rates were 0, 50, 100, and 150 lb K_2O/acre.

The aforementioned K rates were applied preflood in combination with four urea-N rates. The preflood N rates ranged from insufficient to excessive and were broadcast to the soil surface by hand on 8 June for PTRS-ST and -LT and the tests 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 the first eight blocks of PTRS-LT. Samples were dried 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 nine times. 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 using PROC MIXED in SAS v9.1 (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., 2011). Soil test K ranged from 'Very Low' (<61 ppm) to 'Medium' (91 to 130 ppm) at PTRS-LT (Table 2) and was 'Medium' at the PTRS-ST (Table 1). These soil test levels suggest that grain yields would be different among annual K rates at PTRS-LT and rice growth and yield differences would likely be small and perhaps non-significant among K rates at the PTRS-ST.

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, tissue N concentration, and N uptake at early heading and grain yield were not affected by K fertilizer rate. Tissue K concentration and aboveground K uptake differed among K rates, averaged across N rates. Potassium content and concentration were greatest in rice fertilized with 150 lb K_2O/acre, intermediate for rice receiving 100 lb K_2O/acre, and lowest for rice receiving 0 or 50 lb K_2O/acre. Nitrogen fertilizer rate had the greatest influence on rice growth and yield with N rate causing significant differences in tissue N concentration, N uptake, and grain yield, which tended to increase as N rate increased from 80 to 120 and being maximized by application of 160 and 200 lb N/acre. These results are not surprising since soil test K at this site was very near the critical soil test K.

At the PTRS-LT site, both N rate and K rate influenced rice growth and yield, with the magnitude of differences tending to be greater among the K rates (Table 4). Nitrogen rate, averaged across K rates, had no significant influence on rice K concentration or aboveground content, and annual K rate, averaged across N rates, had no influence on tissue K concentration. For the main effect of annual K rate, dry matter, K concentration, and aboveground N and K content generally increased as K rate increased with each incremental rate increase with maximal values reached for rice receiving 120 or 160 lb K_2O/acre/year. Grain yield was maximized by applying 80 lb K_2O/acre.

Among the applied N rates, maximal values were achieved by application of 120 lb N/acre for dry matter, 200 lb N/acre for tissue N concentration, and 160 lb N/acre for aboveground N uptake (Table 4). Grain yield was maximized by 120 or 160 lb N/acre with lower yields produced when the lower and greater N rates were applied. The N by K rate interaction was significant only for grain yield (data not shown). The interaction showed that when K fertilization was sufficient, applying 120 or 160 lb N/acre produced maximal yields and applying 200 lb N/acre generally produced yields that were intermediate between rice fertilized with 120 or 160 and 80 lb N/acre due primarily to lodging. Rice receiving 200 lb N/acre had >40% lodging in all K rates compared to 0 to 11% lodging in all other treatment combinations. Applying 200 lb N/acre produced the lowest yields when no K was applied, likely due to increased disease incidence and/or severity.

SIGNIFICANCE OF FINDINGS

Results from N by K rate trials during the last 2 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 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. Data from these trials will prove useful in developing further assessment decision aids for examining plant tissue analysis 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 rice 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. Wiley Sciences.

Slaton, N.A., R.E. DeLong, C.G. Massey, J. Shafer, S. Clark, and J. Branson. 2011. 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.

Table 1. Selected soil chemical property means (0- to 4-in. depth, n = 4-9) of sites used to evaluate crop response to nitrogen (N) and potassium (K) fertilization rate in short- (ST) and long-term (LT) trials at the Pine Tree Research Station (PTRS) in 2011.

Site	Soil[a] pH	P	K	Ca	Mg	S	Zn
		[ppm (standard deviation)]					
PTRS-LT	8.1	26	49 (7)	2344	365	7	9.2
PTRS-ST	7.3	23	96 (19)	1728	341	16	2.7

The P–Zn columns fall under the printed spanning header "Mehlich-3 extractable soil nutrients".

[a] OM, organic matter by weight loss on ignition. Soil pH measured in a 1:2 soil:water mixture.

Table 2. Soil test potassium (K) as affected by annual K rate for the last three years in the long-term (LT) trial at the Pine Tree Research Station.

Annual K rate	2009	2010	2011
(lb K_2O/acre/yr)	(ppm K)		
0	66	60	49
40	79	64	57
80	86	69	66
120	107	73	78
160	116	82	94
LSD0.10	10	6	6
P-value	<0.0001	<0.0001	<0.0001
C.V., %	14.4	11.3	11.6

Table 3. Rice dry matter and aboveground potassium (K) and nitrogen (N) 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 rate, in the short-term (ST) trial at the Pine Tree Research Station in 2011.

		Concentration		Total uptake		Grain
K rate	Dry matter	N	K	N	K	yield
(lb K_2O/acre)	(lb/acre)	--------(%)-------		-----(lb/acre) ----		(bu/acre)
0	11,699 a	1.76 a	1.57 c	206 a	184 c	183 a
50	11,234 a	1.81 a	1.62 c	203 a	183 c	183 a
100	11,852 a	1.73 a	1.74 b	204 a	207 b	183 a
150	11,892 a	1.80 a	1.91 a	215 a	227 a	187 a
P-value	0.2247	0.3592	~0.0001	0.4860	0.0001	0.7255
(lb N/acre)						
80	11,446 a	1.36 c	1.70 a	157 d	195 a	153 c
120	11,516 a	1.74 b	1.71 a	200 c	197 a	188 b
160	11,762 a	1.94 a	1.70 a	227 b	203 a	196 ab
200	11,953 a	2.05 a	1.57 a	245 a	204 a	198 a
P-value	0.6901	<0.0001	0.9745	<0.0001	0.6561	<0.0001
P-value (interaction)	0.3812	0.9293	0.3982	0.5512	0.7146	0.7076

Table 4. Rice dry matter and aboveground potassium (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 rate, in the long-term trial at the Pine Tree Research Station in 2011.

		Concentration		Total uptake		Grain
K or N rate	Dry matter	N	K	N	K	yield
(lb K_2O/acre)	(lb/acre)	--------(%)-------		-----(lb/acre) ----		(bu/acre)
0	8,890 c	1.84 a	0.76 e	165 c	68 e	141 c
40	9,913 b	1.80 a	1.14 d	180 b	114 d	154 b
80	10,077 ab	1.76 a	1.46 c	178 b	147 c	161 ab
120	10,535 a	1.83 a	1.86 b	195 a	196 b	160 ab
160	10,433 a	1.78 a	2.05 a	187 ab	214 a	164 a
P-value	<0.0001	0.4151	0.0001	0.0013	<0.0001	<0.0001
(lb N/acre)						
80	9,653b	1.56 d	1.48 a	150c	144 a	142 c
120	10,000 a	1.73 c	1.43 a	174 b	145 a	161 a
160	10,242 a	1.93 b	1.47 a	198 a	154 a	165 a
200	10,073 a	1.99 a	1.44 a	201 a	148 a	155 b
P-value	0.0192	0.0001	0.4869	<0.0001	0.1937	<0.0001
P-value (interaction)	0.7780	0.1544	0.8028	0.6565	0.6684	0.0372

RICE QUALITY AND PROCESSING

Comparison of Milling Characteristics of Hybrid and Pureline Rice Cultivars

S.B. Lanning and T.J. Siebenmorgen

ABSTRACT

Milling characteristics of two long-grain pureline and four long-grain hybrid cultivars were compared. Rough rice samples of each cultivar were conditioned to 12.5% moisture content (MC), and subsamples of four cultivars were conditioned to 10.5%, 11.5%, and 13.5% MC in order to evaluate the effect of MC at time of milling. Samples were milled for durations of 10, 20, 30, and 40 s. Hybrids generally reached a target surface lipid content (SLC) in shorter durations than purelines, and the color of hybrid head rice was generally whiter than pureline head rice after milling for any duration. The rate of change in head rice yield (HRY) per unit change in SLC varied among cultivars. Rice milled at greater MC exhibited lesser SLC and greater rates of change in HRY with respect to SLC than rice milled at lesser MC. The findings indicate definite differences in milling behavior between hybrids and purelines, and demonstrate a need to consider SLC in order to equitably compare milling performance and functional properties of rice cultivars.

INTRODUCTION

Degree of milling (DOM) is often expressed as surface lipid content (SLC) and is indicative of the amount of bran remaining on kernels after the milling process. As such, DOM affects rice quality indices and processing characteristics, including head rice yield (HRY) (Cooper and Siebenmorgen, 2007), cooked rice texture (Saleh and Meullenet, 2007), and flour pasting parameters (Perdon et al., 2001).

Milling performance of rice varies due to inherently different physical and chemical properties among cultivars, as well as extrinsic factors such as pre-harvest conditions and post-harvest drying and storage treatments. Siebenmorgen et al. (2006) showed that SLC levels of two long-grain hybrids were less than those of four long-grain pureline cultivars across several milling durations. Different milling characteristics among hybrid and pureline cultivars may result in different DOM levels, producing HRY and processing inconsistencies. Because of the importance of HRY in determining rice economic value, and the importance of DOM in end-use functionality, the rate at which DOM changes in relation to HRY is critical. This study was undertaken to compare the milling characteristics of several current hybrid and pureline rice cultivars over a range of milling MCs.

PROCEDURES

Pureline cultivars Wells and Francis were harvested near Stuttgart, Ark., in 2008 at harvest moisture contents (HMC)[1] of 17.2% and 14.0%, respectively. Also in 2008, hybrid cultivars XL723, Clearfield (CL) XL729, CL XL730, and CL XL745 were harvested near Jonesboro, Ark., at HMCs of 13.4%, 13.9%, 13.7%, and 13.2%, respectively. 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.) maintained at 21 °C and 62% relative humidity (RH) to a MC of approximately 12.5%.

To evaluate the effect of rough rice MC on milling quality, subsamples of Wells, Francis, CL XL729, and CL XL745 were conditioned to MCs of approximately 10.5%, 11.5%, and 13.5%, using the aforementioned chamber, maintained at 21 °C and 44.5%, 53.5%, and 70.0% RHs, respectively. Rough rice MCs were measured by drying 15-g samples in triplicate at 130 °C for 24 h in a convection oven (1370FM, Sheldon Manufacturing, Inc., Cornelius, Ore.).

For each milling test, a 150-g rough rice sample was dehulled in a laboratory sheller (THU, Satake, Tokyo, Japan). The resultant brown rice was milled for 10, 20, 30, or 40 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas) to achieve varying DOM levels. Head rice was separated from brokens using a sizing device (Seedburo Equipment Co., Chicago, Ill.). Head rice yield was expressed as the mass percentage of rough rice remaining as head rice. Three milling repetitions were performed for each cultivar/MC/milling duration treatment.

Surface lipid content of head rice was measured using a diode array analyzer (DA7200, Perten Instruments, Huddinge, Sweden). Each 60-g sample of head rice was placed into a 75-mm diameter sample cup, which rotated during the diode array analysis. Absorbance readings were collected over a near-infrared wavelength range of 950 to 1650 nanometers, at five-nanometer increments. Surface lipid content was predicted using the calibration of Saleh et al., 2008. Three scans were collected from each sample and average SLC values were calculated.

---

[1] All moisture contents are expressed on a wet basis unless otherwise noted.

The *L** (whiteness) color index of head rice was measured with a color meter (Colorflex EZ, Hunterlab, Reston, Va.). Thirty-five grams of rice were placed in a 6-cm diameter glass sample cup. After the first color reading, the sample cup was rotated 90° and a second measurement was performed. An average of the two readings was recorded for each sample.

Statistical software (JMP release 8.0, SAS institute, Cary, N.C.) was used to perform analysis of variance using least significant differences (LSD), at a 5% level of probability, to determine the significance of the differences observed between HRY vs. SLC slopes.

RESULTS AND DISSCUSION

Fig. 1 illustrates SLC vs. milling duration curves of hybrid and pureline cultivars milled at a MC of approximately 12.5% for 10, 20, 30, and 40 s. For all cultivars, SLC decreased exponentially as milling duration increased. Hybrids generally had lower SLCs than purelines when milled for a given duration. Achieving a target SLC required a shorter milling duration for hybrids than purelines. The findings suggest a need to control milling duration with respect to a desired SLC in order to equitably compare HRYs of different cultivars, and, assuming that milling behavior in the McGill #2 mill extends to commercial mills, have implications to mill personnel in terms of greater throughput of hybrids over some purelines.

Fig. 2 shows HRY vs. SLC relationships for cultivars milled at a MC of approximately 12.5% for 10, 20, 30, and 40 s. Head rice yield was linearly and directly correlated with SLC. Slopes of the regression lines, indicating the rate of change in HRY per unit change in SLC, are presented in Table 1. The average slope across all cultivars at a milling MC of 12.5% was 10.7, slightly lower than that observed by Pereira et al. (2008), who found that long-grain cultivars averaged a change of 11.3 percentage points (pp) in HRY for every 1.0 pp change in SLC. These differences in slope again suggest that different milling characteristics among cultivars can significantly impact HRY.

Head rice became significantly ($\alpha = 0.05$) whiter as milling duration increased (Fig. 3). The color of hybrid head rice was whiter than pureline Wells head rice when milled for any duration. These results correspond to SLC trends (Fig. 1), indicating a greater degree of bran removal or inherently whiter endosperm. Color values began to plateau with increasing milling duration (Fig. 3), suggesting that over-milling may compromise yield with diminishing gains in color quality.

Rough rice MC at the time of milling had a significant effect on milling performance. Fig. 4 shows plots of head rice SLC for Wells and CL XL729, milled at rough rice MCs of 10.5%, 11.5%, 12.5%, and 13.5% for 10, 20, 30, and 40 s. Generally, at any milling duration, as the rice MC increased, SLC decreased, indicating a more well-milled condition. This suggests that bran is more easily removed at greater MCs.

Samples milled at greater MCs had greater rates of change in HRY with respect to change in SLC (Table 1). The trends in HRY vs. SLC regression slopes of Wells and CL XL729 cultivars milled at four MCs for 10, 20, 30, and 40 s are shown in Fig. 5.

Increases in slopes were most significant at or above 12.5% MC across all cultivars (data not shown for Francis and CL XL745). These trends again suggest that bran is more easily removed as MC increases.

Kohlwey (1992) speculated that bran removal is facilitated by a micro-scale gelatinization of starch at the surface of the endosperm due to increased temperature of friction in the milling process. Greater MC results in decreased starch gelatinization temperature, which may allow greater ease of bran removal, as well as more endosperm entering the bran stream.

SIGNIFICANCE OF FINDINGS

Results of this study showed that hybrids generally exhibited greater DOM, as evidenced by lesser SLC and greater *L** values, for any given milling duration. Moisture content of rough rice at the time of milling influenced milling performance. Rough rice milled at greater MCs demonstrated a greater rate of change in HRY with respect to SLC than did rice milled at lesser MCs. Due to these differences, SLC should always be considered and measured in order to better compare HRY and subsequent measurements of functional properties that are affected by degree of milling, particularly between hybrid and pureline 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 their financial support.

LITERATURE CITED

Cooper, N.T.W. and T.J. Siebenmorgen. 2007. Correcting head rice yield for surface lipid content (degree of milling) variation. Cereal Chem. 84:88-91.

Kohlwey, D.E. 1992. The quest for the whole grain in rice milling. Cereal Foods World 37:633-639.

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. 78:205-209.

Pereira, T., N. Cooper, and T.J. Siebenmorgen. 2008. Effects of storage temperature and duration on the milling properties of rice. Discovery 9:64-74.

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. 84:119-124.

Saleh, M. I., J.F. Meullenet, and T.J. Siebenmorgen. 2008. Development and validation of prediction models for rice surface lipid content and color parameters using near-infrared spectroscopy: A basis for predicting rice degree of milling. Cereal Chem. 85:787-791.

Siebenmorgen, T.J., A.L. Matsler, and C.F. Earp. 2006. Milling characteristics of rice cultivars and hybrids. Cereal Chem. 83:169-172.

Table 1. Slopes, intercepts and coefficients of determination (R^2) of linear regression lines relating head rice yield to head rice surface lipid content of pureline (Wells and Francis) and hybrid (XL723, CL XL729, CL XL730, and CL XL745) rice cultivars milled at target rough rice moisture contents of 10.5%, 11.5%, 12.5%, and 13.5% for 10, 20, 30, and 40 s in a laboratory mill.

	Rough rice moisture content			Head rice yield vs. head rice surface lipid content	
		Milling			
Cultivar	Harvest	Target	Actual	Slope[§]	R^2
	------------------- (% w.b.) ------------------				
Purelines					
Wells	17.2	10.5	10.7	$8.3^{b,B}$	0.97
		11.5	11.5	$8.3^{b,A}$	0.88
		12.5	12.6	$10.7^{a,BC}$	0.93
		13.5	13.4	$12.7^{a,B}$	0.88
Francis	14.0	10.5	10.6	$8.1^{b,B}$	0.96
		11.5	11.6	$7.3^{b,A}$	0.85
		12.5	12.5	$8.5^{b,D}$	0.94
		13.5	13.4	$17.1^{a,A}$	0.93
Hybrids					
XL723	13.4	12.5	12.5	12.3^{B}	0.96
CL XL729	13.9	10.5	10.6	$7.0^{b,B}$	0.96
		11.5	11.4	$6.9^{b,A}$	0.93
		12.5	12.4	$8.6^{b,D}$	0.97
		13.5	13.4	$13.0^{a,B}$	0.93
CL XL730	13.7	12.5	12.6	9.5^{CD}	0.89
CL XL745	13.2	10.5	10.8	$10.2^{c,A}$	0.93
		11.5	11.3	$7.2^{d,A}$	0.93
		12.5	12.7	$14.4^{b,A}$	0.94
		13.5	13.5	$19.0^{a,A}$	0.93

[§] Lowercase letters represent significant differences in slope among moisture content lots within a cultivar; uppercase letters represent significant differences in slope between cultivars at a given target moisture content.

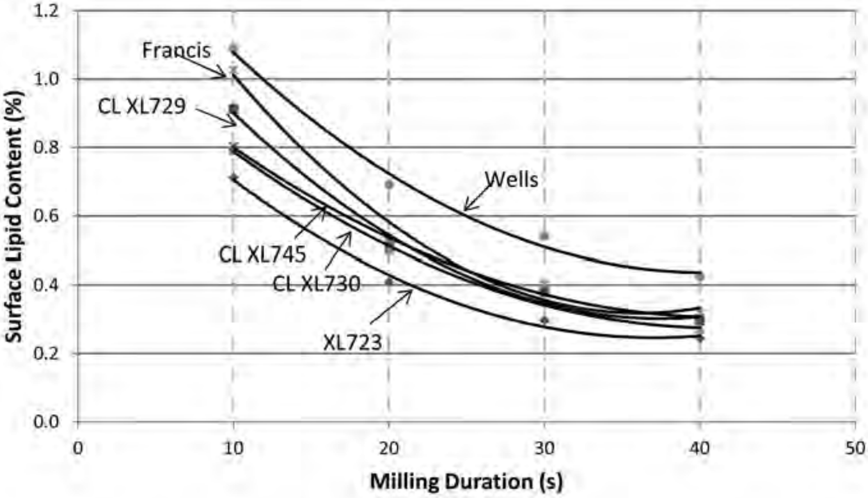


Fig. 1. Head rice surface lipid content of Wells, Francis, XL723, CL XL729, CL XL730, and CL XL745 cultivars after milling at a rough rice moisture content of approximately 12.5% (w.b.) for 10, 20, 30, and 40 s using a laboratory mill. Each data point represents the average surface lipid content measured from three replications of each milling duration.

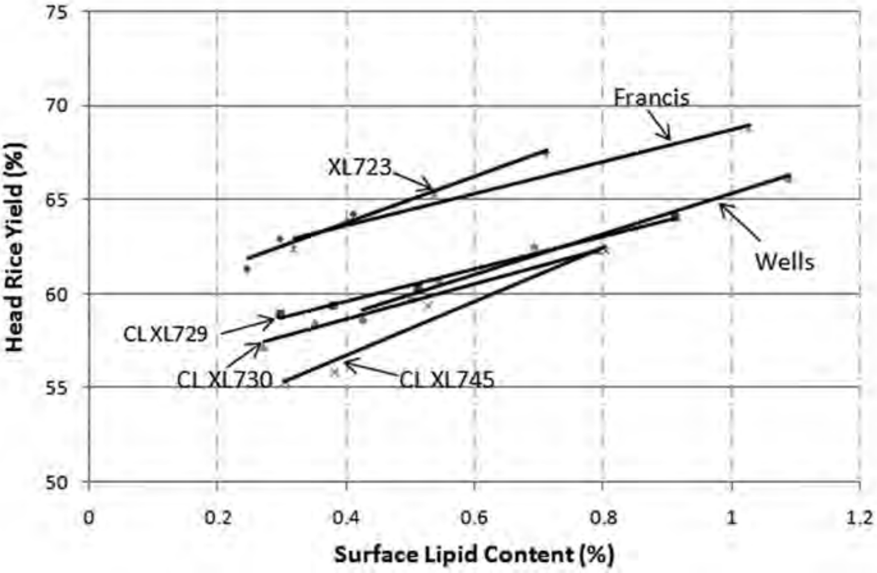


Fig. 2. Head rice yield vs. head rice surface lipid content of Wells, Francis, XL723, CL XL729, CL XL730, and CL XL745 cultivars milled at a rough rice moisture content of approximately 12.5% (w.b.) for 10, 20, 30, and 40 s using a laboratory mill. Each data point represents the average of three milling replications.

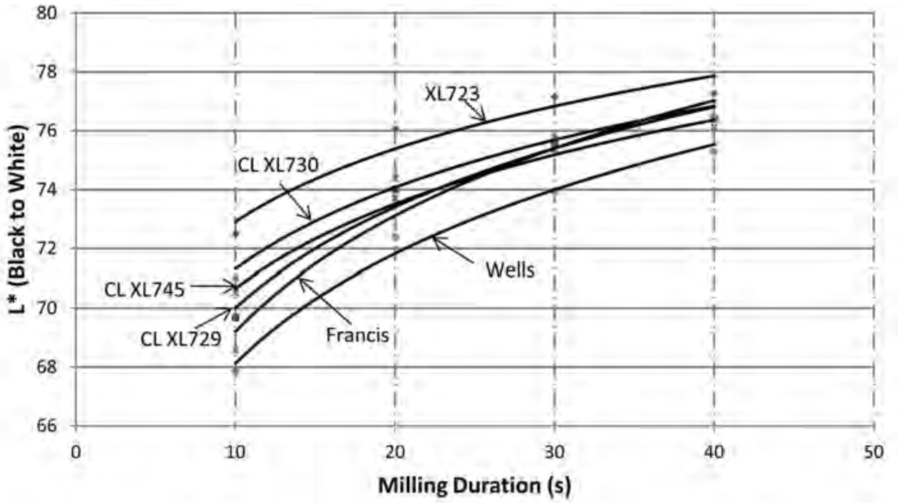


Fig. 3. Head rice color of Wells, Francis, XL723, CL XL729, CL XL730, and CL XL745 cultivars milled at a rough rice moisture content of approximately 12.5% (w.b.) for 10, 20, 30, and 40 s using a laboratory mill. Greater L* values represent greater whiteness. Each data point represents the average L* value from three replications of each milling duration.

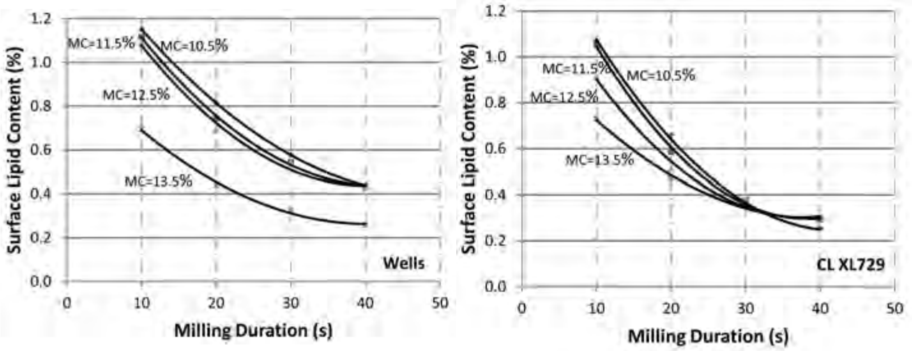


Fig. 4. Head rice surface lipid contents of Wells and CL XL729 cultivars after milling at rough rice moisture contents of approximately 10.5%, 11.5%, 12.5%, and 13.5% (w.b.) for 10, 20, 30, and 40 s using a laboratory mill. Each data point represents an average surface lipid content measured from three replications of each milling duration.

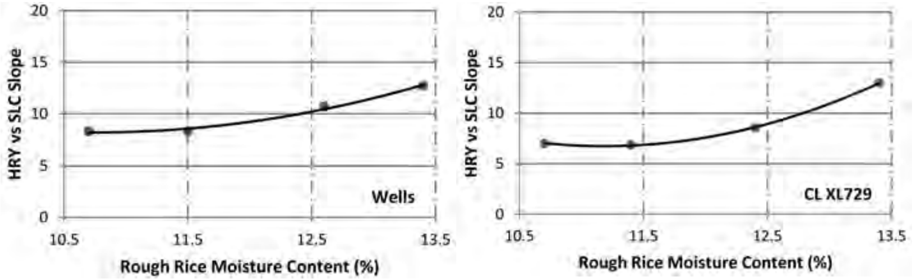


Fig. 5. Head rice yield (HRY) vs. surface lipid content (SLC) regression line slopes of Wells and CL XL729 cultivars milled at rough rice moisture contents of approximately 10.5%, 11.5%, 12.5%, and 13.5% (w.b.) for 10, 20, 30, and 40 s using a laboratory mill. Each data point represents the average slope calculated from each of three milling replications.

Effects of Nighttime Air Temperature During Kernel Development on Rice Physicochemical and Functional Properties

S.B. Lanning, T.J. Siebenmorgen, A.A. Ambardekar, P.C. Counce, and R.J. Bryant

ABSTRACT

Elevated nighttime air temperature (NTAT) during critical grain-filling stages affected rice physicochemical properties, which impacted functional quality. Six cultivars were grown at multiple field locations from northern to southern Arkansas during 2007 to 2010. Nighttime temperatures were recorded throughout production at each of the locations. Amylose and crude protein decreased linearly while total lipid content increased linearly as NTATs increased. Gelatinization temperatures and peak viscosities increased linearly as NTAT increased. The R-stages in which correlations were strongest varied by cultivar and by property, possibly due to differences in kernel development patterns among cultivars. These NTAT effects on physicochemical and functional properties may help explain rice quality variation.

INTRODUCTION

Recent studies in controlled-temperature and field-scale environments have established that elevated nighttime air temperatures (NTATs) occurring during critical grain-filling stages affect rice kernel development, resulting in reduced yield, increased chalk, and reduced milling quality (Ambardekar et al., 2011; Lanning et al., 2011; Cooper et al., 2006; Cooper et al., 2008; Peng et al., 2004). Other studies have shown that the physicochemical makeup of rice is affected by elevated NTAT, including decreased amylose content (AC) (Cooper et al., 2008; Counce et al., 2005; Aboubacar et al., 2006), changes in free amino acid content (Tamaki et al., 1989), and increased lipid content (Cooper et al., 2008).

Limited research has evaluated NTAT effects on rice functional properties. Gelatinization temperature (GT), which is correlated to cooking duration and texture of cooked rice (Maningat and Juliano, 1980), was reported by Aboubacar et al., 2006 to be greater in cultivars grown at an average night temperature of 24 °C during the grain-filling period, compared to 19 °C. Paste viscosity is also affected, as demonstrated by greater peak viscosities (PV) observed in samples grown at higher temperatures than those grown at lower temperatures (Lisle et al., 2000; Dang and Copeland, 2004). The current study objective was to further quantify the effects of elevated NTATs during specific grain-filling stages on rice physicochemical and functional properties at the field-scale level.

PROCEDURES

Six cultivars, (Bengal, Jupiter, LaGrue, Cypress, Wells, and XL723) were grown in triplicate plots at the locations shown in Table 1 each year from 2007 to 2010 as part of the Arkansas Rice Performance Trials (ARPT) system. Reproductive (R) growth stages (Counce et al., 2000) were either visually identified or estimated from weather data, as described by Ambardekar et al. (2011). Annual temperature differences were quantified in the calculation of 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 physicochemical and functional properties that were observed for each year/location/cultivar combination (Figs. 1 and 2).

In each study year and location, samples 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% moisture contents (MC)[1].

Total lipid content (TLC) was measured on 2007, 2009, and 2010 samples. Rough rice (100 g) from each sample was de-hulled in a laboratory sheller (THU, Satake, Tokyo, Japan). A sample mill (3010-30, Udy, Fort Collins, Colo.) fitted with a 0.5 mm screen was used to grind the resulting brown rice into flour. Brown rice TLC was determined in duplicate using a lipid extraction system (Avanti 2055, Foss North America, Eden Prairie, Minn.) according to AACC method 30-20 (AACC International, 2009), with modifications to the petroleum ether washing duration (Matsler and Siebenmorgen, 2005).

Crude protein contents (CPC) of brown rice flour samples (prepared as described above) from the 2008, 2009, and 2010 seasons were measured. A nitrogen analyzer (FP-2000, Leco, St. Joseph, Mich.) was used to measure nitrogen content of each ground sample (single assay) as described in AACC Approved Method 46-30 (AACC International, 2009).

---

[1] Moisture contents are expressed on a wet basis, unless otherwise specified.

Head rice PV for samples in each of the four years was determined. Rough rice (150 g) was dehulled and the resultant brown rice was milled for 30 s in a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Texas). Head rice was separated from broken kernels with a sizing device (Seedburo Equipment Co., Chicago, Ill.). Duplicate 20-g samples of head rice were ground into flour using the sample mill described above, fitted with a 0.5 mm screen. Peak viscosity was determined with a viscometer (RVA Super 4, Newport Scientific, Warriewood, N.S.W., Australia), according to AACC method 61-02.01 (AACC International, 2009).

Apparent AC of head rice flour from lots of Bengal, Cypress, LaGrue, and XL723, harvested in 2009 and 2010, was determined. Samples were prepared as described for PV, except that a 0.25 mm mill screen was used. Amylose concentration was determined by the method of Williams et al. (1958), adapted for use with an automatic analyzer (AutoAnalyzer 3, Seal Analytical, Inc., Mequon, Wis.) using a wavelength of 620 nm (Juliano, 1971).

The head rice flour samples prepared for AC measurement were also used to measure GT_{onset}, using a differential scanning calorimeter (DSC) (Pyris-1, Perkin Elmer Inc., Norwalk, Conn.). The DSC was programmed to heat each sample from 25 °C to 120 °C at a rate of 10 °C/min. Onset temperature was determined from a DSC thermogram generated by the instrument's software (Pyris series ver. 9.1, Perkin Elmer Inc., Norwalk, Conn.).

Coefficients of determination (R^2) were determined by analysis of variance at $\alpha = 0.05$ using polynomial regression analysis (JMP release 8.2, SAS Institute, Cary, N.C.). Correlation coefficients (r-values) between AC, CPC, TLC, PV, and GT_{onset}, and corresponding NT_{95} during an R-stage for each year/cultivar/location combination were determined by multivariate analysis.

RESULTS AND DISCUSSION

Nighttime Air Temperature Effects on Proximate Components

Table 2 shows correlation coefficients calculated to establish relationships between NT_{95} occurring during the R6, R7, and R8 stages, and AC, CPC, and TLC of all cultivars grown from 2007 to 2010. For each proximate component, the R-stages during which the strongest correlations with NT_{95} were observed varied among cultivars. Elevated NTATs during any one or all of these critical grain-filling stages may disrupt the starch-packing and sucrose-conversion processes. Differences in R-stage-specific correlations among cultivars indicate non-homogeneous development of kernels on a panicle from one cultivar to another. Ambardekar et al. (2011), who observed increasingly strong correlations of chalk formation with NT_{95} from R6 to R8, reported that, according to the staging system employed, a plant classified in R8 exhibited a large number of kernels still in R6 or R7, and thereby reasoned that NTATs were actually affecting the metabolic processes occurring in these early grain-filling stages.

Overall, negative correlations of AC with NT_{95} were highly significant across all tested cultivars and R-stages (Table 2). Fig. 1a illustrates decreasing AC with increasing NT_{95} during the R8 stage. Although not significantly different, the trends in slopes of Bengal (-0.82) and Cypress (-0.60) compared to LaGrue (-0.42) and XL723 (-0.44) indicate faster declines in AC with each unit temperature increase.

A decrease in protein was generally observed with increasing NTAT for all cultivars except Cypress, which did not exhibit a significant correlation in any R-stage, suggesting that it is least susceptible to the effects of NTAT on protein. Hybrid cultivar XL723 was the only cultivar to show greater correlation in the R6 stage than in R7 or R8 (Table 2). Fig. 1b illustrates the decrease of CPC as a result of increased NT_{95} during the R8 stage. These findings contradict those of Fitzgerald and Resurreccion (2009), who observed an increased proportion of protein with elevated temperature, relative to total kernel mass. Lin et al. (2010) found no significant difference in CPC due to NTAT, but did report that prolamin and globulin components decreased in response to increasing NTAT, suggesting that cultivar susceptibility may be due to varying ratios and sensitivities of different protein constituents.

Correlations between NTAT and TLC were positive and significant for all cultivars and tested R-stages (Table 2), indicating that TLC increased as NTAT increased. Fig. 1c shows the effect of NTAT on TLC during the R8 stage of the indicated cultivars. The regression slope of Bengal was less steep than others, suggesting lower susceptibility to NTAT effects on TLC.

Nighttime Air Temperature Effects on Functional Properties

Positive correlation coefficients (Table 2) across all cultivars indicated that PV increased with increasing NTATs. Medium-grain cultivars generally exhibited weaker correlations of PV versus NT_{95} than long-grain cultivars, such that PV in Bengal was significantly correlated ($r = 0.57$) to NT_{95} only during the R7 stage. Among long-grain cultivars, correlations between PV and NT_{95} varied in terms of which R-stage resulted in the strongest correlation. Again, variations in cultivar kernel development patterns may be responsible for this variation in R-stage correlation. Fig. 2a illustrates the effect of NTATs occurring during the R8 stage on PV. Regression slopes representing PV versus NT_{95} for all cultivars were similar within this particular R-stage, on average indicating a change in viscosity of 9.3 RVU for each unit increase in NT_{95}. Individually, Cypress was most susceptible to changes in PV, while XL723 was least susceptible.

Positive correlations of GT_{onset} with NT_{95} (Table 2) indicate increasing GTs with increasing NTATs during the critical grain-filling stages. Again, the R-stage in which the strongest correlations occurred varied. Fig. 2b shows the increase in GTs with increasing NTATs for the indicated cultivars during their respective R8 stages. As expected, medium-grain Bengal exhibited a lower GT than the long-grain cultivars tested, due to its lesser AC; however, the rate of increase in GT_{onset} per unit increase in NT_{95} was not significantly different among cultivars. The average rate of increase across all cultivars was 0.5, indicating that GT increased by 0.5 °C with every unit increase in NT_{95}. Similar observations were made by Suzuki et al. (2003), who reported that lower environmental temperatures significantly decreased onset, peak, and conclusion GTs, as well as gelatinization enthalpies, of four rice cultivars with varying ACs. Since increased GT results in greater temperature requirements to gelatinize starch, exposure to elevated NTATs has significant implications on end-use processing operations.

SIGNIFICANCE OF FINDINGS

Physicochemical and functional properties were strongly correlated with NTATs that occurred during different reproductive stages. Susceptibility to NTAT varied among cultivars, suggesting that in commercial applications, where rice lots are blended from a variety of cultivars, growing locations, and harvest dates, the degree of variation may result in inconsistent finished-product quality. The findings of this four-year study offer a possible explanation for the inexplicable variation in quality that often plagues end-use processors.

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

AACC International. 2009. Approved Methods of the American Association of Cereal Chemists, 11th ed. Methods 30-20, 46-30, and 61-02.01. The Association: St. Paul, Minn.

Aboubacar, A., K. Moldenhauer, A.M. McClung, D.H. Beighley, and B.R. Hamaker. 2006. Effect of growth location in the United States on amylose content, amylopectin fine structure, and thermal properties of starches of long grain rice cultivars. Cereal Chem. 83:93-98.

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 and rice milling quality. Field Crops Res. 122:179-185.

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. 85:276-282.

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

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

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.

Dang, J.M.-C. and L. Copeland. 2004. Genotype and environmental influences on pasting properties of rice flour. Cereal Chem. 81:486-489.

Fitzgerald, M.A. and A.P. Resurreccion. 2009. Maintaining the yield of edible rice in a warming world. Funct. Plant Biol. 36:1037-1045.

Juliano, B.O. 1971. A simplified assay for milled-rice amylose. Cereal Sci. Today. 16:334-340, 360.

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. 124:132-136.

Lin, C.-J., C.-Y. Li, S.-K. Lin, F.-H. Yang, J.-J. Huang, Y.-H. Liu, and H.-S. Lur. 2010. Influence of high temperature during grain filling on the accumulation of storage proteins and grain quality in rice (*Oryza sativa* L.). J. Agric Food Chem. 58:10545-10552.

Lisle, A.J., M. Martin, and M.A. Fitzgerald. 2000. Chalky and translucent rice grains differ in starch composition and structure and cooking properties. Cereal Chem. 77:627-632.

Maningat, C.C. and B.O. Juliano. 1980. Starch lipids and their effect on rice properties. Starch - Stärke. 32:76-82.

Matsler, A.L. and T.J. Siebenmorgen. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a Soxtec system. Cereal Chem. 82:282-286.

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 with higher night temperature from global warming. Proc. Nat. Acad. Sci. 101:9971-9975.

Suzuki, Y., Y. Sano, T. Ishikawa, T. Sasaki, U. Matsukura, and H.-Y. Hirano. 2003. Starch characteristics of the rice mutant du2-2 Taichung 65 highly affected by environmental temperatures during seed development. Cereal Chem. 80:184-187.

Tamaki, M., M. Ebata, T. Tashiro, and M. Ishikawa. 1989. Physio-ecological studies on quality formation of rice kernel. Jap. J. Crop Sci. 58:695-703.

Williams, V.R., W.-T. Wu, H.Y. Tsai, and H.G. Bates. 1958. Varietal differences in amylose content of rice starch. Ag. and Food Chem. 4:47-48.

Table 1. Average nighttime air temperatures (NTATs) recorded throughout the R6 to R8 stages of rice reproductive development during harvest years 2007 to 2010 for each cultivar at each growing location.

		Average NTAT[a] (°C)							
Year	Location	Bengal	Jupiter	Cypress	LaGrue	Wells	XL723	Cultivar Avg NTAT	Cult/loc Avg NTAT
2007	Corning	23.9	23.7	24.5	24.6	23.4	23.6	23.9	23.7
	Newport	22.9	22.8	22.8	23.0	22.7	22.4	22.8	
	Stuttgart	23.5	23.5	24.5	23.8	24.3	24.6	24.0	
	Rohwer	24.2	24.2	24.4	24.3	24.3	23.8	24.2	
2008	Corning	20.1	20.4	20.5	20.7	21.3	21.1	20.7	19.2
	Pine Tree	14.7	14.9	17.1	14.7	16.5	15.0	15.5	
	Stuttgart	21.3	21.1	21.4	20.8	21.3	21.4	21.2	
	Rohwer	19.2	19.3	20.3	18.2	18.1	20.4	19.3	
2009	Keiser	14.2	14.2	13.8	13.5	13.7	14.2	13.9	18.6
	Pine Tree	18.8	18.3	19.9	18.6	20.0	20.1	19.3	
	Stuttgart	21.3	21.3	20.9	21.2	21.2	21.2	21.2	
	Rohwer	20.0	20.2	20.8	19.4	20.0	19.8	20.0	
2010	Keiser	21.7	22.0	21.7	20.9	21.6	23.0	21.8	23.4
	Newport	19.8	20.2	19.6	19.3	19.5	19.4	19.6	
	Pine Tree	22.2	22.4	23.0	22.8	23.0	22.3	22.6	
	Stuttgart	25.8	25.5	25.9	25.9	25.9	25.8	25.8	
	Rohwer	27.1	27.1	26.5	26.9	26.5	27.3	26.9	

[a] Average ambient air temperatures recorded at 30-minute intervals during the time of day extending from 8:00 pm to 6:00 am.

Table 2. Correlation coefficients of amylose content (AC), crude protein content (CPC), total lipid content (TLC), peak viscosity (PV), and onset gelatinization temperature (GT_{onset}) with the 95th percentiles of nighttime air temperature frequencies (NT_{95}) during the R6, R7, and R8 reproductive stages of medium- and long-grain rice cultivars grown in Arkansas from 2007 to 2010.

		Cultivars					
		Medium-grain		Long-grain			
Property	R-Stage	Bengal	Jupiter	Cypress	LaGrue	Wells	XL723
AC	R6	-0.91	NA[a]	-0.84	-0.94	NA	-0.86
	R7	-0.94	NA	-0.86	-0.84	NA	-0.90
	R8	-0.91	NA	-0.96	-0.86	NA	-0.85
CPC	R6	NS[b]	NS	NS	NS	NS	-0.73
	R7	-0.62	-0.58	NS	NS	NS	-0.59
	R8	-0.63	-0.68	NS	-0.77	-0.64	-0.65
TLC	R6	0.92	0.72	0.86	0.82	0.71	0.68
	R7	0.89	0.85	0.81	0.78	0.62	0.81
	R8	0.73	0.88	0.78	0.77	0.90	0.84
PV	R6	NS	0.50	0.81	0.72	0.59	0.69
	R7	0.57	0.60	0.79	0.82	0.65	0.68
	R8	NS	0.61	0.78	0.73	0.66	0.74
Gt_{onset}	R6	0.86	NA	0.82	0.96	NA	0.92
	R7	0.93	NA	0.80	0.85	NA	0.83
	R8	0.79	NA	0.95	0.92	NA	0.86

[a] NA = not available.

[b] NS = not significant ($P < 0.05$).

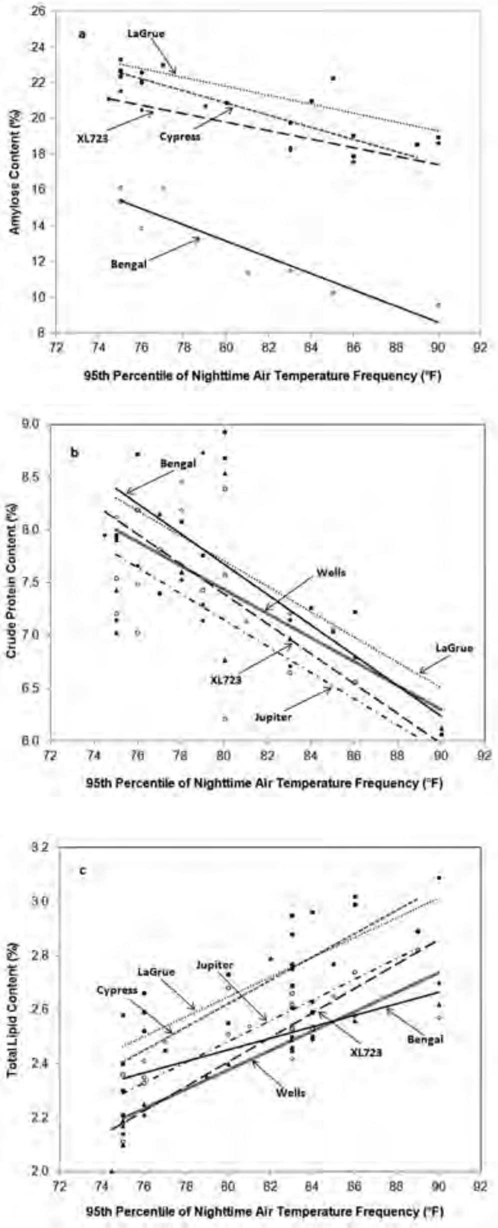
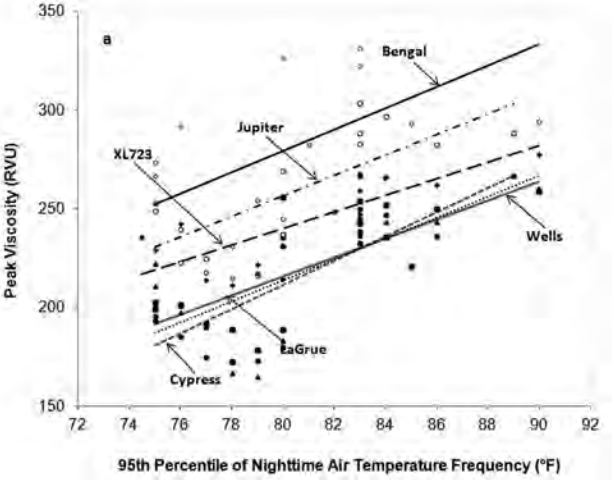


Fig. 1. Relationships of a) head rice amylose content, b) brown rice protein content, and c) brown rice total lipid content and 95th percentiles of nighttime air temperature frequencies during the R8 stages of the indicated cultivars grown from 2007 to 2010. (Amylose data was obtained from harvest years 2009 and 2010 only.)



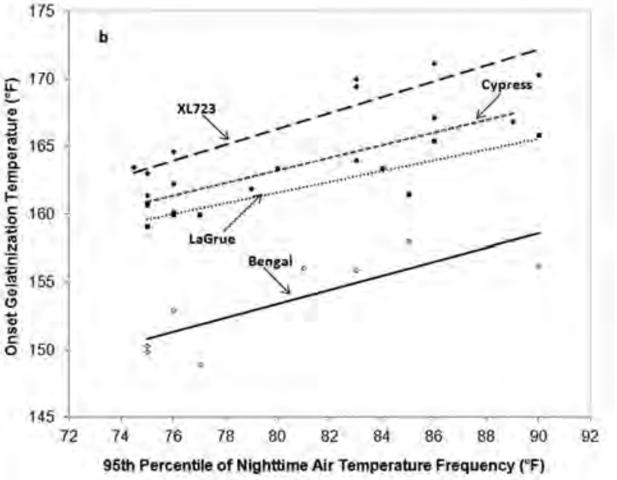


Fig. 2. Relationships of head rice (a) peak viscosity and (b) onset gelatinization temperatures and 95th percentiles of nighttime air temperature frequencies during the R8 stages of the indicated cultivars grown from 2007 to 2010. (Onset gelatinization temperature data was obtained from harvest years 2009 and 2010 only.)

Grain Filling and Gene Expression in Response to Increased Nighttime Air Temperatures in Developing Rice Grains

L.D. Nelson, N.L. Lawson, P.A. Counce,
K.A.K. Moldenhauer, T.J. Siebenmorgen, and K.L. Korth

ABSTRACT

Increasing air temperatures can have a serious negative impact on both the yield and quality of rice harvests. Both field and controlled-climate experiments have demonstrated a reduction in head-rice yields and an increase in chalk formation following exposure to high nighttime temperatures during grain-filling stages. Our goal is to determine fundamental changes that occur in developing rice grains as they respond to high nighttime air temperatures. Panicles collected from field-grown Cypress and LaGrue plants at growth stages R6, R7, and R8 show that as the plant reproductive growth stage progresses, there are a larger proportion of grains at filling stages. We examined relative levels of gene transcripts in response to high nighttime temperatures in varieties resistant [cultivars (cvs.) Cypress and Jupiter] and susceptible (cvs. LaGrue and Wells) to chalk formation. Endosperm was collected at late stages of grain development from plants exposed to nighttime temperatures of either 18 °C or 30 °C. Slight decreases in sucrose and starch synthesis gene expression, and a slight increase in transcript levels of genes for starch degradation, such as amylase, were observed in high-temperature treatments. Chalk levels were higher in LaGrue plants treated at 30 °C as compared to those at 18 °C, confirming the impact of temperature treatments on chalk formation.

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 air temperature (Peng et al., 2004). The opaque appearance of chalk is due to loosely packed amyloplasts and starch granules. Exposure of plants to high nighttime temperatures during the reproductive stage can result in significant increases in chalk formation and decreased amylose content, and rice cultivars vary greatly in their response (Cooper et al., 2008; Lisle et al., 2000). Likewise, starch-component profiles are impacted by changes in air temperature. The proportion of amylopectin at chain-lengths 13 to 24 increases in response to high nighttime temperatures (Counce et al., 2005). Several quantitative trait loci (QTL) have been associated with high-temperature induced chalk formation (e.g., Zhou et al., 2009), indicating the presence of genetic components controlling this trait. Studies of rice grain starch formation show that fine-tuned regulation of starch biosynthesis networks are ultimately responsible for controlling quality (Tian et al., 2009). Gene expression studies showed a temperature-induced decrease in transcripts of genes involved in sucrose and starch synthesis, and increases in those involved in starch degradation (Yamakawa et al., 2007; Liu et al., 2010). To assess the genetic control of starch deposition in developing grains of U.S. rice cultivars, a study of development in field-grown plants and targeted gene expression assays in temperature controlled conditions was performed. The longer term goals of this work are to determine whether key molecular and enzymatic differences exist between these varieties.

PROCEDURES

Plant Growth and Tissue Collection

Individual plants in five replicated plots at Stuttgart, Ark., were tagged at R2 and the progression through reproductive growth stages was recorded. Panicles were collected from cvs. LaGrue and Cypress at plant growth stages R6, R7, and R8 and frozen. Individual kernels on these panicles were separated to groups of R5 and below, R6, R7, and R8, frozen in liquid nitrogen, and stored at -80 °C until counting.

For controlled-temperature treatments, cv. Cypress, LaGrue, Wells, and Jupiter plants were maintained in flooded pots, five sibling plants per pot, in the 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 to 1200 h at 25 °C; 1200 to 1600 h at 27 °C; and 1600 to 2100 h at 25 °C. Nighttime (dark) temperatures were set at either 18 °C or 30 °C from 2100 to 0600 h. When individual grains reached R6 (soft to hard dough stages), they were collected at 1000 h, and endosperm fractions were frozen in liquid nitrogen. The grain on some plants was left intact until maturity and panicles were collected for chalk quantification.

Chalk Measurement

Rough rice was manually de-hulled, and chalk in the resulting brown rice kernels was visualized with a standard flatbed scanner. Chalk was quantified via WinSeedle™

Pro 2005a (Regent Instruments Inc., Sainte-Foy, Quebec, Canada) and expressed as percentage of opaque relative to translucent area, as described (Ambardekar et al., 2011). For each treatment, three sets of 30 grains each were scanned and the data compiled. Significant differences between samples were determined by pairwise comparisons of least square means using Student's *t*-test.

Semi-Quantitative Reverse Transcription Polymerase Chain Reaction

Total RNA was isolated from endosperm material using Masterpure Plant RNA purification kit (Epicentre Inc., Madison, Wis.) and cDNA generated with iScript cDNA synthesis kits (Bio-Rad, Hercules, Calif.). Gene-specific primers (Table I) were used in standard Polymerase Chain Reactions (PCR) 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, and 72 °C; followed by 5 min at 72 °C. Reverse Transcription PCR (RT-PCR) products were separated on 1.2% TAE agarose gels stained with gel-red dye.

RESULTS AND DISCUSSION

Panicles from Cypress and LaGrue plants collected at late plant reproductive stages R7 and R8 contain a larger proportion of grains at filling stages than in the R6 stage (Fig. 1). The rate at which grains fill might differ with developmental stage of the plant, and this could have important implications for how long grains at a given stage are subject to exposure to high air temperatures.

The high-temperature treatments during grain development in climate-controlled growth led to significantly higher chalk only in cv. LaGrue (Fig. 2). In the other cultivars tested, the means of chalk levels were higher in 30 °C temperature treatments, although not at statistically significant levels. Not unexpectedly, these observations confirm that higher nighttime temperatures led to more chalk in LaGrue, and overall show that Jupiter has the lowest chalk levels among the lines tested.

Gene expression patterns in the endosperm tissue were not substantially different among temperature treatments, according to semi-quantitative RT-PCR (Fig. 3), although slight decreases in sucrose and starch biosynthetic genes, along with a slight increase in transcripts for an amylase gene were detected. Furthermore, we did not observe substantial differences in expression patterns between cultivars, suggesting that all the lines tested here are responding in similar ways for the genes tested here. One explanation for this finding is that the higher chalk phenotype in some lines is regulated by differential regulation of other genes, or by other mechanisms such as differential enzyme activities or post-transcriptional events.

SIGNIFICANCE OF FINDINGS

Careful tracking of grain development in field-grown plants showed that at later plant reproductive stages, there is a higher proportion of grains at the late stages of filling, R6, R7, and R8. This observation could be useful in identifying which stages of grain and plant development are sensitive to higher air temperatures, and the time spans that a given developmental stage is potentially exposed to high temperatures. 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. As expected, cultivars Cypress and Jupiter had lower overall levels of chalk than Wells or LaGrue, confirming earlier observations that temperature-induced chalk is consistently higher in some of these cultivars. The gene expression data indicate that starch synthesis is down-regulated in high-temperature conditions, whereas starch degradation might be induced. Although significant differences in chalk were observed between cultivars, no corresponding differences were observed in the gene expression data. These data suggest that, at least for the genes examined, differences in gene expression between cultivars do not sufficiently explain the varying chalk phenotypes observed among cultivars.

ACKNOWLEDGMENTS

We thank the Arkansas Rice Research and Promotion Board for their generous support, and additional support comes from the Arkansas ASSET II Initiative P3 project. We thank Michelle Martin and Red Burgos for technical assistance.

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 Research 122:179-185.

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. 85:276-282.

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.

Lisle, A.J., M. Martin, and M.A. Fitzgerald. 2000. Chalky and translucent rice grains in starch composition and structure and cooking properties. Cereal Chem. 77:627-632.

Liu, X., T. Guo, X. Wan, H. Wang, M. Zhu, A. Li, N. Su, Y. Shen, B. Mao, H. Zhai, L. Mao, and J. Wan. 2010. Transcriptome analysis of grain-filling caryopses reveals involvement of multiple regulatory pathways in chalky grain formation in rice. BMC Genomics 11:730.

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., T. Hirose, M. Kuroda, and T. Yamaguchi. 2007. Comprehensive expression profiling of rice grain filling-related genes under high temperature using DNA microarray. Plant Physiol. 144:258-277.

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.

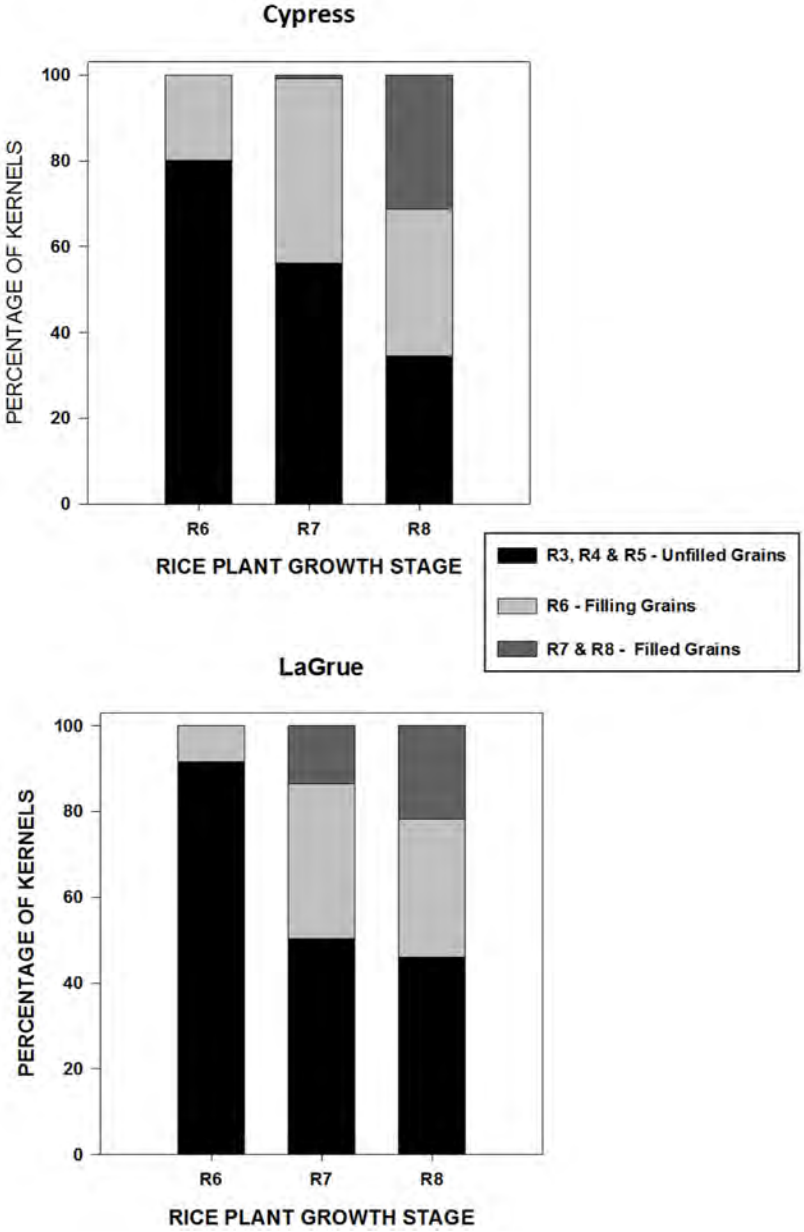


Fig. 1. Graphs indicate percentage of individual grains in field-grown Cypress or LaGrue plants at various developmental steps, when measured at plant growth stages R6, R7, and R8. Grains at R6 have been collected and will be used for subsequent enzyme and gene expression assays.

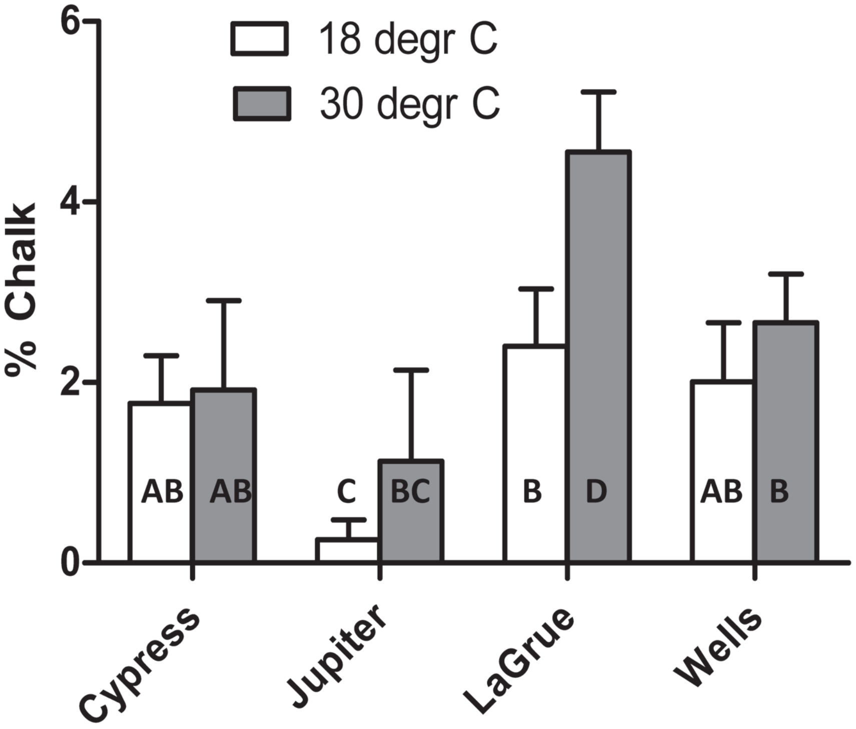


Fig. 2. Percentage of chalk in mature grain from plants treated with nighttime temperatures of either 18 °C or 30 °C in plant growth chambers from plant growth stage R4 to maturity. Chalk levels were determined by digital scanning of brown rice followed by analysis with WinSeedle™ Pro software. Columns with the same letter are not significantly different (Student's *t*-test, *P* > 0.05).

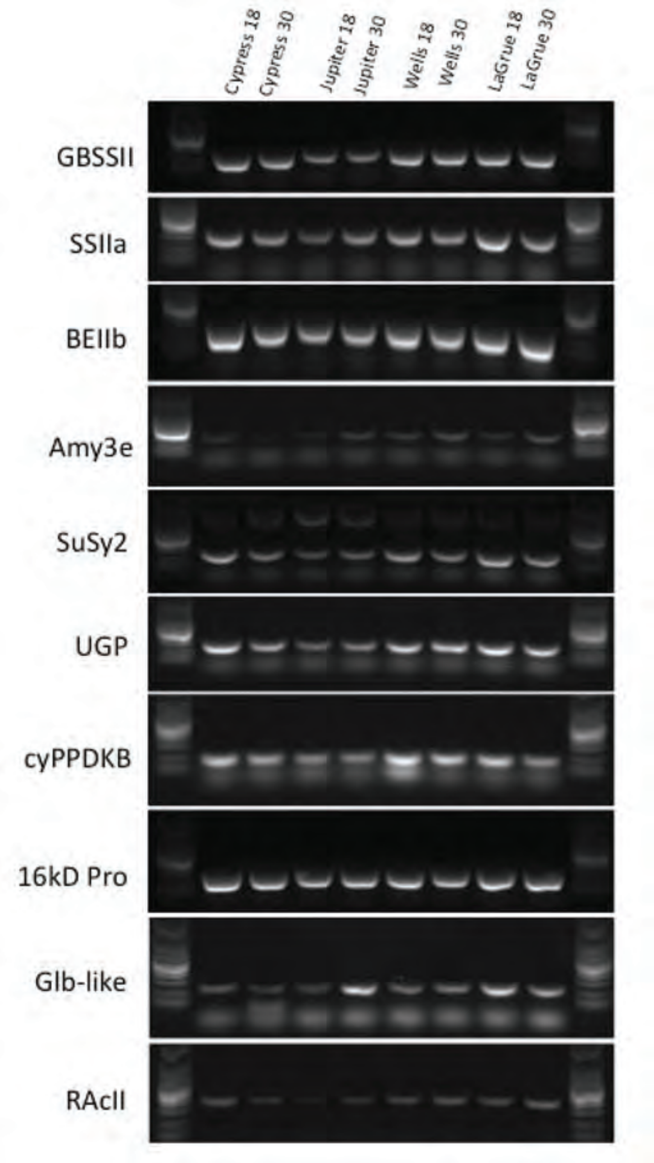


Fig. 3. Gene expression levels in developing rice grains as measured by semi-quantitative Reverse Transcription Polymerase Chain Reactions (RT-PCR). The RT-PCR was run for 25 cycles and products were analyzed on agarose gels. Gene-specific primers were used to amplify transcripts encoding products as shown: GBSSII, granule bound starch synthase; SSIIa, starch synthase IIa; BEIIb, starch branching enzyme IIb; Amy3e, alpha amylase; SuSy2, sucrose synthase 2; UGP, UDP-glucose pyrophosphorylase; cyPPDKB, orthophosphate dikinase; 16kD Pro, prolamin; Glb-like, globulin-like protein; RAcII, actin.

Equilibrium Moisture Contents of Pureline, Hybrid, and Parboiled Rice

G.O. Ondier, T.J. Siebenmorgen, and A. Mauromoustakos

ABSTRACT

Equilibrium moisture contents (EMCs) of long- and medium-grain rough rice of both pureline and hybrid cultivars, and a parboiled rough rice of unknown cultivar, were measured in a near static air environment at temperatures ranging from 50 to 140 °F and relative humidities ranging from 10% to 70% using a gravimetric method. Results showed that there were no consistent significant differences between the EMCs of pureline and hybrid or medium- and long-grain rice cultivars. However, the EMC of parboiled rice was significantly less than that of non-parboiled rice, for almost all air conditions. Empirical constants of five models used for describing grain sorption isotherms were estimated to describe the equilibrium data. The Modified Chung-Pfost equation best described equilibrium data of non-parboiled samples, followed by the Modified GAB, Modified Oswin, Modified Halsey, and Modified Henderson equations. The Modified Chung-Pfost was also superior when describing parboiled-rice equilibrium data.

INTRODUCTION

The control of moisture content (MC) and temperature during extended storage of rough rice is very important, especially in on-farm drying and storage systems (Sun and Byrne, 1998). If not properly monitored, rewetting can occur in the region near the ventilation inlet leading to growth of undesirable microorganisms that cause reduction in quality, including yellowing and odor development (Labuza, 1975).

Equilibrium moisture content (EMC) is the MC at which a hygroscopic material such as rice neither gains nor loses moisture. Surrounding air temperature and relative humidity (RH) determine the EMC for a material. Sorption equations, such as the Modified Chung-Pfost, Modified Halsey, Modified Henderson, Modified GAB, and Modified Oswin (Table 1), are commonly used to describe the relationship between rice EMC and air equilibrium relative humidity (ERH) and temperature (Sun and Woods, 1997a, 1997b). These sorption equations facilitate modeling and optimization of rough rice drying and aeration processes.

The objectives of this study were to: 1) measure the EMCs of long- and medium-grain rough rice of commonly-grown pureline and hybrid cultivars, and parboiled rice at different air temperatures and RHs; 2) estimate the empirical coefficients of the sorption equations (Table 1) from the experimental data; and 3) evaluate the suitability of each equation for describing EMC data of rough rice for the range of temperatures and RHs studied.

PROCEDURES

Sample Collection and Preparation

Long- and medium-grain pureline cultivars, Wells and Jupiter, respectively, and a hybrid long-grain cultivar, CL XL730, were harvested from Arkansas in the fall of 2007 at MCs[1] ranging from 17% to 24%. In the spring of 2008, a long-grain parboiled rough rice of an unknown cultivar was obtained from Riceland Foods, Jonesboro, Ark., at 29% MC. All samples were cleaned (MC® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and dried on screens held in an environment where temperature and RH were maintained by an air control unit (Model AA-558, Parameter Generation & Control, Inc., Black Mountain, N.C.) at 77 °F and 56%, respectively. The resulting sample MC ranged from 11.6% to 12.8%; the samples were stored in sealed plastic tubs (0.22 m^3) at 39 °F for four months. Before the EMC experiments, approximately 30 g of rough rice was obtained from each bulk sample and MC determined by drying in duplicate, 15-g subsamples for 24 h in a convection oven (Shellblue, Sheldon Mfg., Inc., Cornelius, Ore.) held at 266 °F (130 °C) (Jindal and Siebenmorgen,1987).

Equilibrium Apparatus

A schematic of the system used to conduct the EMC experiments is shown in Fig. 1. The apparatus consisted of a 900-L oven (ESL 4CA Platinous Temperature and Humidity Chamber, Espec, Hudson, Mich.) capable of automatically maintaining temperature in the range of -89.6 °F to 302 °F and RH in the range of 6% to 98%. The air in the oven was circulated at 0.38 m^3/s and air conditions were monitored using a digital temperature and RH probe (Hygro-M2, General Eastern, Woburn, Mass.).

A weighing and data collection system, separate from the automated temperature and RH oven, was constructed and installed in the oven chamber. It consisted of nineteen thin-beam, full-bridge load cells (LCL-227G, Omega Engineering, Inc.,

---

[1] All moisture contents are expressed on a wet basis unless otherwise specified.

Stamford, Conn.), each with a capacity of 227 g, which were mounted 10 cm apart on aluminum bars attached to a 3.8-cm thick laminated plywood frame. Each load cell was connected to a data logger (CR3000 Micrologger, Campbell Scientific, Logan, Utah). Rice samples were spread in square baskets (8.9 cm × 8.9 cm × 2.9 cm deep) fabricated from 6.4-mm, welded-wire mesh (4 mesh/in.). The baskets were suspended on the load cells using 0.67-mm (gauge 23) wires. Each basket was lined with brass wire mesh (80 openings/in., 1.4-mm wire dia.). Loggernet software, version 3.3.1 (Campbell Scientific, Logan, Utah) was used to record digital signals from the load cells and the temperature and RH probe at five-minute intervals.

At the start of each experiment, the baskets containing the rice samples were placed inside an open-top box (54.6 cm × 54.6 cm × 25 cm deep) made from 1.25 cm-thick plywood. Once samples were loaded into the baskets and suspended, a linear actuator (LACT12P, IEI, Taiwan), connected to the open-top box via a cable, was activated to raise the box. In the elevated position, the laminated plywood frame from which the load cells were suspended served as the top cover of the box, forming a tight seal, and thereby enclosing the baskets to prevent inadvertent loss of moisture during the oven stabilization period. When the desired temperature and RH were attained within the chamber (Fig. 1), the box was lowered to expose the samples contained in the baskets.

Equilibrium Moisture Content Determination

Equilibrium moisture contents of all samples were determined at temperatures of approximately 50, 68, 86, 113, and 140 °F and RHs from 10% to 70%. Fifteen-g samples from each rice lot were conditioned in each sample basket per run. The samples and baskets were weighed every 5 minutes until the change in mass was less than 0.01 g. The average duration required to reach equilibrium varied from 10 to 35 days, depending on the temperature and RH. The final MCs of the samples were determined using the oven method previously described (Jindal and Siebenmorgen, 1987) and were defined as the EMCs for a given temperature and RH. Each experimental temperature and RH run was replicated.

RESULTS AND DISCUSSION

Equilibrium Moisture Content

Equilibrium MC data are presented in Table 2 as averages of four values, i.e., two replicated EMC measurements, with each measurement comprising two oven-MC duplicates. As expected, greater EMCs were observed at greater RHs for the same temperature and lesser EMCs were observed at greater temperatures for the same RH.

Effect of Cultivar and Processing

There were no consistent significant differences between the EMCs of pureline, Wells, and hybrid, CL XL730, cultivars. Differences in EMCs for the medium-grain cultivar, Jupiter, compared to the long-grain cultivars, Wells and CL XL730, were mostly non-significant. However, the EMC of parboiled rice was approximately one percentage point less than that of non-parboiled rice for almost all temperature and RH conditions (Table 2). The lesser EMCs observed for the parboiled rice may be attributed to the presence of retrograded, gelatinized starch that has less water holding capacity compared to unaltered starch (Lamberts et al., 2006).

Estimation of Empirical Coefficients and Evaluation of Isotherm Models

Estimates of coefficients A, B, and C of the EMC equations, and the indices used to evaluate these models, are shown in Table 3. Based on minimizing root mean square error (RMSE), for temperatures ranging from 50 °F to 140 °F and RHs from 10% to 70%, the Modified Chung-Pfost equation was the best model for describing equilibrium data of non-parboiled rice samples, followed by the Modified GAB, Modified Oswin, Modified Halsey, and Modified Henderson equations. However, the Modified Chung-Pfost and Modified GAB equations gave nearly identical RMSE values (< 0.80) that were superior to the other three EMC models when describing EMC data of individual cultivars, suggesting that both models were appropriate on an individual-cultivar basis. The Modified Chung-Pfost equation was the best for describing parboiled-rice equilibrium data. The residual plots of the Modified Chung-Pfost and Modified GAB equations followed random patterns and were deemed acceptable from this criterion. Sorption isotherms of non-parboiled and parboiled rough rice, determined by the Modified Chung-Pfost equation with statistically-estimated A, B, and C values, are shown in Figs. 2a and 2b, respectively.

SIGNIFICANCE OF FINDINGS

Measuring the rough rice EMCs of long- and medium-grain pureline cultivars Wells and Jupiter, respectively, hybrid long-grain cultivar CL XL730, and parboiled rice of an unknown long-grain cultivar revealed that the EMC of parboiled rough rice was generally one percentage point less than that of non-parboiled rough rice across the air conditions of this study. There were no consistent significant differences in EMCs of long- and medium-grain or pureline and hybrid cultivars at any given air condition. Of the five EMC models investigated, the Modified Chung-Pfost equation best described the experimental EMC data, although the Modified GAB equation was similar in accuracy to the Modified Chung-Pfost when describing EMC data of individual cultivars.

ACKNOWLEDGMENTS

The authors extend their gratitude to 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

ASABE Standards. 2007. ASAE D245.6.15 DEC02. Moisture relationships of plant-based agricultural products. American Society of Agricultural and Biological Engineers. St. Joseph, Mich.

Iguaz, A. and P. Versada. 2007. Moisture desorption isotherm of rough rice at high temperatures. J. Food Engineering 79:794-802.

Jindal, V.K., and T.J. Siebenmorgen. 1987. Effects of oven drying temperature and drying time on rough rice moisture content determination. Trans. ASABE 30:1185-1192.

Labuza, T.P. 1975. Sorption phenomena in foods: Theoretical and practical aspects. pp. 197-214. *In:* C. Rha (ed.). Theory, Determination and Control of Physical Properties of Food Materials. D. Reidel Publishing Company, Holland.

Lamberts, L., E. De Bie, V. Derycke, W.S. Veraverbeke, W. De Man, and J.A. Delcour. 2006. Effects of processing conditions on color change of brown and milled parboiled rice. Cereal Chem. 83:80-85.

Sun, D.-W. and J.L. Woods. 1997a. Simulation of heat and moisture transfer process during drying and in deep beds. Drying Technology 15:2479-2508.

Sun, D.-W. and J.L. Woods. 1997b. Deep bed simulation of the cooling of stored grain with ambient air: a test bed for ventilation control strategies. J. Stored Product Research 33:299-312.

Sun, D.-W. and C. Byrne. 1998. Selection of EMC/ERH isotherm for rapeseeds. J. Agric. Eng. Res. 69:307-315.

Table 1. Equilibrium models used for describing rough rice sorption data.

Modified Henderson[a]	$M_{d.b.} = \left[\frac{Ln(1-RH)}{(-A)(T+B)} \right]^{\frac{1}{C}}$
Modified Chung-Pfost[a]	$M_{d.b.} = \frac{-1}{C} Ln\left[\frac{-(T+B)LnRH}{A} \right]$
Modified Oswin[a]	$M_{d.b.} = (A + B \times T)\left[\frac{1-RH}{RH} \right]^{\frac{-1}{C}}$
Modified Halsey[a]	$M_{d.b.} = \left[-\frac{\exp(A + B \times T)}{(LnRH)} \right]^{\frac{1}{C}}$
Modified GAB[b]	$M_{d.b.} = \frac{A \times B \times \left(\frac{C}{T}\right) \times RH}{(1 - B \times RH)\left[1 - B \times RH + \left(\frac{C}{T}\right) \times B \times RH\right]}$

---

[a] Listed in ASABE standards, 2007

[b] Described in Iguaz and Versada, 2007: Where: $M_{d.b.}$ is equilibrium moisture content (EMC) expressed as decimal dry-basis; *RH* is relative humidity, expressed as a decimal; *T* is temperature in °C; and *A*, *B*, and *C* are grain-specific empirical coefficients.
To estimate constants A, B, and C of the EMC models, experimental moisture contents were converted from percentage wet-basis (w.b.) to percentage dry-basis (d.b.) using the formula:

$$MC_{d.b.} = \frac{100 \times MC_{w.b.}}{100 \times MC_{w.b.}}$$

Table 2. Rough rice equilibrium moisture contents (EMCs) of pureline cultivars Jupiter and Wells, hybrid cultivar CL XL730, and parboiled rough rice of unknown cultivar, exposed to temperatures from 50 °F to 140 °F and relative humidities from 10% to 72%.

		Equilibrium moisture content[¶]			
Air temperature	Relative humidity	Parboiled (long-grain) (MC_1[†] = 12.8%)	Jupiter (medium-grain) (MC_1 = 12.1%)	Wells (long-grain) (MC_1 = 11.8%)	CL XL730 (long-grain) (MC_1 = 11.6%)
(°F)	(%)	------------------------------------(% wet basis) ---------------------------------			
50.0	10.2	6.7^{b}	8.5^{a}	8.0^{a}	8.2^{a}
50.0	17.3	7.3^{b}	9.0^{a}	8.6^{a}	9.1^{a}
50.0	28.2	8.4^{b}	10.0^{a}	9.7^{a}	10.9^{a}
50.0	49.4	10.4^{b}	11.7^{a}	11.3^{a}	12.4^{a}
50.0	68.5	12.8^{a}	$13.6^{\S a}$	$13.0^{\S a}$	$13.0^{\S a}$
68.5	9.7	6.6^{b}	7.2^{b}	7.4^{b}	7.3^{b}
68.2	18.3	7.0^{b}	7.2^{b}	8.0^{a}	8.1^{a}
68.2	28.5	8.4^{b}	8.8^{b}	9.3^{a}	9.6^{a}
69.3	49.8	11.3^{b}	11.8^{a}	12.3^{a}	12.4^{a}
67.6	69.8	12.4^{b}	13.8^{a}	$13.6^{\S a}$	$13.5^{\S a}$
86.0	10.1	4.6^{b}	5.5^{a}	5.3^{a}	4.8^{a}
86.4	19.2	6.7^{b}	7.6^{a}	7.8^{a}	7.6^{a}
86.0	28.9	6.9^{b}	8.2^{a}	8.1^{a}	8.3^{a}
86.0	50.3	9.7^{b}	10.2^{a}	10.3^{a}	10.4^{a}
85.8	69.1	12.3^{a}	$12.9^{\S a}$	$12.7^{\S a}$	$12.9^{\S a}$
113.0	10.0	3.9^{b}	4.9^{a}	4.7^{a}	4.4^{b}
115.0	18.7	4.6^{b}	5.8^{a}	5.7^{a}	5.4^{a}
113.2	30.2	6.6^{b}	7.4^{a}	7.6^{a}	7.4^{a}
113.5	50.0	8.7^{b}	9.6^{a}	9.6^{a}	9.7^{a}
112.5	71.8	11.3^{b}	11.8^{a}	11.7^{a}	11.6^{a}
140.0	10.3	2.8^{b}	4.0^{a}	3.7^{a}	3.6^{a}
140.2	20.0	4.7^{b}	5.6^{a}	6.1^{a}	5.6^{a}
140.4	29.6	5.1^{b}	6.4^{a}	6.2^{a}	6.7^{a}
140.7	49.6	8.1^{b}	8.6^{a}	8.6^{a}	8.5^{a}
139.8	71.6	9.1^{b}	10.5^{a}	10.6^{a}	10.8^{a}

[¶] Each value is an average of four measurements, i.e., two EMC replications with each replicate moisture content measured in duplicate. For each temperature-relative humidity combination, EMC values across individual rows having the same superscripted letter are not significantly different.

[†] MC_i is the initial sample moisture content, % wet-basis.

[§] Adsorption equilibrium moisture content.

Table 3. Estimated coefficients of the Modifed Chung-Pfost (MCP), Modified Henderson (MH), Modified Oswin (MO), Modified Guggenheim Anderson DeBoer (MGAB), and Modified Halsey (MHa) equations, and the statistical parameters used to evaluate the models.

		Estimated model coefficients ¶			Evaluation parameters	
Rice lot	Model	A	B	C	RMSE	Residual plot pattern
Pureline (medium-grain) JUPITER	MCP	475.1747	16.9175	0.2336	0.464	Random
	MH	1.1784×10^{-4}	12.4788	2.9563	0.772	Random
	MO	14.684	-0.0978	3.8320	0.657	Random
	MGAB	11.7793	0.3828	590.3383	0.704	Random
	MHa	6.3369	-0.0221	2.4937	0.702	Random
Hybrid (long-grain) CL XL730	MCP	501.7992	23.6330	0.2279	0.736	Random
	MH	1.2454×10^{-4}	19.7259	2.8692	0.948	Random
	MO	14.2852	-0.0886	3.7527	0.862	Random
	MGAB	11.2528	0.4134	587.7960	0.724	Random
	MHa	6.1548	-0.0196	2.4594	0.995	Trend
Pureline (long-grain) WELLS	MCP	519.4373	20.6428	0.2355	0.655	Random
	MH	1.0296×10^{-4}	16.4011	2.9766	0.883	Random
	MO	14.3952	-0.0912	3.8826	0.772	Random
	MGAB	11.3953	0.3947	629.1636	0.726	Random
	MHa	6.3821	-0.0208	2.5348	0.877	Trend
Pureline and Hybrid (long-grains) CL XL730 & WELLS	MCP	511.7649	22.1226	0.2316	0.942	Random
	MH	1.135×10^{-4}	18.0306	2.9219	0.889	Random
	MO	14.3406	-0.0899	3.8166	0.794	Trend
	MGAB	11.3237	0.4042	607.7889	0.703	Random
	MHa	6.2669	-0.0201	2.4966	0.909	Trend
Non-parboiled rice (all of the above lots pooled)	MCP	498.9584	20.3125	0.2322	0.611	Random
	MH	1.1518×10^{-4}	16.0667	2.9326	0.841	Random
	MO	14.455	-0.0925	3.8219	0.740	Random
	MGAB	11.4659	0.3975	601.7981	0.691	Random
	MHa	6.2906	-0.0208	2.4958	0.835	Random

continued

Table 3. Continued.

		Estimated model coefficients[¶]			Evaluation parameters	
Rice lot	Model	A	B	C	RMSE	Residual plot pattern
Parboiled (long-grain)	MCP	406.902	23.6172	0.2303	0.684	Random
	MH	3.4322×10^{-4}	19.5649	2.5603	0.879	Random
	MO	13.2783	-0.0908	3.3586	0.735	Random
	MGAB	10.1469	0.4599	443.9290	0.811	Random
	MHa	5.3244	-0.0198	2.2059	0.849	Random

[¶] To estimate coefficients A, B, and C, equilibrium data of this study were first converted from percentage wet (w.b) to percentage dry-basis (d.b) using the formula given in Table 1. As such, the coefficients of this Table can be used in conjunction with the models in Table 1 to yield equilibrium moisture contents (EMCs) expressed on a decimal dry-basis. In order to express EMC on a percentage wet-basis, the following equation can be used by entering $MC_{d.b.}$ as a percentage

$$MC_{d.b.} = \frac{100 \times MC_{w.b.}}{100 \times MC_{w.b.}}$$

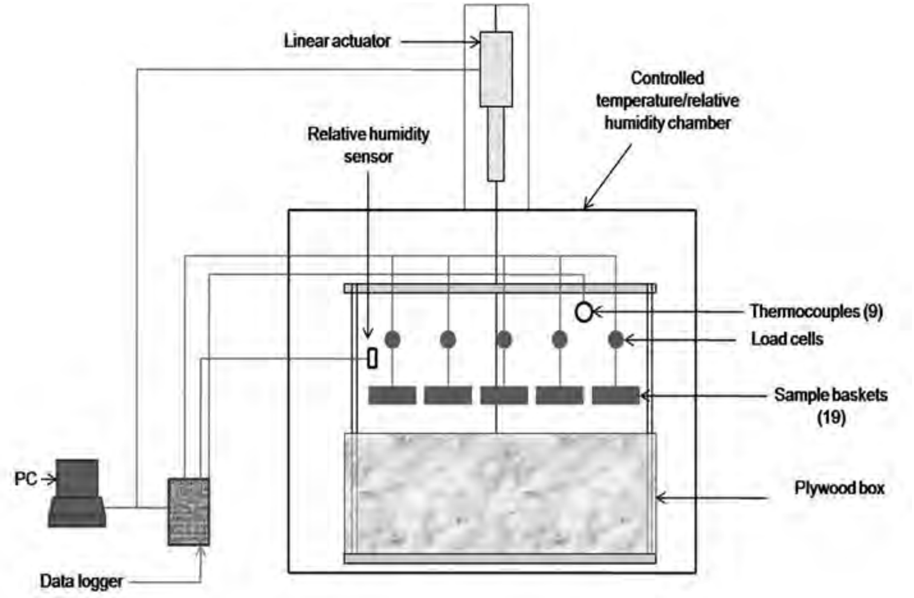


Fig. 1. Schematic of the system used to conduct equilibrium moisture content experiments.

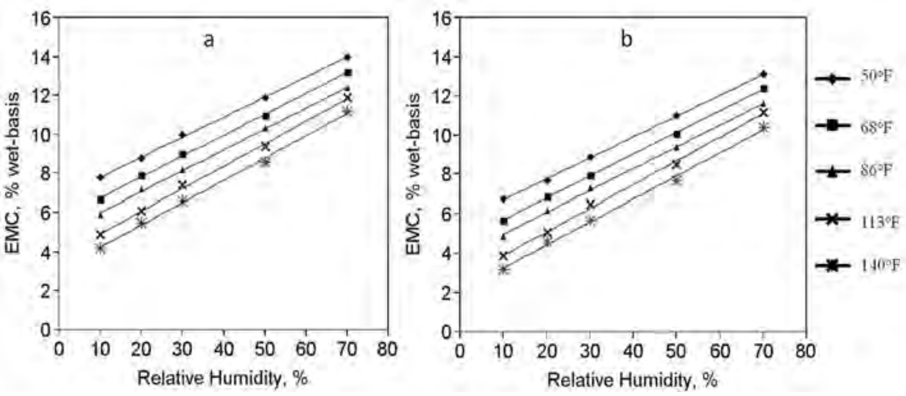


Fig. 2. Equilibrium isotherms predicted by the Modified Chung-Pfost equation; the isotherm predictions are based on model constants A, B, and C listed in Table 3 for 1) non-parboiled rough rice (pooled Jupiter, Wells, and CL XL730 cultivars) and b) parboiled rough rice.

Equilibrium Moisture
Contents of Rice Kernel Components

G.O. Ondier, T.J. Siebenmorgen, and A. Mauromoustakos

ABSTRACT

The effects of temperature and relative humidity (RH) on the equilibrium moisture contents (EMCs) of rough rice, brown rice, and head rice from non-parboiled pureline cultivars Wells (long-grain) and Jupiter (medium-grain), hybrid cultivar CL XL730 (long-grain), and a parboiled rice (long-grain) of unknown cultivar, were investigated. In addition, EMCs of broken kernels, bran, and hulls of Wells cultivar were investigated. Air conditions were maintained at temperatures of 50 °F to 140 °F, and RHs of 10% to 70% to measure kernel-fraction moisture contents. Rice hulls attained the lowest EMC followed by rice bran, brown rice, broken kernels, and head rice; this held for both parboiled and non-parboiled samples. The Modified Henderson, Modified Chung-Pfost, Modified Halsey, Modified Oswin, and Modified Guggenheim-Anderson-DeBoer equations were evaluated to describe the sorption data of each kernel fraction. The Modified Chung-Pfost and Modified Guggenheim-Anderson-DeBoer equations were the most suitable for describing equilibrium data of rough rice, brown rice, broken kernels, and head rice of both parboiled and non-parboiled samples. The Modified Oswin equation was the most suitable for rice bran and hulls.

INTRODUCTION

Generally, rice is harvested and stored as rough rice with the hull, bran, and endosperm intact, but is primarily consumed as milled rice with the hull, embryo and bran layers removed. A lesser proportion is consumed as brown rice, but this proportion may increase due to the recent classification of brown rice as a whole grain by the U.S. Food and Drug Administration (USA Rice Federation, 2011). Other rice kernel components handled by the food industry include rice bran and rice hulls. The value of rice bran has risen due to its nutritional aspects and potential for recovering oil containing essential fatty acids, protein, and functional ingredients such as fiber and carotenoids (Abdul-Hamid et al., 2007). Rice hulls are increasingly used as fuel because they contain organic volatiles (Bharadwaj et al., 2004), with a heating value of 13 to 15 MJ/kg (Jerkins, 1989; Natarajan et al., 1998), and are abundantly available, being by-products of rice milling. There is, therefore, a need to determine the handling and processing characteristics of not just rough rice, but also brown rice, milled rice, rice bran, and rice hulls.

The objectives of this study were to: 1) quantify the EMCs of rough rice, brown rice, and head rice of non-parboiled and parboiled samples of current pureline and hybrid cultivars across a range of temperatures and RHs. In addition, the EMCs of broken kernels, rice bran, and rice hulls were quantified for one of the pureline, non-parboiled cultivars, and 2) estimate the empirical coefficients of five sorption models commonly used to describe equilibrium data and evaluate the suitability of these models for describing EMCs of rice kernel components.

PROCEDURES

Sample Collection and Preparation

Long- and medium-grain pureline cultivars, Wells and Jupiter, respectively, and a hybrid long-grain cultivar CL XL730, were harvested from Arkansas in the fall of 2007 at moisture contents (MCs) ranging from 17% to 24%[1]. In the spring of 2008, a long-grain parboiled rough rice of unknown cultivar was obtained from Riceland Foods, Jonesboro, Ark., at 29% MC. All samples were cleaned (MC® Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.) and dried on screens held in an environment where temperature and RH were maintained by an air control unit (Model AA-558, Parameter Generation & Control, Inc., Black Mountain, N.C.) at 77 °F and 56%, respectively. The resulting sample MC ranged from 11.6% to 12.8%; the samples were stored in sealed plastic tubs (0.22 m^3) at 39 °F for four months. Before the EMC experiments, approximately 30 g of rough rice were obtained from each bulk sample and MC determined by drying duplicate, 15-g subsamples for 24 h in a convection oven (Shellblue, Sheldon Mfg., Inc., Cornelius, Ore.) held at 266 °F/130 °C (Jindal and Siebenmorgen,1987).

Duplicate, 150-g samples of rough rice from each lot were dehulled using a laboratory huller (Satake Rice Machine, Satake Engineering Co., Ltd., Tokyo, Japan) to produce brown rice and hulls. Brown rice samples were milled using a laboratory mill (McGill #2, Rapsco, Brookshire, Texas) for 30 s to produce milled rice and bran. The milled rice was aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.) to remove loose bran particles from the surface of rice kernels. Head rice was then separated from broken kernels using a double tray sizing machine

---

[1] All moisture contents are expressed on a wet basis unless otherwise specified.

(Grainman, Grain Machinery MFG, Miami, Fla.). Head rice was considered as kernels that were at least three-fourths of the original kernel length after milling (USDA, 2005).

Equilibrium Apparatus

A schematic of the system used to conduct the EMC experiments is shown in Fig. 1. The apparatus consisted of a 900-L oven (ESL 4CA Platinous Temperature and Humidity Chamber, Espec, Hudson, Mich.) capable of automatically maintaining temperature in the range of -90 °F to 300 °F and RH in the range of 6% to 98%. The air in the oven was circulated at 0.38 m^3/s and air conditions were monitored using a digital temperature and RH probe (Hygro-M2, General Eastern, Woburn, Mass.). The weighing and data collection system, separate from the automated temperature and RH controller, is described in Ondier et al. (2011). Equilibrium moisture contents of all samples were determined at temperatures of approximately 50, 68, 86, 113, and 140 °F and RHs from 10% to 70%.

Statistical Analysis

Table 1 shows five models commonly used to describe sorption behavior of most starchy grains, namely; the Modified Chung Pfost (MCP), Modified Henderson (MH), Modified Oswin (MO), Modified Halsey (MHa), and Modified Guggenheim-Anderson-de Boer (MGAB) equations (Gal, 1981). The empirical coefficients A, B, and C, of these five models were estimated from the experimental data using a non-linear regression analysis platform (JMP 8.0.1. SAS Institute, Cary, N.C.). The model with the least root-mean-square-error (RMSE) and that displayed a random pattern of residuals around the baseline of zero was considered most suitable (Chen and Morey, 1989).

RESULTS AND DISCUSSION

Equilibrium Moisture Content of Rice Kernel Components

The EMCs of rough rice, brown rice, head rice, broken kernels, rice bran, and hulls of non-parboiled samples from Wells cultivar at a temperature of approximately 86 °F and RHs of 10% to 70% are shown in Fig. 2. The EMCs of all rice kernel components increased with increasing RH at constant temperature, but decreased with increasing temperatures (Tables 2 to 4) due to greater kinetic energy of water molecules. In almost all conditions, rice hulls had the lowest EMCs of the rice kernel components, followed by rice bran, rough rice, and brown rice (Fig. 2). Head rice and broken kernels tended to have the greatest EMCs at all air conditions.

Effect of Cultivar, Kernel Type, and Parboiling

The EMCs of rough rice, brown rice, and head rice obtained at all experimental conditions are presented in Tables 2, 3, and 4, respectively. Though there were a few instances where significant differences were observed among EMCs of a given kernel component (rough rice, brown rice, and head rice) across cultivars, the trends were inconsistent and differences were random. Thus from a practical standpoint, there were generally little to no significant differences in EMCs of rough, brown, or head rice due to the cultivar tested. However, the EMCs of parboiled rice kernel components were significantly lower (p-value < 0.05) than those of the non-parboiled rice in almost all experimental conditions.

Estimation of Empirical Coefficients and Evaluation of Equilibrium Models

The estimates of coefficients A, B, and C of the sorption models and the statistical parameters used to evaluate them, are given in Tables 5 and 6 for non-parboiled and parboiled rice kernel components, respectively. For the air conditions of this study, i.e., temperatures from 50 °F to 140 °F and RHs from 10% to 70%, the equations that best described equilibrium data of rough rice, brown rice, and milled rice for both parboiled and non-parboiled rice were the Modified Chung-Pfost (MCP) and Modified Guggenheim-Anderson-DeBoer (MGAB), followed by the Modified Oswin (MO) and Modified Henderson (MH). The MO gave the best fit for equilibrium data of rice bran and rice hulls. The Modified Halsey (MHa) gave the worst fits with high RMSEs and patterned residual plots, and was thus deemed unsuitable for describing parboiled and non-parboiled rice kernel-fraction equilibrium data measured within the range of experimental conditions.

SIGNIFICANCE OF FINDINGS

Measuring the EMCs of rice kernel components revealed that rice hulls had the lowest EMCs, followed by rice bran, brown rice, broken kernels, and head rice. The EMCs of parboiled kernel components were less than those of non-parboiled kernel components for most air conditions. The Modified Chung-Pfost and Modified Guggenheim-Anderson-DeBoer equations were the best models for predicting EMCs of rough rice, brown rice, and milled rice kernel components for the air conditions of this study. The Modified Oswin was best for rice bran and hulls.

ACKNOWLEDGMENTS

The authors extend their gratitude to 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

Abdul-Hamid, A., R.R. Sulaiman, A. Osman, and N. Saari. 2007. Preliminary studies of the chemical composition of rice milling components stabilized by microwave heating. J. Food Composition and Analysis 20:627-637.

ASABE Standards. 2007. ASAE D245.6.15 DEC02. Moisture relationships of plant-based agricultural products. American Society of Agricultural and Biological Engineers. St. Joseph, Mich.

Bharadwaj, A., Y. Wang, S. Sridhar, and V.S. Arunachalam. 2004. Pyrolysis of rice husk. Current Science 87:981-986.

Chen, C. and R.V. Morey. 1989. Equilibrium relative humidity (ERH) relationships for yellow-dent corn. Trans. ASABE 32:999-1006.

Gal, S. 1981. Recent developments in techniques for obtaining complete sorption isotherms. Water Activity: Influence on food quality: Academic Press: London, New York, pp. 89-97.

Jerkins, B. M. 1989. Physical Properties of Biomass, Gordon and Breach, New York.

Jindal, V.K. and T.J. Siebenmorgen. 1987. Effects of oven drying temperature and drying time on rough rice moisture content determination. Trans. ASABE 30: 1185-1192.

Iguaz, A. and P. Versada. 2007. Moisture desorption isotherm of rough rice at high temperatures. J. Food Eng. 79:794-802.

Natarajan, E., A. Nrodin, and A.N. Rao. 1998. Overview of combustion and gasification of rice husk in fluidized bed reactors. Biomass Bionergy 14:533.

Ondier, G.O., T.J. Siebenmorgen, R.C. Bautista, and A. Mauromoustakos. 2011. Equilibrium moisture contents of pureline, hybrid, and parboiled rice. Trans. ASABE 54:1007-1013.

USA Rice Federation. The U. S. Rice Industry At-A-Glance. (2011). Accessed 25 July 2011 from www.usarice.com

USDA. 2005. Standards for rice, revised: Federal Grain Inspection Service; U.S. GPO: Washington, D.C.

Table 1. Equilibrium models used for describing rough rice sorption data.

Modified Henderson[a]	$M_{d.b.} = \left[\frac{Ln(1-RH)}{(-A)(T+B)} \right]^{\frac{1}{C}}$
Modified Chung-Pfost[a]	$M_{d.b.} = \frac{-1}{C} Ln\left[\frac{-(T+B)LnRH}{A} \right]$
Modified Oswin[a]	$M_{d.b.} = (A + B \times T)\left[\frac{1-RH}{RH} \right]^{\frac{-1}{C}}$
Modified Halsey[a]	$M_{d.b.} = \left[-\frac{\exp(A + B \times T)}{(LnRH)} \right]^{\frac{1}{C}}$
Modified GAB[b]	$M_{d.b.} = \frac{A \times B \times \left(\frac{C}{T}\right) \times RH}{(1 - B \times RH)\left[1 - B \times RH + \left(\frac{C}{T}\right) \times B \times RH\right]}$

[a] Listed in ASABE standards, 2007

[b] Described in Iguaz and Versada, 2007: Where: $M_{d.b.}$ is equilibrium moisture content (EMC) expressed as decimal dry-basis; *RH* is relative humidity, expressed as a decimal; *T* is temperature in °C; and *A*, *B*, and *C* are grain-specific empirical coefficients.

To estimate constants A, B, and C of the EMC models, experimental moisture contents were converted from percentage wet-basis (w.b.) to percentage dry-basis (d.b.) using the formula:

$$MC_{d.b.} = \frac{100 \times MC_{w.b.}}{100 \times MC_{w.b.}}$$

Table 2. Rough rice equilibrium moisture contents (EMCs) of pureline cultivars Jupiter and Wells, hybrid cultivar CL XL730, and parboiled rough rice of unknown cultivar, exposed to temperatures from 50 °F to 140 °F and relative humidities from 10% to 72%.

		Equilibrium moisture content¶			
Air temperature	Relative humidity	Parboiled (long-grain) ($MC_1^{\dagger}$ = 12.8%)	Jupiter (medium-grain) (MC_1 = 12.1%)	Wells (long-grain) (MC_1 = 11.8%)	CL XL730 (long-grain) (MC_1 = 11.6%)
(°F)	(%)	------------(% wet basis)------------			
50.0	10.2	6.7^{b}	8.5^{a}	8.0^{a}	8.2^{a}
50.0	17.3	7.3^{b}	9.0^{a}	8.6^{a}	9.1^{a}
50.0	28.2	8.4^{b}	10.0^{a}	9.7^{a}	10.9^{a}
50.0	49.4	10.4^{b}	11.7^{a}	11.3^{a}	12.4^{a}
50.0	68.5	12.8^{a}	$13.6^{\S a}$	$13.0^{\S a}$	$13.0^{\S a}$
68.5	9.7	6.6^{b}	7.2^{b}	7.4^{b}	7.3^{b}
68.2	18.3	7.0^{b}	7.2^{b}	8.0^{a}	8.1^{a}
68.2	28.5	8.4^{b}	8.8^{b}	9.3^{a}	9.6^{a}
69.3	49.8	11.3^{b}	11.8^{a}	12.3^{a}	12.4^{a}
67.6	69.8	12.4^{b}	13.8^{a}	$13.6^{\S a}$	$13.5^{\S a}$
86.0	10.1	4.6^{b}	5.5^{a}	5.3^{a}	4.8^{a}
86.4	19.2	6.7^{b}	7.6^{a}	7.8^{a}	7.6^{a}
86.0	28.9	6.9^{b}	8.2^{a}	8.1^{a}	8.3^{a}
86.0	50.3	9.7^{b}	10.2^{a}	10.3^{a}	10.4^{a}
85.8	69.1	12.3^{a}	$12.9^{\S a}$	$12.7^{\S a}$	$12.9^{\S a}$
113.0	10.0	3.9^{b}	4.9^{a}	4.7^{a}	4.4^{b}
115.0	18.7	4.6^{b}	5.8^{a}	5.7^{a}	5.4^{a}
113.2	30.2	6.6^{b}	7.4^{a}	7.6^{a}	7.4^{a}
113.5	50.0	8.7^{b}	9.6^{a}	9.6^{a}	9.7^{a}
112.5	71.8	11.3^{b}	11.8^{a}	11.7^{a}	11.6^{a}
140.0	10.3	2.8^{b}	4.0^{a}	3.7^{a}	3.6^{a}
140.2	20.0	4.7^{b}	5.6^{a}	6.1^{a}	5.6^{a}
140.4	29.6	5.1^{b}	6.4^{a}	6.2^{a}	6.7^{a}
140.7	49.6	8.1^{b}	8.6^{a}	8.6^{a}	8.5^{a}
139.8	71.6	9.1^{b}	10.5^{a}	10.6^{a}	10.8^{a}

¶ Each value is an average of four measurements, i.e., two EMC replications with each replicate moisture content measured in duplicate.For each temperature-relative humidity combination, EMC values across individual rows having the same superscripted letter are not significantly different.

† MC_i is the initial sample moisture content, % wet-basis.

§ Adsorption equilibrium moisture content.

Table 3. Brown rice equilibrium moisture contents (% wet-basis) of long-grain pureline cultivar, Wells, medium-grain pureline cultivar, Jupiter, long-grain hybrid cultivar, CL XL730, and long-grain commercially-parboiled rice of unknown cultivar exposed to temperatures from 50 °F to 140 °F and relative humidities from 10% to 72%.

		Equilibrium moisture content[¶]			
Air	Relative	Medium-gran	Long-grain		
temperature	humidity	Jupiter	Wells	CL XL730	Parboiled
(°F)	(%)	------------------------------------(% wet basis) --------------------------------			
50.0	10.2	8.6^{a}	8.3^{a}	8.2^{a}	7.4^{b}
50.0	17.3	9.0^{a}	8.8^{a}	8.9^{a}	8.0^{b}
50.0	28.2	10.5^{a}	9.8^{b}	10.2^{a}	9.1^{c}
50.0	49.4	12.4^{a}	12.4^{a}	11.5^{b}	10.7^{b}
50.0	68.5	14.1^{a}	13.4^{b}	14.0^{a}	13.1^{b}
68.5	9.7	7.2^{b}	7.4^{b}	7.3^{b}	6.6^{b}
68.2	18.3	8.1^{a}	8.0^{a}	8.1^{a}	7.0^{b}
68.2	28.5	9.3^{a}	9.4^{a}	9.6^{a}	8.4^{b}
69.3	49.8	12.6^{a}	12.3^{a}	12.4^{a}	11.2^{b}
67.6	69.8	13.9^{a}	13.6^{a}	13.5^{a}	12.8^{b}
86.0	10.1	5.6^{a}	5.4^{a}	5.2^{a}	5.7^{a}
86.4	19.2	8.3^{a}	8.3^{a}	8.1^{a}	7.0^{b}
86.0	28.9	8.4^{a}	8.8^{a}	8.8^{a}	7.2^{b}
86.0	50.3	12.6^{a}	12.4^{a}	10.4^{b}	8.9^{c}
85.8	69.1	13.4^{a}	13.2^{a}	13.5^{a}	12.7^{b}
113.0	10.0	5.1^{a}	5.3^{a}	4.8^{a}	3.6^{b}
115.2	18.7	6.2^{a}	6.7^{a}	6.5^{a}	5.2^{b}
113.2	30.2	7.9^{a}	8.2^{a}	8.0^{a}	6.6^{b}
113.5	50.0	9.8^{a}	10.6^{a}	10.3^{a}	9.1^{b}
112.5	71.8	12.4^{a}	12.7^{a}	13.0^{a}	11.9^{b}
140.0	10.3	4.3^{a}	4.0^{a}	4.0^{a}	2.9^{b}
140.2	20.0	5.8^{a}	6.1^{a}	6.2^{a}	4.3^{b}
140.4	29.6	6.9^{b}	7.8^{a}	7.2^{b}	5.3^{c}
140.7	49.6	9.5^{a}	9.4^{a}	9.1^{a}	8.4^{b}
139.8	71.6	10.7^{b}	11.6^{a}	11.6^{a}	11.6^{a}

[¶] Each value is an average of four measurements, i.e., two EMC replications with each replicate moisture content measured in duplicate. For each temperature and relative humidity combination, EMC values across individual rows having the same superscripted letter are not significantly different.

Table 4. Head rice equilibrium moisture contents (% wet-basis) of long-grain pureline cultivar, Wells, medium-grain pureline cultivar, Jupiter, long-grain hybrid cultivar, CL XL730, and long-grain commercially-parboiled rice of unknown cultivar exposed to temperatures from 50 °F to 140 °F and relative humidities from 10% to 72%.

		Equilibrium moisture content[¶]			
Air	Relative	Medium-grain	Long-grain		
temperature	humidity	Jupiter	Wells	CL XL730	Parboiled
(°F)	(%)	(% wet basis)			
50.0	10.2	7.9^a	7.9^a	7.7^a	7.3^b
50.0	17.3	8.9^a	9.0^a	9.0^a	7.8^b
50.0	28.2	10.4^a	10.2^a	10.0^a	8.9^b
50.0	49.4	12.4^a	12.3^a	11.4^b	10.5^c
50.0	68.5	14.2^a	14.2^a	14.0^a	13.3^b
68.5	9.7	7.1^a	7.2^b	6.9^b	6.5^b
68.2	18.3	8.2^a	8.3^a	8.5^a	7.0^b
68.2	28.5	9.7^a	9.7^a	9.8^a	8.4^b
69.3	49.8	12.5^a	12.4^a	12.1^a	11.1^b
67.6	69.8	14.2^a	14.0^a	13.5^b	12.9^c
86.0	10.1	5.1^a	5.6^a	5.2^a	5.1^a
86.4	19.2	8.5^a	8.5^a	8.2^a	7.3^b
86.0	28.9	8.8^a	8.8^a	8.4^a	7.6^b
86.0	50.3	12.7^a	12.5^a	10.1^b	9.2^c
85.8	69.1	13.4^a	13.5^a	13.4^a	12.4^b
113.0	10.0	4.9^a	5.6^a	5.0^a	4.0^b
115.2	18.7	6.6^a	6.8^a	6.1^a	4.9^b
113.2	30.2	7.7^a	8.4^a	8.3^a	6.6^b
113.5	50.0	10.2^a	10.9^a	10.6^a	9.0^b
112.5	71.8	12.8^a	13.0^a	12.9^a	11.7^b
140.0	10.3	4.2^a	4.1^a	4.1^a	3.4^b
140.2	20.0	6.4^a	6.3^a	5.2^b	4.7^c
140.4	29.6	7.1^b	8.0^a	6.7^b	5.6^c
140.7	49.6	9.6^a	9.7^a	9.7^a	8.5^b
139.8	71.6	10.9^b	12.0^a	10.6^b	10.6^b

[¶] Each value is an average of four measurements, i.e., two EMC replications with each replicate moisture content measured in duplicate. For each temperature and relative humidity combination, EMC values across individual rows having the same superscripted letter are not significantly different.

Table 5. Estimated coefficients of the Modified Chung-Pfost (MCP), Modified Henderson (MH), Modified Oswin (MO), Modified Guggenheim Anderson DeBoer (MGAB), and Modified Halsey (MHa) equations. The data from the three non-parboiled cultivars, namely, Wells, Jupiter, and CL XL730 were pooled. The model coefficients for bran and hulls were estimated for Wells cultivar only.

Non-parboiled		Model coefficients[¶]			Statistical parameters	
Rice fraction	Model	A	B	C	RMSE	Residual plot pattern
Rough	MCP	498.9584	20.3125	0.2322	0.611	Random
	MGAB	11.4659	0.3975	601.7981	0.691	Random
	MO	14.455	-0.0925	3.8219	0.740	Random
	MH	1.1518×10^{-4}	16.0667	2.9326	0.841	Random
	MHa	6.2906	-0.0208	2.4958	0.835	Random
Brown	MCP	572.7456	26.9868	0.2190	0.670	Random
	MGAB	11.5380	0.4343	638.5563	0.667	Random
	MO	14.6400	-0.0085	3.8219	0.790	Random
	MH	8.3662×10^{-6}	21.4933	2.9387	0.826	Random
	MHa	6.3855	-0.0180	2.5064	0.932	Trend
Head	MCP	567.5001	29.7166	0.2123	0.714	Random
	MGAB	11.5227	0.4487	610.8201	0.710	Random
	MO	15.0500	-0.0854	3.7230	0.792	Random
	MH	9.5663×10^{-6}	23.4725	2.8589	0.820	Random
	MHa	6.2369	-0.0175	2.4461	0.962	Trend
Broken	MCP	617.7767	32.6043	0.2161	0.7706	Random
	MGAB	11.3443	0.4506	646.8532	0.7404	Random
	MO	14.8703	-0.0813	3.7747	0.8029	Random
	MH	8.3183×10^{-6}	25.9576	2.8989	0.8275	Random
	MHa	6.3015	-0.0169	2.4827	0.9880	Trend
Bran	MCP	374.0921	22.0710	0.2308	0.899	Random
	MGAB	10.9495	0.4023	393.8938	0.924	Random
	MO	13.1828	-0.0958	3.2665	0.852	Random
	MH	4.7910×10^{-5}	15.8222	2.4823	0.876	Random
	MHa	5.2025	-0.0213	2.1594	1.009	Trend

continued.

Table 5. Continued.

Non-parboiled		Model coefficients¶			Statistical parameters	
Rice fraction	Model	A	B	C	RMSE	Residual plot pattern
Hulls	MCP	348.6157	15.7268	0.3016	0.844	Random
	MGAB	9.5507	0.3235	423.1776	0.832	Random
	MO	10.7693	-0.0869	3.3804	0.725	Random
	MH	8.2374×10^{-5}	11.0014	2.5665	0.834	Random
	MHa	4.9649	-0.0248	2.2410	0.883	Trend

¶ To estimate coefficients A, B, and C, equilibrium data of this study were first converted from percentage wet (w.b) to percentage dry-basis (d.b) using the formula given in Table 1. As such, the coefficients of this Table can be used in conjunction with the models in Table 1 to yield EMCs expressed as decimal dry-basis. In order to express EMC as percentage wet-basis from percentage dry-basis, the following equation can be used:

$$MC_{d.b.} = \frac{100 \times MC_{w.b.}}{100 \times MC_{w.b.}}$$

Table 6. Estimated coefficients of the Modified Chung-Pfost (MCP), Modified Henderson (MH), Modified Oswin (MO), Modified Guggenheim Anderson DeBoer (MGAB), and Modified Halsey (MHa) equations for predicting equilibrium data for long-grain parboiled rice.

Parboiled		Model coefficients¶			Statistical parameters	
Rice fraction	Model	A	B	C	RMSE	Residual plot pattern
Rough	MGAB	10.1470	0.4599	443.9291	0.811	Random
	MO	13.2783	-0.0908	3.3586	0.735	Random
	MH	3.4322×10^{-5}	19.5649	2.5603	0.879	Random
	MHa	5.3244	-0.0198	2.2059	0.849	Random
	MCP	407.6028	30.3865	0.2121	0.651	Random
Brown	MGAB	9.7243	0.5363	441.0837	0.711	Random
	MO	13.4463	-0.0806	3.2608	0.943	Random
	MH	3.0631×10^{-5}	24.1943	2.5169	1.025	Random
	MHa	5.1497	-0.0165	2.1296	0.934	Trend
Head	MCP	435.7464	26.0542	0.2233	0.509	Random
	MGAB	9.8401	0.5092	472.3943	0.668	Random
	MO	13.4496	-0.0830	3.3649	0.732	Random
	MH	2.7142×10^{-5}	21.9874	2.5940	0.839	Random
	MHa	5.3283	-0.0176	2.1972	0.753	Trend

¶ To estimate coefficients A, B, and C, equilibrium data of this study were first converted from percentage wet (w.b) to percentage dry-basis (d.b) using the formula given in Table 1. As such, the coefficients of this Table can be used in conjunction with the models in Table 1 to yield EMCs expressed as decimal dry-basis. In order to express EMC as percentage wet-basis from percentage dry-basis, the following equation can be used:

$$MC_{d.b.} = \frac{100 \times MC_{w.b.}}{100 \times MC_{w.b.}}$$

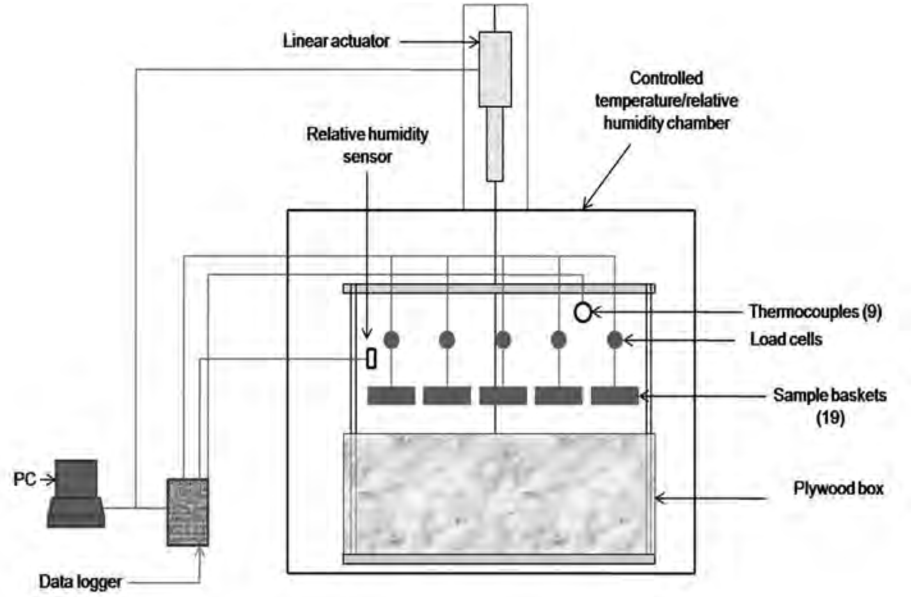


Fig. 1. Schematic of the system used to conduct equilibrium moisture content experiments.

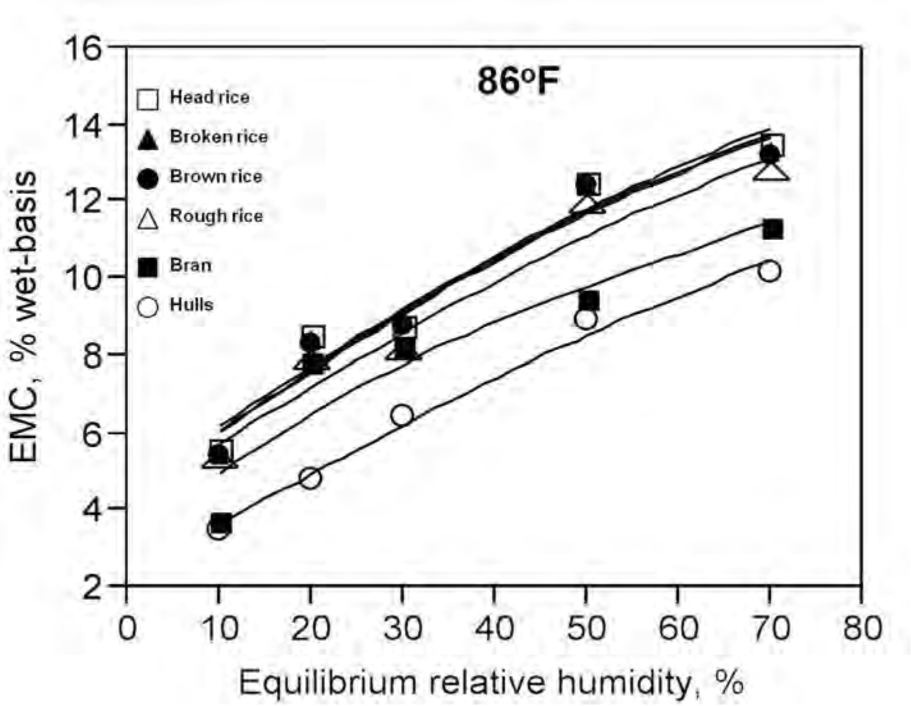


Fig. 2. Equilibrium moisture contents of Wells rice kernel components after exposure to 86 °F and 10% to 70% relative humidity. Each value is an average of four measurements, i.e., two EMC replications with each replicate moisture content measured in duplicate.

ECONOMICS

An Economic Risk Analysis of No-till Management for the Rice-Soybean Rotation System Used in Arkansas

T. Hristovska, K.B. Watkins, and M.M. Anders

ABSTRACT

Arkansas is the top domestic rice producer, representing nearly half of total U.S. rice production. Sediment is one of the major pollutants in rice-producing areas of Arkansas. In order to mitigate this problem, no-tillage (NT) management is often recommended. No-tillage is not well understood by farmers who believe that NT is less profitable due to lower yields offsetting cost savings. This study evaluates the profitability and variability of NT in the typical rice-soybean rotation used in Arkansas rice production. Crop yields, prices, and prices for key production inputs (fuel and fertilizer) are simulated for the rotation, and net return distributions for rice, soybean, and the two-year rotation are evaluated for NT and conventional till. The results indicate that no-till soybeans contribute greatly to the overall profitability of the NT rotation.

INTRODUCTION

Arkansas is the leading rice-producing state in the United States, accounting for over 45% of total U.S. rice production in 2009 (USDA, ERS, 2011). Historically, rice has been of great importance for the Arkansas economy. Rice is Arkansas' highest valued crop, accounting for 37% of crop production value for the state in 2010 (USDA, NASS, 2011). Approximately 1.78 million acres of rice were harvested in 2010 in Arkansas, yielding approximately 6,480 lb and producing about 115.67 million cwt of rice. Arkansas's 2010 rice production was valued at approximately $1.3 billion (USDA, NASS, 2011).

Rice is typically rotated with soybeans in Arkansas. Although rice is a more profitable crop than soybean, the latter crop is generally rotated with rice as a means of controlling red rice, a close weed relative to rice. A two-year rice-soybean rotation is typical for most rice acreage in Arkansas. In 2009, the rice-soybean rotation accounted for almost 68% of Arkansas rice acreage (Wilson et al., 2009). However, some acres may be continuous rice or rotated with other crops such as corn, sorghum, cotton, and wheat (Wilson et al., 2009).

Nearly all rice is produced in the eastern part of Arkansas along the Mississippi Delta region. Agriculture, geography, and climate have major impacts to surface water quality in eastern Arkansas. According to Kleiss et al. (2000), eastern Arkansas soils are predominantly composed of dense alluvial clay sub-soils that limit water infiltration. Surface soils contain silt and clay particles that are moved by heavy rainfall from tilled fields, and these soils also contain little organic matter (Huitink et al., 1998). Sediment is the primary pollutant identified for most eastern Arkansas waterways, and conservation practices like no-tillage (NT) are commonly recommended as remedial mechanisms (Huitink et al. 1998). While conventional-till (CT) is cultivation intensive, NT provides maximum erosion control, conserves soil moisture, improves soil organic matter, and has lower fuel and labor input costs (USDA NRCS, 2006).

Conventional rice production in Arkansas involves intensive cultivation. Fields are "cut-to-grade" every few years, disked annually in either late fall or early spring, and "floated" (land planed) annually in early spring to ensure smooth water movement across the field. In 2009, conventional till (spring tillage and floating) accounted for 52.5% of all planted rice acres in Arkansas, while stale seedbed (fall tillage followed by burn-down herbicides prior to planting in the spring) accounted for over 35.3% of planted rice acres. True NT management (rice planted directly into the previous crop residue without tillage at any time) accounted for 12.2% of planted Arkansas rice acres in 2009 (Wilson et al., 2009).

The profitability of NT rice has been investigated using enterprise budget analysis (Hignight et al., 2009), whole-farm analysis (Watkins et al., 2006), and risk analysis from the perspectives of both the landlord and the tenant in typical Arkansas tenure arrangements (Watkins et al., 2008). Hignight et al. (2009) evaluated the economic contributions of both rice and soybean to the rotation under NT management but did not conduct a risk analysis. The two other studies looked solely at returns to the rice-soybean rotation under NT management and did not evaluate the economic contributions made by either rice or soybean to the rotation. The Watkins et al. (2008) study also considered only price and yield risk and did not evaluate systematic production cost risk associated with high and volatile fuel and fertilizer prices. Rice in particular is a high-cost crop relative to other field crops due to its large fuel, fertilizer, and irrigation expenses (Childs and Livezey, 2006).

The objective of this study is to evaluate the profitability of NT relative to CT management for the typical rice-soybean production system used in Arkansas rice production. Crop yields, crop prices, and prices for key production inputs (diesel and fertilizer) are simulated and net return distributions for rice, soybean, and the two-year rotation are evaluated separately for both NT and CT management.

PROCEDURES

Crop yields, crop prices, and prices for fuel and fertilizer were simulated using the Excel Add-In, SIMETAR (Richardson et al., 2008). Multivariate empirical distributions (MVEs) were used to simulate 500 iterations of yields and prices. A MVE distribution simulates random values from a frequency distribution made up of actual historical data and has been shown to appropriately correlate random variables based on their historical correlation (Richardson et al., 2000). Parameters for the MVE include the means, deviations from the mean or trend expressed as a fraction of each variable, and the correlation among variables. The MVE distribution is used in instances where data observations are too few to estimate parameters for another distribution (Pendell et al., 2006).

Rice and soybean yield distributions under CT and NT were simulated using 11 years of historical yield data from a long term rice-based cropping systems study at Stuttgart, Ark., for the period 2000 to 2010 (Anders and Hignight, 2010). The historical crop yields represent yields obtained in a two-year rice-soybean rotation. Deviations from 11-year means were used to estimate the parameters for the MVE yield distributions, and mean yields over the 11-year period were used as expected yields for the MVE yield distributions. Summary statistics for the simulated yields are presented in Table 1. Rice yields for NT are lower by approximately 100bu/acre than CT rice yields. Soybean yields for NT on the other hand are higher for about 1bu/acre for NT than CT soybean. Anders and Hignight (2010) also found that, over time, NT rice yields declined compared to CT, while NT soybean yields steadily increased compared to CT.

Multivariate empirical distributions were used to simulate crop prices (rice, soybean) and prices for key production inputs (diesel, urea, phosphate, and potash). All price simulations were based on historical prices obtained from the USDA, National Agricultural Statistics Service (2002, 2006, 2009, 2010 a,b) for the 2000 to 2010 period, adjusted to 2010 dollars using the Producer Price Index. Deviations from the means and their associated correlations were used to simulate the MVE price distributions for each price series, but mean prices for the period 2005 to 2010 were used rather than 11-yr means to represent expected prices for the MVE price distributions. Prices for the latter five years of the 11-yr period better represent current farmer price expectations. The MVE approach has been shown to reproduce the historical correlation matrix and maintain the historical coefficient of variation from the original historical data series even when using means different from the historical mean (Ribera et al., 2004). Summary statistics for simulated prices are presented in Table 1.

Direct and fixed expenses for the analysis were based on cost data used in the 2010 Arkansas Rice Research Verification Program (Runsick et al., 2010) and input data for rice and soybeans grown in a two-year rotation obtained from the long term rice cropping systems study at Stuttgart, Ark. Direct expenses included expenses associated with fertilizer, pesticides, seed, operator labor, machinery and irrigation fuel, machinery and irrigation repairs and maintenance, and interest on operating capital. Fixed expenses included machinery and irrigation depreciation and interest. Average budgeted expenses are presented by crop enterprise and tillage method on a per hectare basis in Table 2.

No-till is less labor and machinery intensive, therefore it is a fuel saving practice, but it requires more herbicide and custom chemical/fertilizer applications. Average direct expenses for NT rotation were found to be $396.02/acre, while CT rotation average direct expenses were $403.15/acre. The NT fixed expenses were also found to be lower on average than CT rotation fixed expenses ($65.58/acre for NT; $78.55/acre for CT). Consequently, total expenses for NT rotation were lower on average than those for CT rotation ($461.59/acre for NT; $481.70/acre for CT).

Using the above data, net returns per acre for the rice-soybean rotation were estimated based on the 500 simulated iterations using the following formula:

$$NR_j = 0.5 * \sum_{i=1}^{2} \left\{ \left(Y_{ij} * P_{ij} \right) - SVC_{ij} - SHC_{ij} - NSVC_i - F_i \right\}$$

where i = 1 to 2 crops (rice, soybean); j = 1 to 500 simulated iterations; NRj is the total net revenue per hectare of the rice-soybean rotation for iteration j; Yij is the stochastic yield per hectare of crop i and iteration j; Pij is the stochastic price per kilogram for crop i and iteration j; SVCij is the total stochastic variable cost of fuel and fertilizer per hectare of crop i and iteration j; SHCij is the total stochastic harvest cost per hectare of drying, check off and hauling for crop i and iteration j; NSVCi is the total non-stochastic variable cost per hectare for crop i; and Fi is the fixed cost per hectare for crop I. Equation 1 is multiplied by 0.5 to reflect a rotation of 50% rice and 50% soybeans.

RESULTS AND DISCUSSION

Net Returns to Rice, Soybean, and the Rotation

Summary statistics of simulated net returns to rice, soybean, and the two-year rotation are presented by tillage method in Table 3. Average returns to rice in the two-year rotation are slightly larger for CT than for NT, but the relative variability of returns to rice under the two tillage methods as measured by the coefficient of variation is equal (CV = 70 for both CT rice and NT rice net returns). Average returns to soybean are lower than average returns to rice regardless of the tillage method used, implying rice is the more profitable crop in the two-year rotation. However, the soybean average returns are larger under NT than under CT management, and the relative variability of soybean returns is smaller for NT than for CT (CV = 73 for NT soybean; CV = 101 for CT soybean). Average returns for the two-year rotation are also slightly larger and less variable under NT management than under CT management. These results are due primarily to the soybean portion of the rotation, which is both more profitable and less risky under NT management. In all three instances (rice, soybeans, and the rotation), the minimum and maximum returns are larger for NT than for CT. These results imply NT performs better than CT in both "poor" crop years (higher minimum returns) and "good" crop years (higher maximum returns) for both rotation crops and the rotation itself.

Besides being more profitable, no-till can reduce sediment run-off and contribute to improved water and soil conservation. Lower fuel emissions are also one of the many no-till benefits that result from lowered machine fuel usage. No-till management may also contribute to carbon sequestration in rice production. This study evaluates profitability only and does not seek to quantify environmental benefits of no-till management. Given the great interest in soil and water conservation practices, future studies should be conducted to measure such benefits.

SIGNIFICANCE OF FINDINGS

This study evaluates the profitability and risk efficiency of NT for the typical rice-soybean rotation used in Arkansas based on data from a continuous 10-yr study. Net return distributions for rice, soybean, and the two-year rotation are evaluated separately for both NT and CT management. The results support previous findings that NT management is indeed more profitable on average but more importantly this study evaluates and highlights the case of rice-soybean rotation that is most commonly used in Arkansas. These results indicate that NT soybeans contribute greatly to the overall profitability of the rice-soybean rotation.

ACKNOWLEDGMENTS

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

LITERATURE CITED

Anders, M.M. and J.A. Hignight. 2010. Environmental impact, soil quality, grain yield, and the economic viability of a rice-soybean rotation. *In:* R.J. Norman and K.A.K. Moldenhouer (eds.). B.R. Wells Rice Research Studies 2009. University of Arkansas Agricultural Experiment Station, Research Series 581:237-247. Fayetteville.

Anderson, J.R. and J.L. Dillon, 1992. Risk analysis in dryland farming systems. Farming Systems Management Series No. 2, FAO, Rome.

Childs, N.W and Livezey, J. 2006. Rice Backgrounder. U.S. Department of Agriculture, Economic Research Service, RCS-2006-01, December 2006.

Hignight, J., K.B. Watkins, and M.M. Anders. 2009. Economic Benefits of No-Till in a Rice-Soybean Rotation. University of Arkansas Extension Service Fact Sheet. http://www.uaex.edu/Other_Areas/publications/PDF/FSA-38.pdf

Huitink, G., P. Tacker, J. Sills, M. Daniels, and J.C. Boils Jr. 1998. Soil Erosion and Clear Water. University of Arkansas Cooperative Extension Service Fact Sheet FSA1028, Little Rock, Ark.: University of Arkansas Division of Agriculture.

Kleiss, B.A., R.H. Coupe, G.J. Gonthier, and B.G. Justus. 2000. Water Quality in the Mississippi Embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee, and Kentucky, 1995-98. United States Geological Survey Circular 1208, Reston, Virginia: US Department of the Interior.

Pendell, D.L., J.R. Williams, C.W. Rice, R.G. Nelson, and S.B. Boyles. 2006. Economic feasibility of no-tillage and manure for soil carbon sequestration in corn production in northeastern Kansas. J. Environmental Quality 35:1364-1373.

Ribera, L.A., F.M. Hons, and J.W. Richardson. 2004. An economic comparison between conventional and no-tillage farming systems in Burleson County, Texas. Agronomy Journal 96:415-424.

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. and Appl. Econ. 32:229-315.

Richardson, J.W., K.D. Schumann, and P.A. Feldman. 2008. SIMETAR, Simulation & Econometrics to Analyze Risk. College Station: Agricultural and Food Policy Center, Department of Agricultural Economics, Texas A&M University, 2008.

Runsick, S., R. Mazzanti, C. Wilson Jr., and B. Watkins. 2010 University of Arkansas Rice Research Verification Program. University of Arkansas Cooperative Extension Service. http://www.aragriculture.org/crops/rice/Verification/RRVP10.pdf

Watkins, K.B., J.L. Hill, and M.M. Anders. 2008. An economic risk analysis of no-till management and rental arrangements in Arkansas rice production. J. Soil and Water Cons. 63:242-250.

Watkins K.B., J.L. Hill, M.M. Anders, and T.E. Windham. 2006. Whole-farm evaluation of no-till profitability in rice production using mixed integer programming. J. Agric. and Appl. Econ. 38:611-627.

Wilson Jr., C.E., S.K. Runsick., and R. Mazzanti. 2009. 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.

USDA, Economic Research Service. 2011. 2009/10 Rice Yearbook. Economic Research Service Report RCS-2010, January 2011.

USDA, National Agricultural Statistics Service. 2011. 2010 State Agricultural Overview, Arkansas. Accessed 24 June 2011 http://www.nass.usda.gov/Statistics_by_State/Ag_Overview/AgOverview_AR.pdf

USDA, National Agricultural Statistics Service, Arkansas Field Office. 2010a. Monthly Prices Received by Arkansas Farmers for Crops. Accessed 31 December 2010 http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Statistical_Bulletin/econcrop.pdf

USDA, National Agricultural Statistics Service. 2010b. Prices Paid by Farmers and Ranchers. Accessed 30 April 2010 http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Economic_Releases/index.asp

USDA, National Agricultural Statistics Service. 2009. Agricultural Prices 2008 Summary. August 2009, Pr 1-3 (09).

USDA, National Agricultural Statistics Service. 2006. Agricultural Prices 2005 Summary. July 2006, Pr 1-3 (06).

USDA, National Agricultural Statistics Service. 2002. Agricultural Prices 2001 Summary. July 2002, Pr 1-3 (02)a.

USDA Natural Resources Conservation Service. 2006. Tillage Practice Guide. http://www.mn.nrcs.usda.gov/technical/ecs/agron/Tillage%20Practice%20Guide.pdf

Table 1. Summary statistics of simulated yields and prices.

Variable[a]	Mean[b]	SD[c]	CV[d]	Minimum	Maximum
CT rice yield (bu/acre)	184.07	12.49	6.78	159.84	199.25
NT rice yield (bu/acre)	177.21	13.45	7.59	161.75	209.25
CT soybean yield (bu/acre)	47.02	14.52	30.89	16.68	65.88
NT soybean yield (bu/acre)	48.06	11.48	23.89	31.25	68.31
Rice price ($/bu)	5.45	1.56	28.55	2.92	7.88
Soybean price ($/bu)	9.09	1.68	18.51	6.54	11.85
Diesel price ($/gal)	2.47	0.78	31.47	1.54	4.28
Urea ($/lb)	0.22	0.04	19.91	0.14	0.29
Phosphate ($/lb)	0.24	0.09	38.74	0.17	0.52
Potash ($/lb)	0.23	0.13	53.91	0.14	0.59

[a] CT = conventional till; NT = no-till.

[b] Summary statistics calculated from 500 simulated iterations.

[c] SD = Standard deviation.

[d] Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation divided by the mean.

Table 2. Average direct and fixed expenses for a rice-soybean rotation by crop, rotation, and tillage, 2010 dollars.

	Rice		Soybean		Rotation	
Expense item	CT[a]	NT	CT	NT	CT	NT
	($/acre)					
Seed	69.48	69.48	58.80	58.80	64.14	64.14
Fertilizers[b]	113.48	113.48	60.93	60.93	87.21	87.21
Agrotain	8.15	8.15	0.00	0.00	4.07	4.07
Herbicide	64.04	70.68	8.72	10.86	36.38	40.77
Insecticide	0.54	0.54	0	0	0.27	0.27
Custom chemical and fertilizer application	38.00	38.00	17.25	25.88	27.63	31.94
Irrigation supplies	7.45	7.45	1.95	1.95	4.70	4.70
Survey levees	5.50	5.50	0	0	2.75	2.75
Labor	10.78	8.67	7.80	5.63	9.29	7.15
Diesel fuel[b]	110.70	95.98	50.57	44.29	80.63	70.14
Repairs & maintenance	21.71	20.36	11.89	10.93	16.80	15.65
Post-harvest expenses[b]	107.41	103.41	11.76	12.02	59.58	57.71
Interest on operating capital	13.01	12.65	6.39	6.40	9.70	9.53
Total direct expenses	570.25	554.35	236.05	237.68	403.15	396.02
Fixed expenses	102.30	87.42	54.79	43.73	78.55	65.58
Total expenses	672.56	641.77	290.84	281.41	481.70	461.59

[a] CT = conventional till; NT = no-till.

[b] Expense item is stochastic (average calculated from 500 simulated iterations).

Table 3. Summary statistics of net returns for a rice-soybean rotation by tillage, crop, and rotation.

Variable[a]	Mean[b]	SD[c]	CV[d]	Minimum	Maximum
($/acre)					
CT Rice	331.00	232.23	70.16	-109.37	772.22
NT Rice	324.49	226.75	69.88	-84.31	831.04
CT Soybean	136.60	138.27	101.23	-207.35	392.41
NT Soybean	155.85	114.10	73.21	-33.98	421.73
CT Rotation	233.80	163.46	69.91	-121.57	582.32
NT Rotation	240.17	155.76	64.85	-58.76	621.82

[a] CT = conventional till; NT = no-till.

[b] Summary statistics calculated from 500 simulated iterations.

[c] SD = Standard deviation.

[d] Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation divided by the mean.

ECONOMICS

Is ACRE Program Participation During the 2012 Farm Bill Likely to Pay Off for Arkansas Producers? Preliminary Evidence from the Representative Panel Farms Framework

V. Karov, E.J. Wailes, and K.B. Watkins

ABSTRACT

The Average Crop Revenue Election (ACRE), an optional and voluntary revenue support counter-cyclical program, was made available to United States farmers starting in the 2009 crop year. However, participation rates nationally have remained low due to a number of factors. This study estimates the effect on Arkansas farmers of participation in this program during the 2012 Farm Bill assuming full program continuation. Five Arkansas representative panel farms provide the framework for the analysis. Ten-year historical data is used to develop national and world crop price, as well as farm-specific yield and expense empirical distributions by using multivariate empirical probability distributions. Stochastic baseline projections for 2012 to 2016 with 500 random draws are simulated in SIMETAR. The results imply that program participation pays off for Arkansas farmers during the years 2012 to 2016 even though the probability of receiving a program payment is low across all farm-crop combination pairs.

INTRODUCTION

The Average Crop Revenue Election (ACRE) program was a novel program in the 2008 Farm Bill. It was an optional and voluntary revenue support counter-cyclical program available to producers starting in 2009. Once enrolled, producers: were ineligible to receive counter-cyclical payments (CCPs); had their direct payments (DPs) reduced by 20%; had their loan rates reduced by 30%; and must have remained enrolled in the program during the whole period 2009 to 2012.

In order for ACRE payments to be received, two triggers (one at the State and one at the farm level) must be met:

- Actual State revenue<ACRE State revenue guarantee
- Actual farm revenue<ACRE farm benchmark revenue

When both triggers are met, the total program payment for the crop of interest is calculated as:

- ACRE payment rate per planted acre* 83.3% of the farm-specific actual (or considered) planted acres for the years 2009 to 2011 (85% in 2012)*farm-specific productivity ratio[1]

Since 2009, participation rates in ACRE across all states have remained low (8% of eligible farms in the 2009 crop year). Participation rates in Arkansas have also remained low during this period. Several factors likely have had an impact on this trend. First, DPs are of critical importance to the subsistence of Arkansas farms. Second, two triggers must be met in order for program payments to be received. Third, adverse selection is a major issue with the program.[2] Fourth, complicated program structure, rules and regulations have likely prevented producers from participation. Fifth, any potential payments are received late after crop harvest. Finally, the decision to participate in 2009 was irrevocable during the whole period 2009 to 2012.

The goal of this study is to assist Arkansas producers in making better informed decisions regarding participation in Federal agricultural programs during the 2012 Farm Bill. The objective is to assess the impact on Arkansas producers of participation in the ACRE program during the 2012 Farm Bill (assuming full program continuation). To achieve the main goal, two scenarios are considered:

- What is the probability of receiving an ACRE payment during 2012 to 2016 on a by farm, crop, and year basis?
- Does it pay off for Arkansas farmers to participate in the ACRE program during 2012 to 2016?

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 two to three 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,

---

[1] The United States Department of Agriculture's Economic Research Service (USDA/ERS) 2008 Farm Bill Side-By-Side Comparison provides specific detail on all ACRE program-related variables (USDA, ERS, 2009).

[2] Adverse selection refers to the process of making a decision (Federal farm commodity program participation in this case) without possessing all the necessary information in order to do so (in this case, a decision must be made while facing future risk and uncertainty).

location-specific price wedges relative to the mean national prices, assets, costs, loan interest rates, and depreciation method is collected (Hignight, 2007).

Table 1 shows characteristics for 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.

Following Richardson, Klose, and Gray (2000), a procedure for developing multivariate empirical (MVE) probability distributions for farm-related variables is employed. Specifically, ten-years of historical data are employed to develop national and world crop price, as well as farm-specific yield and expense (diesel fuel, fertilizer, and electricity) empirical distributions. SIMETAR is used to simulate stochastic baseline five-year projections for the period 2012 to 2016 with 500 iterations per variable per year.

Historical national and adjusted world prices are obtained from the USDA's National Agricultural Statistics Service (USDA/NASS; USDA, NASS, 2012), the USDA/ERS Rice Yearbook (USDA, ERS, 2012a) and the Rice Outlook (USDA, ERS, 2012b). Actual historical farm-specific yields, on the other hand, are obtained during the representative panel farm interview process. 2008 Farm Bill policy variables such as crop-specific direct payment rates, loan rates and target prices are obtained from the USDA/ERS Side-By-Side Comparison (USDA, ERS, 2009). Finally, historical farm expense data (diesel fuel, potash, nitrogen, and phosphate) are obtained from USDA/NASS and the U.S. Energy Information Administration (electricity) (USDA, NASS, 2012; EIA, 2012).

The "February 2011 Baseline Update for United States Agricultural Markets" by the Food and Agriculture Policy Research Institute (FAPRI)-University of Missouri is used to obtain projected crop prices. An earlier version of the same publication (March 2011), on the other hand, is used to obtain projected indices of prices paid by farmers (FAPRI, 2012). Finally, projected farm-specific crop yields are calculated by the authors by assuming farm and crop-specific growth trends.

RESULTS AND DISCUSSION

Table 2 shows the results from the first scenario. The probabilities of receiving an ACRE payment during the period 2012 to 2016 are low across all farm-crop combination pairs. For example, such probabilities are in the 18% (Hoxie farm in 2016) to 48% (Stuttgart farm in 2013) range for long-grain rice and the 16% (Hoxie farm in 2016) to 42% (Stuttgart farm in 2012) range for irrigated soybeans.

Tables 3 and 4 illustrate the results from the second scenario. Average annual ACRE payments on a per acre basis range from $21 (Stuttgart and Wynne farm) to $33 (Leachville farm). Across all sample crops, the highest ACRE payments on a per acre basis as an annual average over the years 2012 to 2016 are received for corn (e.g., $53 for the McGehee farm) and medium-grain rice (e.g., $43 for the Hoxie farm) and the lowest for wheat (e.g., $12 for the Stuttgart farm) and dryland soybeans (e.g., $7 for dryland soybeans for the Hoxie farm). Finally, in terms of profitability for ACRE farm participants, only one of the sample farms (Wynne) has a negative net income on a per acre basis as an annual average during 2012 to 2016 (-$137). The reason for this is the relatively high depreciation cost of this farm. For all other farms under ACRE participation, average annual net incomes during the same period range from $22/acre (Hoxie farm) to $189/acre (Leachville farm). On the other hand, under BASE participation (farmers choose not to participate in ACRE), the Wynne farm again is the only farm that has a negative net income on a per acre basis as an annual average during the years 2012 to 2016. For the other farms, under BASE participation, average annual net incomes during the same period range from $9/acre (Hoxie farm) to $163/acre (Leachville farm). However, across all sample farms, the annual average net farm income/acre is greater under ACRE participation as compared to BASE participation. Net farm income/acre differences among both participation options range from $11 (Wynne farm) to $26 (Leachville farm).

The results suggest that the Leachville farm, an irrigated and dryland cotton farm, would benefit the most from ACRE participation during the 2012 Farm Bill even though the analysis shows that the highest ACRE payments on a per acre basis as an annual average during 2012 to 2016 are received for corn and medium-grain rice. This can be explained with the small number of planted acres in the sample for these two crops (e.g., only the Hoxie farm grows medium-grain rice; 150 acres).

SIGNIFICANCE OF FINDINGS

During the period 2009 to 2012, ACRE participation rates in Arkansas (as well as across all other States) have been low. Numerous factors have likely had an impact on such a trend. This study examines the impact on Arkansas farmers of ACRE participation during the 2012 Farm Bill assuming full program continuation. The results suggest that ACRE participation pays off for Arkansas producers during the years 2012 to 2016 even though the probability of receiving an ACRE payment is low across all farm-crop combinations. Therefore, it remains unclear whether or not a producer should potentially participate in ACRE and the decision to participate should be cautiously examined by each producer individually. The main reason for this is that a certain level of uncertainty exists in terms of yield and price variation at both the farm and State level. However, due to the recently stronger market price environment (relative to the year 2009 when farmers could initially enroll) it is likely that farmers would have a greater incentive to participate in ACRE during 2012 to 2016.

ACKNOWLEDGMENTS

Funding for this study was provided by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Food and Agricultural Policy Research Institute (FAPRI). University of Missouri. 2012. U.S. Baseline Briefing Book. Available online at: http://www.fapri.missouri.edu/index.asp?current_page=home

Hignight, J.A. 2007. "An Economic Comparison of Alternative Farm Policies on Arkansas Representative Panel Farms." MS thesis, University of Arkansas, Fayetteville.

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. and Appl. Econ. 32:299-315.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2012a. Rice Yearbook. Available online at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1229.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2012b. Rice Outlook. Available online at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1285.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2009. The 2008 Farm Bill Side-By-Side Comparison. Available online at: http://www.ers.usda.gov/FarmBill/2008/.

U.S. Department of Agriculture (USDA). National Agricultural Statistics Service (NASS). 2012. Available online at: http://www.nass.usda.gov/

U.S. Energy Information Administration (EIA). 2012. Available online at: http://www.eia.gov/.

Table 1. Arkansas representative panel farm characteristics.

Farm name	ARHR3000	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

Table 2. Percentage probability of receiving an average crop revenue election (ACRE) payment (2012 to 2016), by farm, crop, and year.

	Stuttgart			Wynne			Leachville		Hoxie					McGehee					
Year	LGR[a]	IRSB	W	LGR	IRSB	DLSB	IRCT	DLCT	LGR	MGR	CN	IRSB	DLSB	LGR	CN	W	IRCT	FSSB	DCSB
2012	39	42	22	38	23	35	49	50	33	54	56	27	33	35	57	24	40	32	42
2013	48	37	49	46	30	31	38	39	43	43	51	21	29	46	52	50	31	31	37
2014	32	33	30	30	29	29	23	23	27	31	32	23	29	31	33	28	19	30	31
2015	20	23	19	20	24	19	24	25	19	24	29	20	18	20	30	23	25	24	21
2016	19	22	21	19	21	16	24	25	18	25	30	16	18	19	29	17	24	21	20

[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 3. Average crop revenue election (ACRE) payments/acre (2012 to 2016), by farm, crop, and year (in $ U.S.).

	Stuttgart			Wynne			Leachville		Hoxie					McGehee					
Year	LGR[a]	IRSB	W	LGR	IRSB	DLSB	IRCT	DLCT	LGR	MGR	CN	IRSB	DLSB	LGR	CN	W	IRCT	FSSB	DCSB
2012	35	23	8	34	15	13	61	48	30	76	75	17	10	33	83	8	59	22	22
2013	50	18	27	51	18	12	40	30	47	54	66	12	9	51	73	26	37	21	18
2014	29	15	12	29	17	11	22	15	27	35	39	12	8	31	43	11	21	19	14
2015	15	10	7	15	13	6	20	15	15	24	32	11	5	16	34	8	26	13	9
2016	13	9	8	13	10	4	20	15	12	23	29	9	5	14	32	6	26	11	8
Mean	28	15	12	29	15	9	33	25	26	43	48	12	7	29	53	12	34	17	14

[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 4. Annual average net farm income from 2012 to 2016, in $/acre (by farm).

	Annual average (2012 to 2016)				
Farm location	Wynne	Hoxie	Stuttgart	Leachville	McGehee
	($/acre)				
Market receipts	638	656	539	935	721
DPs (ACRE)	42	41	38	16	28
LDPs (ACRE)	0	0	0	3	1
Weighted ACRE payments (ACRE), by planted acres	21	23	21	33	28
Total government payments (ACRE)	**64**	**64**	**59**	**51**	**57**
Total receipts (ACRE)	**702**	**720**	**598**	**986**	**778**
DPs (BASE)[a]	53	51	47	20	35
LDPs (BASE)	0	0	0	4	1
CCPs (BASE)	0	0	0	1	1
Total government payments (BASE)	**53**	**51**	**47**	**25**	**37**
Total receipts (BASE)	**691**	**707**	**586**	**960**	**758**
Total cash expenses	672	649	469	737	642
Depreciation	167	49	61	60	61
Net farm income (ACRE)	**-137**	**22**	**68**	**189**	**75**
Net farm income (BASE)	**-148**	**9**	**56**	**163**	**55**
Difference (BASE-ACRE)	*-11*	*-13*	*-12*	*-26*	*-20*

[a] Under BASE participation, farmers receive deficiency payments (DPs), counter-cyclical payments (CCPs) and loan-deficiency payments (LDPs), and do not participate in the Average Crop Revenue Election (ACRE) program.

ECONOMICS

Arkansas Representative Panel Farm Analysis of Loan Rates and Target Prices for the 2012 Farm Bill

V. Karov, E.J. Wailes, and K.B. Watkins

ABSTRACT

The 2008 Farm Bill expires in 2012 and the need to draft a new legislation has emerged. Modification of the 2008 Act will be heavily influenced by reduced funding to address the federal budget deficit. Hence, this study is an analysis of the impacts of alternative (or modified) safety net programs. In light of the currently high crop market prices and record United States net farm income in 2011, the general public and most farm interest groups have endorsed the removal of direct payments (DPs). However, DPs have historically been important in providing a safety net for Arkansas producers, who are particularly affected by volatility in crop prices and energy based input prices such as fuel and fertilizers. The goal of this study is to assist Arkansas farmers and policy makers in understanding the effects of alternative commodity program modification and in helping to develop positions regarding formulation of the 2012 Farm Bill. The objective is to estimate the effects on Arkansas farmers of fully removing DPs during 2012 to 2016 and to determine what size of adjustment in loan rates and target prices would be meaningful in maintaining a safety net for Arkansas producers during this period. Five Arkansas representative panel farms provide the framework for the analysis. Ten-year historical data is used to develop national and world crop price, as well as farm-specific yield and expense empirical distributions by using multivariate empirical probability distributions. Stochastic baseline projections for 2012 to 2016 with 500 random draws annually/variable are simulated in SIMETAR. The results suggest that removing direct payments in the 2012 Farm Bill would negatively affect all five representative panel farms. Rice growers would be particularly negatively affected by such a policy. To remedy the potential loss of DPs and to maintain a safety net for

producers in Arkansas based on loan deficiency payments and/or counter-cyclical payments, considerable adjustments in loan rates and target prices across all crops during the 2012 Farm Bill would be required.

INTRODUCTION

The 2008 Food, Conservation, and Energy Act (better known as the 2008 Farm Bill) is set to expire in 2012. In November 2011, the by-partisan "Super Committee" failed to reach a federal deficit reduction agreement in which the 2012 Farm Bill would have been included based on a proposal drafted by the House and Senate agricultural committees. As a result, the need to draft new legislation in 2012 has emerged. Such a bill is destined to be a result of a much more open process with proposed agricultural programs facing added public scrutiny as well as congressional amendments through floor debates.

The debate is underway on how to modify the 2008 Farm Bill, given the prospects of reduced funding for the 2012 legislation due to large federal budget deficits, relatively high crop prices and incomes in agriculture, and World Trade Organization (WTO) constraints while maintaining a safety net for producers. Increasing farm input costs, crop losses due to floods and lobbying by interest groups are factors that are also likely to shape the way in which the 2012 Farm Bill will be written. As a result, there is a need to examine the impacts of alternative or modified safety net programs.

In light of the current policy environment, most interest groups have endorsed a removal of direct payments (DPs). However, DPs historically have played a prominent role in providing a safety net for Arkansas producers. In addition, under the current market price environment, Arkansas producers do not receive any loan deficiency payments (LDPs) and counter-cyclical payments (CCPs) (with rare exceptions for cotton), while participation rates in the Average Crop Revenue Election (ACRE) program have remained low rendering DPs as the only farm program that has provided some stability to Arkansas crop farm incomes.

The goal of this study is to assist Arkansas farmers and policy makers in understanding the impact of removing DPs and in developing their positions regarding the 2012 Farm Bill. The objective is to examine the impacts of alternative proposals that would modify the 2008 Farm Bill. To achieve the main goal, four scenarios are considered:

- A full continuation of 2008 Farm Bill commodity programs. Farmers do not choose to participate in ACRE (Baseline)
- A complete removal of DPs
- What is the minimum level at which loan rates can be raised to trigger LDPs during 2012 to 2016?
- Assuming DP rates remain at 2012 levels, what is the minimum level at which target prices can be raised to trigger CCPs during 2012 to 2016?

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 two to three 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 1 shows characteristics for 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.

Following Richardson, Klose, and Gray (2000), a procedure for developing multivariate empirical (MVE) probability distributions for farm-related variables is employed. Specifically, ten-year historical data are used to develop empirical distributions for national and world crop prices, as well as farm-specific yields and expenses (diesel fuel, fertilizer, and electricity). SIMETAR is used to simulate stochastic baseline five-year projections for the period 2012 to 2016 with 500 iterations/variable/year.

Historical national and adjusted world prices are obtained from the United States Department of Agriculture's National Agricultural Statistics Service (USDA/NASS; USDA, NASS, 2012), the USDA's Economic Research Service (ERS) Rice Yearbook (USDA, ERS, 2012a) and Rice Outlook (USDA, ERS, 2012b). Actual historical farm-specific yields, on the other hand, are obtained during the panel farm interview process. 2008 Farm Bill policy variables such as crop-specific direct payment rates, loan rates and target prices are obtained from the USDA/ERS Side-By-Side Comparison (USDA, ERS, 2009). Finally, historical farm expense data (diesel fuel, potash, nitrogen, and phosphate) are obtained from USDA/NASS and the U.S. Energy Information Administration (electricity) (USDA, NASS, 2012; EIA, 2012).

The "February 2011 Baseline Update for United States Agricultural Markets" by the Food and Agriculture Policy Research Institute (FAPRI)-University of Missouri is used to obtain projected crop prices. An earlier version of the same publication (March 2011), on the other hand, is used to obtain projected indices of prices paid by farmers (FAPRI, 2012). Finally, projected farm-specific crop yields are calculated by the authors by assuming farm and crop-specific growth trends.

RESULTS AND DISCUSSION

Table 2.1 provides baseline estimates for a continuation of the 2008 commodity program parameters in the 2012 Farm Bill. As Table 2.1 illustrates, results from the first scenario suggest that a full continuation of 2008 Farm Bill commodity programs during 2012 to 2016 results in four of the five farms having a positive net income on a per acre basis as an annual average during this period. Relatively high depreciation costs for the smaller sized Wynne farm results in negative net income per acre. As Table 2.2 shows, on a per acre basis, most DPs as an annual average for the years 2012 to 2016 are received for rice (e.g., $98/acre for long-grain rice for the Hoxie farm) with cotton being a distant second (e.g., $48 and $20/acre for irrigated cotton for the McGehee and Leachville farm, respectively).

Table 3 summarizes the results from the second scenario. A complete removal of DPs for the years 2012 to 2016 results in two of the five farms (Wynne and Hoxie) having a negative net income on a per-acre basis as an annual average during this period. Across all farms, net income changes relative to the baseline range from -567% (Hoxie) to -12% (Leachville).

Results from the third scenario are presented in Table 4. The analysis for rice and cotton applies to all farms since the calculation of LDPs for these two crops is based on the respective adjusted world prices, unlike other crops for which the posted county prices (PCPs) are employed. In 2012, the rice loan rate can be raised to $12.23/cwt (an 88 % increase relative to the current loan rate) before any LDPs are triggered. By 2016, the rice loan rate could potentially be raised up to $13.03/cwt without triggering LDPs for any rice producer. On the other hand, analysis at the specific farm-level suggests that the soybeans loan rate can be increased to $11.14/bu in 2012 (a 123% increase relative to the current loan rate) before any LDPs are received by the Stuttgart farm.

Table 5 shows the results from the final scenario. This analysis is not farm-specific since across all sample crops the CCPs (and effective prices) calculation is based on national loan rates and national average farm prices. The results indicate that in 2012, the rice target price can be raised to $14.51/cwt before any CCPs are triggered for long-grain rice (a 38% increase relative to the current rice target price). By 2016, the rice target price could potentially be raised to $15.37/cwt without triggering CCPs for any rice producer. For medium-grain rice, on the other hand, the rice target price can be increased from as low as $18.16/cwt (in 2012) to as high as $18.78/cwt (in 2016) before any CCPs are triggered.

SIGNIFICANCE OF FINDINGS

Historically, DPs have played a significant role in providing a safety net for farmers in Arkansas. This study finds that a removal of the DPs program in the 2012 Farm Bill negatively impacts Arkansas producers with rice growers being particularly affected. Such findings are especially alarming under the current market price environment in which farmers do not receive any LDPs and CCPs (with cotton being a rare exception). Moreover, ACRE participation rates have remained low since 2009. To maintain a safety net for Arkansas rice farmers, a significant adjustment in target prices and particularly in loan rates during the 2012 legislation is needed.

ACKNOWLEDGMENTS

Funding for this study was provided by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Food and Agricultural Policy Research Institute (FAPRI). University of Missouri. 2012. U.S. Baseline Briefing Book. Available online at: http://www.fapri.missouri.edu/index.asp?current_page=home

Hignight, J.A. 2007. "An Economic Comparison of Alternative Farm Policies on Arkansas Representative Panel Farms." MS thesis, University of Arkansas, Fayetteville.

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. and Appl. Econ. 32:299-315.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2012a. Rice Yearbook. Available online at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1229.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2012b. Rice Outlook. Available online at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1285.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2009. The 2008 Farm Bill Side-By-Side Comparison. Available online at: http://www.ers.usda.gov/FarmBill/2008/.

U.S. Department of Agriculture (USDA). National Agricultural Statistics Service (NASS). 2012. Available online at: http://www.nass.usda.gov/

U.S. Energy Information Administration (EIA). 2012. Available online at: http://www.eia.gov/.

Table 1. Arkansas representative panel farm characteristics.

Farm name	ARHR3000	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

Table 2.1. Annual average net farm income, by farm, from 2012 to 2016 in $/acre.

	Annual average (2012 to 2016)				
Farm location	Wynne	Hoxie	Stuttgart	Leachville	McGehee
	------------------------------- ($/acre) ----------------------------------				
Market receipts	**638**	**656**	**539**	**935**	**721**
DPs[a]	53	51	47	20	35
LDPs	0	0	0	4	1
CCPs	0	0	0	1	1
Total government payments	**53**	**51**	**47**	**26**	**36**
Total receipts	**691**	**707**	**586**	**961**	**757**
Total cash expenses	672	649	469	737	642
Depreciation	167	49	61	60	61
Net farm income	**-148**	**9**	**56**	**164**	**54**

[a] DP = direct payments, LDP = loan deficiency payments, and CCP = counter-cyclical payments.

Table 2.2. Annual average direct payments, by farm and crop, from 2012 to 2016 in $/acre.

	Annual average (2012 to 2016) by crop				
Farm location	Wynne	Hoxie	Stuttgart	Leachville	McGehee
	------------------------------- ($/acre) ----------------------------------				
DPs[a]	53	51	47	20	35
Long-grain rice	95	98	84	---	91
Medium-grain rice	---	94	---	---	---
Irrigated soybeans	11	10	9	---	10
Dry soybeans	11	10	---	---	0
Irrigated cotton	---	---	---	20	48
Dry cotton	---	---	---	21	---
Corn	---	0	---	---	0
Wheat	---	---	12	---	0

[a] DP = direct payments.

Table 3. Annual average net farm income, by farm, from 2012 to 2016 in $/acre.

	Annual average (2012 to 2016)				
Farm location	Wynne	Hoxie	Stuttgart	Leachville	McGehee
	($/acre)				
Market receipts	**638**	**656**	**539**	**935**	**721**
DPs[a]	0	0	0	0	0
LDPs	0	0	0	4	1
CCPs	0	0	0	1	1
Total government payments	**0**	**0**	**0**	**5**	**2**
Total receipts	**638**	**656**	**539**	**941**	**722**
Total cash expenses	672	649	469	737	642
Depreciation	167	49	61	60	61
Net farm income (Scenario 2)	**-201**	**-42**	**9**	**144**	**19**
Net farm income (Scenario 1)	**-148**	**9**	**56**	**164**	**54**
Difference (Scenario 2-Scenario 1)	*-53*	*-51*	*-47*	*-20*	*-35*

[a] DP = direct payments, LDP = loan deficiency payments, and CCP = counter-cyclical payments.

Table 4. Highest potential loan rate level increases without triggering loan-deficiency payments (2012 to 2016), by crop, farm, and year.

Crop	Unit	Loan rate 2012	Farm	2012	2013	2014	2015	2016
Rice	$/cwt	6.50	All	12.23	12.11	12.29	12.73	13.03
Cotton	$/lb	0.52	All	0.73	0.77	0.79	0.82	0.85
Soybeans	$/bu	5.00	Stuttgart	11.14	11.14	11.08	11.18	11.32
Wheat	$/bu	2.94	Stuttgart	6.07	5.62	5.78	6.03	6.13
Soybeans	$/bu	5.00	Wynne	11.32	11.32	11.26	11.36	11.50
Soybeans	$/bu	5.00	Hoxie	11.51	11.51	11.45	11.55	11.69
Corn	$/bu	1.95	Hoxie	4.81	4.75	4.83	4.92	4.89
Soybeans	$/bu	5.00	McGehee	11.28	11.28	11.22	11.32	11.46
Corn	$/bu	1.95	McGehee	4.81	4.75	4.83	4.92	4.89
Wheat	$/bu	2.94	McGehee	6.07	5.62	5.78	6.03	6.13

Table 5. Highest potential target price level increases without triggering counter-cyclical payments (2012 to 2016), by crop and year.

Crop	Unit	Target price 2012	2012	2013	2014	2015	2016
Long-grain rice	$/cwt	10.50	14.51	14.31	14.58	15.02	15.37
Medium-grain rice	$/cwt	10.50	18.16	17.77	18.32	18.50	18.78
Cotton	$/lb	0.7125	0.8249	0.8446	0.8649	0.8796	0.8908
Soybeans	$/bu	6.00	11.72	11.72	11.66	11.76	11.90
Wheat	$/bu	4.17	6.59	6.14	6.30	6.55	6.65
Corn	$/bu	2.63	5.09	5.03	5.11	5.20	5.17

Stochastic Analyses of Commodity Program for U.S. Rice: Adjustments on Deficiency Payments, Target Price, and Loan Rate

E.J. Wailes and E.C. Chavez

ABSTRACT

This study focuses on analyzing the impact potential elimination of direct payments and changes in target price and loan rate in rice have on farm income. The model is simulated using stochastic analysis, where rice yields in the U.S. and the rest of the world are randomized based on historical variability. Three scenarios are analyzed assuming that direct payments were to be eliminated totally in 2012. If both the current target price and loan rate are maintained (Scenario 1), the probable production market values (PMVs) range from \$2.42 to \$4.33 billion, with an average of \$3.14 billion. No random draw results in counter-cyclical payments (CCP) under this scenario. On the other hand if both the target price and loan rate were to be increased by 25% (Scenario 2), the probable PMVs will be the same as Scenario 1; but it is probable that 57% of the time there will be zero CCP; and 43% of the time there will be government CCP expenditure of \$3 million or more, with a maximum of \$302.8 million. Per hundredweight, this is equivalent to an average probable CCP payment of \$0.18, with a maximum of \$1.58. Lastly, if the current target price is to be removed and current loan rate is maintained (Scenario 3), results show no government payment at all, i.e., only PMVs are generated in the same magnitude as that of Scenario 1.

INTRODUCTION

As budget deficit and budget savings become the main focus of current discussion in the U.S. Congress and elsewhere in the country, farm commodity program funding is being subjected to more scrutiny for dramatic changes than ever before. A number of ideas on possible program changes to generate government savings have been proposed. However, there is a scarcity of quantitative estimates of the potential impacts of such changes. This study focuses on analyzing the impact on farm income of potential elimination of direct payments and potential changes in target price and loan rate in rice. Results of this analysis can contribute to a better understanding of the potential impact of alternative scenarios on commodity program adjustments. This is timely considering that new policies have to be formulated and enacted into a new law as the current Farm Act (2008) is set to expire in 2012.

PROCEDURES

The analytical tool we used in this study is the Arkansas Global Rice Model (AGRM). The AGRM is a multi-country econometric framework which has over 250 equations representing rice supply and demand relationships in 43 countries and 5 regions around the world developed and maintained by the Department of Agricultural Economics and Agribusiness, University of Arkansas in Fayetteville. The theoretical structure and the general equations of the AGRM are documented online by Wailes and Chavez (2011).

Having the ability to look at several potential alternatives, as well as a possible range of options, is important in good policy decision-making. This study addresses this need by making use of stochastic analysis which provides information on the possible range of outcomes for any given change or scenario. It makes sense to use stochastic analysis given the fact that underlying assumptions usually do not hold true in practice, i.e., actual market outcomes deviate from average estimates. The analysis covers the five-year period 2012 through 2016. The three specific scenarios analyzed, all of which assume elimination of direct payments, include the following:

- Scenario 1: Maintains the current target price and loan rate
- Scenario 2: Increases both the current target price and loan rate by 25%
- Scenario 3: Removes the current target price, and maintains the current loan rate

The baseline projections used in this analysis are based on assumptions of current policies, macroeconomic variables, and average weather conditions. As in the case of most analyses, it is important to point out that results will vary when baseline numbers and assumptions are changed.

The stochastic framework is generated using multivariate empirical distributions (MVE) of the yield for each of the 48 countries and regions in the model, as well as for each of the six rice-producing states in the U.S. Yield is used because it is the variable that not only differs by year and region but is also very sensitive to changes in weather conditions and water availability—factors that are critical for rice production. A total of 500 random draws were implemented using a 28-year empirical distribution of historical yields generated using the software Simulation & Econometrics to Analyze Risk (SIMETAR) developed by Richardson et al. (2008).

RESULTS AND DISCUSSION

When applicable, the detailed results of the stochastic analyses are presented as cumulative distribution functions (cdf) and probability density functions (pdf) of the production market values and the counter-cyclical payments in Figs. 1a to 3b. Scenario 1: The results of this scenario are presented in Figs. 1a and 1b. The probable production market values (PMVs) range from $2.42 to $4.33 billion, with an average of $3.14 billion. This scenario results in zero counter-cyclical payments (CCP) for all the random draws. This indicates that it is unlikely that producers will receive CCP under this scenario given the baseline numbers.

Scenario 2: Figures 2a to 3b show the detailed results of this scenario. The probable PMVs range from $2.42 to $4.33 billion, with an average of $3.13 billion. It is probable that 57% of the time there will be zero CCP; and 43% of the time there will be total government CCP expenditure of $3 million or more, with maximum of $302.8 million. Per unit, there is 43% probability that producers will receive CCP of $0.016 or more per cwt, with an average probable CCP payment of $0.18 per cwt and maximum payment of $1.58 per cwt. Thus, under this scenario, producers have the chance, albeit only 43%, to receive CCP benefits given the baseline numbers.

Scenario 3: This scenario results in no government payment at all, i.e., only PMV is generated in the same magnitude as those of Scenarios 1 and 2.

Looking at the pdf is another way to better understand how the range of outcomes is distributed. The pdf divides the frequency distribution into four equal parts: the lower quartile represents the 25th percentile, the second quartile shows the 50th percentile (or median), and the upper quartile indicates the 75th percentile.

When applied to Scenario 1, Fig. 1b shows that 25% of the frequency distribution of the production market values falls below $2.52 billion (the lower quartile), 50% falls below $3.13 billion (the second quartile), 75% falls below $3.87 billion (the upper quartile), and the other 25% of the distribution lies at or above the $3.87 billion.

For Scenario 2, Fig. 2b shows that 25% of the frequency distribution of the production market values falls below $2.53 billion (the lower quartile), 50% falls below $3.13 billion (the second quartile), 75% falls below $3.90 billion (the upper quartile), and the other 25% of the distribution (25%) lies at or above the $3.90 billion. For Scenario 2 CCPs, Fig. 3b shows that 25% of the frequency distribution falls below zero, 50% falls below $34.6 million, 75% falls below $213.9 million, while the remaining 25% of the distribution lies at or above the $213.9 million.

On a per-hundredweight-basis, the pdf values of CCP for Scenario 2 are equivalent to the following: 25% of the frequency distribution falls below zero, 50% falls below $0.18, 75% falls below $1.12, while the remaining 25% of the distribution lies at or above the $1.12. The frequency distribution of the production market values for Scenario 3 is exactly the same as that of Scenario 2.

To sum up, results indicate that under the assumptions in this analysis, producers will be better off under Scenario 2 which increases both the target price and loan rate by 25%. This is the only scenario out of the three considered in this analysis under which they have a chance of receiving CCP. On the other hand, Scenarios 1 and 3 have better chances of resulting in savings from the government's point of view. Thus, the focus of the conclusion can vary depending on which side one is coming from.

SIGNIFICANCE OF FINDINGS

Arkansas accounts for nearly 50% of U.S. rice output, and hence rice has a predominant role in the Arkansas agricultural economy. Direct U.S. government payments are an important component of returns from rice and other major crops and as such any potential dramatic changes in these payments are of utmost interest to rice stakeholders. The results presented in this report represent an improved research tool that uses global stochastic framework in a system of equations to determine the impact of possible elimination of direct payments (Wailes and Chavez, 2011) and changes in target price and loan rate for domestic rice. This information is of interest to Arkansas rice producers and millers and other stakeholders as it shows the range of possible outcomes from several policy alternatives, thereby contributing to the better understanding of potential quantitative impact of commodity program adjustments.

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 modified for analyzing the scenarios presented in this report.

LITERATURE CITED

Richardson, J.W., K.D. Schumann, and P.A. Feldman. 2008. SIMETAR. Simulation & Econometrics to Analyze Risk. Simetar, Inc. College Station, Texas. (manual)

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 01-2011. Published at: http://ageconsearch.umn.edu/handle/102650

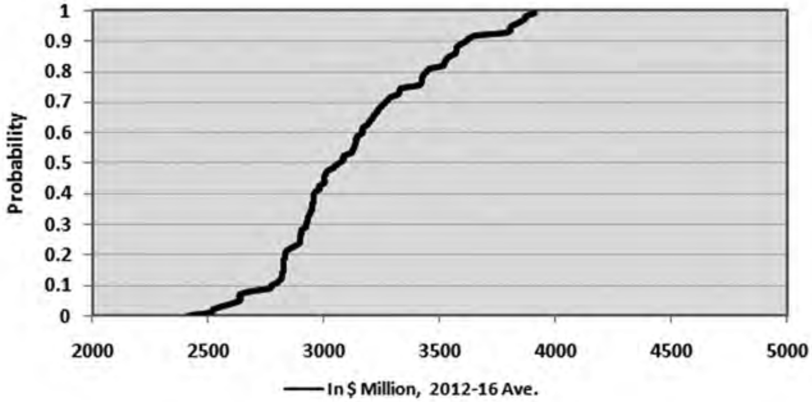


Fig. 1a. Cumulative distribution functions of U.S. Rice Production Market Values, No Direct Payments, No Change in Target Price and Loan Rate (Scenario 1).

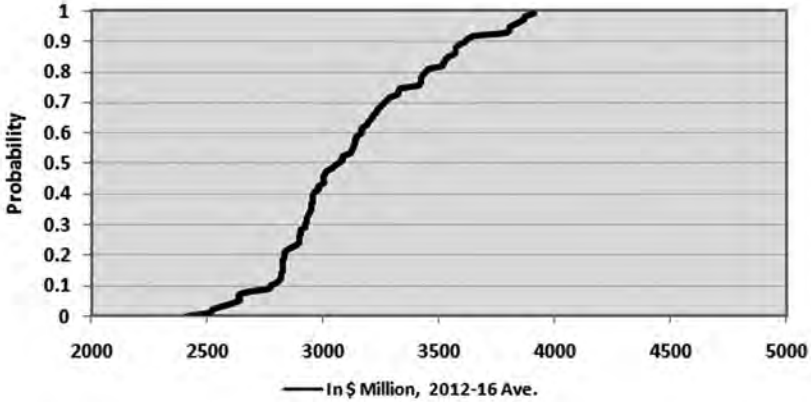


Fig. 1b. Probability density functions of U.S. Rice Production Market Values, No Direct Payments, No Change in Target Price and Loan Rate (Scenario 1).

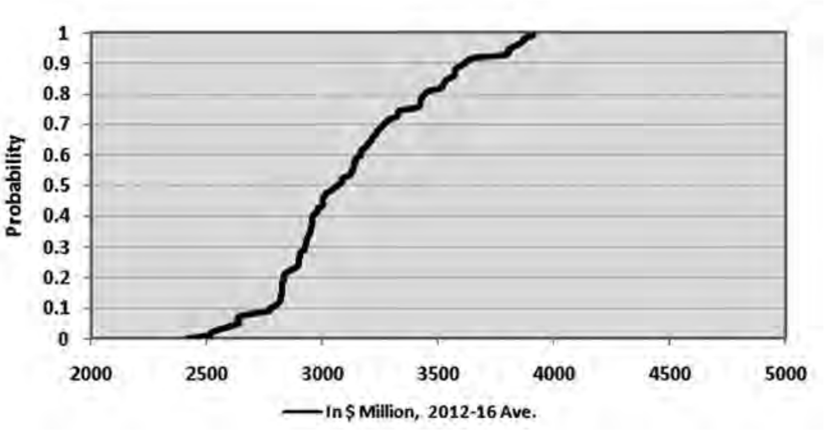


Fig. 2a. Cumulative distribution functions of U.S. Rice Production Market Values, No Direct Payments with 25% Increase in both Target Price and Loan Rate (Scenario 2).

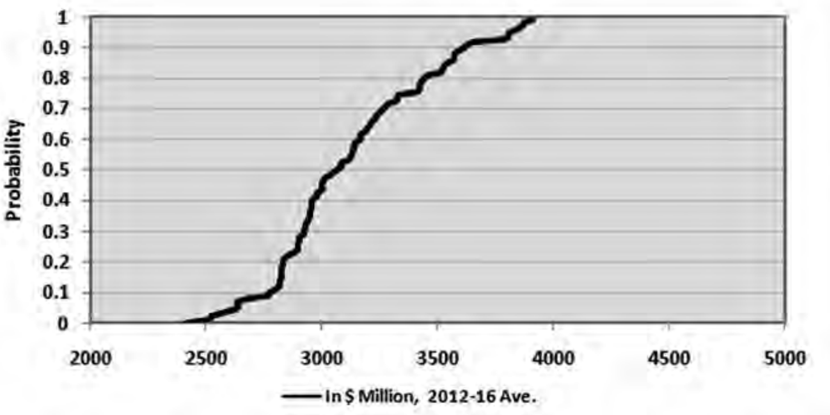


Fig. 2b. Probability density functions of U.S. Rice Production Market Values, No Direct Payments with 25% Increase in both Target Price and Loan Rate (Scenario 2).

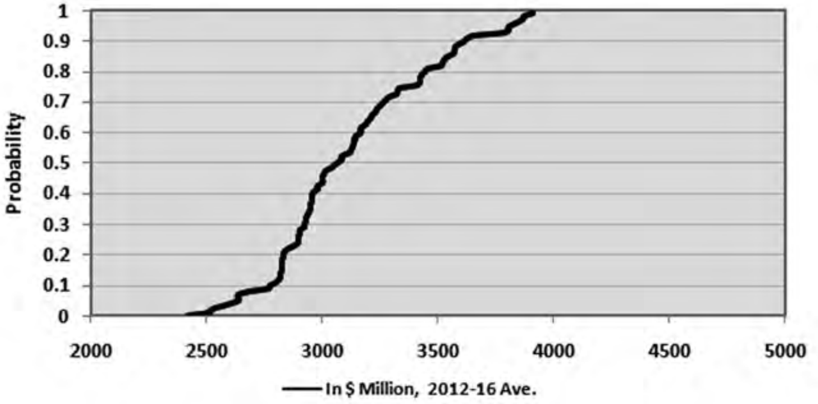


Fig. 3a. Cumulative distribution functions of U.S. Rice Countercyclical Payments, No Direct Payments with 25% Increase in both Target Price and Loan Rate (Scenario 2).

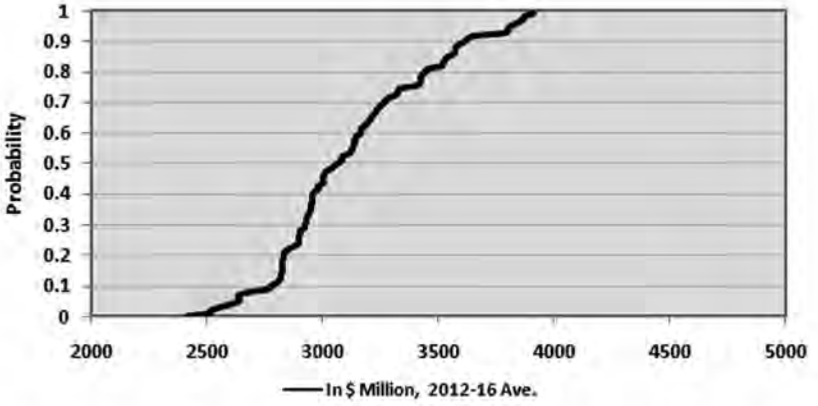


Fig. 3b. Probability density functions of U.S. Rice Countercyclical Payments, No Direct Payments with 25% Increase in Target Price and Loan Rate (Scenario 2).

ECONOMICS

World Rice Outlook: International Rice Deterministic and Stochastic Baseline Projections, 2012-2021[1]

E.J. Wailes and E.C. Chavez

ABSTRACT

This study presents baseline projections for international rice which includes both deterministic and stochastic estimates. The deterministic component assumes continuation of existing policies; current macroeconomic variables; no new World Trade Organization (WTO) trade reforms; and average weather conditions. The stochastic component uses multivariate empirical analysis where rice yields in the U.S. and the rest of the world are randomized based on historical variability.

Over the baseline period, world rice output grows at 1.00% per year with 0.80% coming from yield improvement and 0.20% coming from slight growth in area harvested. Driven solely by population growth, global rice consumption gains 1.06% annually—as per capita use remains flat. Net trade continues to grow at 2.54% per year. A combination of flat consumption and increased output are expected to dampen prices over the baseline period.

INTRODUCTION

The U.S. exports nearly half of its total rice production and ranks fifth among the top world rice exporters. Thus U.S. rice prices are heavily influenced by the global rice economy. Supply, demand, trade, and stocks as well as policies in the U.S. and other major exporters and importers determine rice price paths. This study provides a sum-

---

[1] This material is based upon work supported with funding provided by the Arkansas Rice Research and Promotion Board. The macro data are from Global Insight and the base Production, Supply & Demand rice data are from USDA-ERS.

mary of ten-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. This research benefitted from input information provided by the Food and Agricultural Policy Research Institute (FAPRI) which included macroeconomic data and U.S. crop costs and returns. However, all the results presented in this report remain the responsibility of the authors. The deterministic baseline numbers presented are average projections of what could happen if basic assumptions used in the analysis hold true. However, actual market outcomes usually deviate from average estimates. This is where the usefulness of the stochastic component of the analysis comes in, as it shows a range of possible outcomes considering historical uncertainties in the rice market.

PROCEDURES

The baseline deterministic and stochastic estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a multi-country statistical simulation and econometric framework developed and maintained by the Department of Agricultural Economics and Agribusiness at the University of Arkansas in Fayetteville. The global model is disaggregated into 43 of the major rice producing, consuming, and trading rice countries; and the rest of the world is aggregated into five regions: 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 documentation by Wailes and Chavez (2011). Updated macroeconomic assumptions used in the model are provided by FAPRI-ISU and the costs and returns for U.S. crops are based on FAPRI-MO U.S. March 2012 baseline (2012).

The deterministic baseline assumes the following: continuation of existing policies; current macroeconomic variables; no new WTO trade reforms; and average weather conditions.

The stochastic component of the analysis provides a range of possible outcomes, as opposed to the deterministic analysis which generates average point estimates. It makes sense to also include stochastic analysis given the fact that underlying assumptions in the deterministic baseline usually do not hold true in practice, i.e., actual market outcomes deviate from average estimates.

The stochastic framework is generated using multivariate empirical distributions (MVE) of the yield for each of the 48 countries and regions in the model, as well as for each of the six rice-producing states in the U.S. Yield is used because it is the variable that not only varies by year and country but is also very sensitive to changes in weather conditions and water availability—factors that are critical for rice production. A total of 500 random draws are implemented using a 28-year empirical distribution of historical yields generated using the software Simulation & Econometrics to Analyze Risk (SIMETAR) developed by Richardson et al. (2008).

RESULTS AND DISCUSSION

Deterministic Baseline

As expected in last year's baseline outlook (Wailes and Chavez, 2011), India, with its mounting rice and wheat stocks has officially lifted the ban on non-basmati rice exports as of September 2011—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 rice pledging scheme implemented by Thailand's new government administration—where producers are paid high prices, coupled with high minimum export prices—has not affected the international rice trade as much as initially anticipated due to the increased price competition from the other major rice exporting countries of India, Vietnam, and Pakistan. Recently, rice export volumes from Thailand declined dramatically, while export supplies from the three other major exporters dominated international trade. As a consequence, the Thai prices which are quoted very high have diminished usefulness as the international reference prices. Consistent with this observation, it should not be surprising that the equilibrium international prices generated by AGRM are closer to the prevailing export prices of Vietnam and India. For this baseline, we call this price "International Reference Price" instead of Thai price.

Detailed results of the analysis for the world and the U.S. showing 12 years of information (2010 to 2021) are presented in Tables 1 to 4. Over the baseline period, world rice output grows at 1.00% per year with 0.80% coming from yield improvement and 0.20% coming from slight growth in area harvested. Driven solely by population growth, global rice consumption gains 1.06% annually—as per capita use remains flat (Tables 2 and 4).

Net trade continues to grow at 2.54% per year. International rice prices are projected to be flat or decline slightly as self-sufficiency in rice and the use of high-yielding hybrids and other improved production technology increasingly become the focus of major consuming countries. A combination of flat consumption and increased output are expected to dampen prices over the baseline period (Table 1).

The international rice market is characterized by high volatility due to a number of reasons. Aside from rice supply and demand being inelastic, rice is also thinly traded. Only about 7% of rice production is traded as opposed to 10% for coarse grains and 16% for wheat (computed from FAPRI, 2010). There is also high concentration among leading rice exporters. The top five exporters composed of Thailand, Vietnam, India, Pakistan, and the U.S. combined account for 85% of global net trade (Table 1).

Despite current uncertainties in the impact of Thailand's pledging scheme and other rice policies in the future, the country, with its resources and strong focus on quality and branding, is expected to remain the top global rice exporter over the baseline period. Slower rice export growth is expected for Vietnam and the U.S. due to area limitations, and irrigation constraints in the case of the U.S. India will surpass Vietnam and replace the latter as the second top rice exporter over the same period. Cambodia and Myanmar are projected to increase rice exports steadily as production continues to exceed consumption. Rice exports of the U.S., on the other hand, are projected to decline from 2.9 million metric tons (mmt) in 2010 to 2.1 mmt by 2021, as domestic consumption continues to grow and area harvested drops substantially in 2011 and remains relatively flat over the baseline (Table 3).

Global net rice exports will grow by 9.3 mmt over the baseline period. Net exports of India, Vietnam, Myanmar, and Cambodia will grow by 9.9 mmt combined while those of Thailand and the U.S. will contract by 1.7 mmt.

The bulk (31.6%) of the total rice net import demand is projected to come from the Philippines, Nigeria, Bangladesh, Iran, and Indonesia; and 16.7% from Iraq, Saudi Arabia, Ivory Coast, Malaysia, and Senegal. However, 33.2% of the growth in net rice imports is accounted for by the Philippines and Bangladesh; 32.8% by Africa; and 16.7% by the Middle East.

India, China, Indonesia, Bangladesh, and Thailand account for 68.1% of the world's total area harvested. While a number of notable countries expanded their rice area, others contracted theirs over the baseline period. A total of 3.4 million hectares will be added by India, Pakistan, Thailand, and Bangladesh which more than compensates for the total decline of 1.5 million hectares in China, and 0.5 million hectares in the U.S., Japan, South Korea, and Vietnam. A number of challenges face potential rice expansion worldwide: constraints in land and water, farm demographics, climate change, and rice carbon footprint.

The world's top milled rice producers are China, India, Indonesia, Bangladesh, and Vietnam–which combined accounts for 72.3% of global output. Global milled rice production expands by 51.3 mmt over the same period, with 62.2% coming from India, Indonesia, Bangladesh, Vietnam, and Thailand combined; and 24.7% comes from China, Egypt, Cambodia, Myanmar, Pakistan, the Philippines, and Nigeria combined.

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 good. Demographic trends also weaken rice demand as aging populations and increasing health consciousness shift preferences away from carbohydrates and towards protein-based diets. About 70% of total global rice consumption is accounted for by China, India, Indonesia, Bangladesh, and Vietnam over the baseline period. World total rice consumption expands by 54.8 mmt (net), with 54.2% coming from the same group five countries above; and 6.1% accounted for by the Philippines and Pakistan.

Stochastic Analysis

The detailed results of the stochastic analyses for selected variables for the world and the U.S. are presented in Figs. 1 thru 10, showing the direction and spread of the stochastic outcome distribution. Included in the charts are the stochastic average, the 10th, and the 90th percentiles. Intuitively, the gap between the two percentiles (10th and 90th) indicates volatility. Widening indicates increased volatility and narrowing indicates decreased volatility.

Fig. 1 shows the long-grain rice international reference price. For 2012 while the stochastic average is $562 per metric ton (mt), the stochastic distribution indicates that 10% of the time the average price will be higher than $656/mt; and lower than $484/mt 10% of the time. Note that the gaps between the 10th and 90th percentiles are $171 in 2012, $121 in 2016 and $130 in 2021.

Fig. 9 shows the U.S. long-grain export price which indicates a stochastic average of $546/mt in 2012. The stochastic distribution indicates that 10% of the time the average price will be higher than $600/mt, and lower than $496/mt 10% of the time. The gaps between the 10th and 90th percentiles are $104 in 2012, $198 in 2016 and $231 in 2021, indicating increasing volatility over the baseline relative to the more stable international reference price shown in Fig. 1 above.

This feature of the stochastic analysis provides an advantage as it indicates how the outcomes are distributed, an analytic limitation of the average point estimates generated by deterministic analysis. Analyses similar to those made for Figs. 1 and 9 can be made for the rest of the stochastic results for the other selected variables (Figs. 2 through 8). The same principle holds in explaining the results of the rest of the charts, with the difference lying only with varying units and absolute numbers. Hence the details of the remaining stochastic charts will not be discussed in this paper in order to save space. However, a more complete presentation and discussion of results for individual countries will be made available in a separate paper to be published at the AgEcon Search website.

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 deterministic baseline and stochastic 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.

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 enhanced for the specific purpose of analyzing the deterministic and stochastic analyses presented in this report.

LITERATURE CITED

FAPRI U.S. Baseline Briefing Book. FAPRI-MU Report #01-12. March 2012. 68 pages. Published at: http://www.fapri.missouri.edu/outreach/publications/2012/FAPRI_MU_Report_01_12.pdf

FAPRI. 2010. FAPRI 2010 U.S. and World Agricultural Outlook. Fapri Staff Report 10-FSR1.

Richardson, J.W., K.D. Schumann, and P.A. Feldman. 2008. SIMETAR. Simulation & Econometrics to Analyze Risk. College Station, Texas.

Wailes, E.J. and E.C. Chavez. 2011. "World Rice Outlook: International Rice Baseline Projections, 2011-2020". University of Arkansas Department of Agricultural Economics and Agribusiness, Division of Agriculture Staff Paper 2011-02. Published at http://ageconsearch.umn.edu/handle/112998

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.

Table 1. Projected rice trade over the next 10 years, 2010/11 to 2021/22

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(thousand metric tons											
Net Exporters				)								
Argentina	640	638	639	612	580	600	578	568	586	595	605	616
Australia	200	346	333	327	338	347	343	355	368	394	396	409
Cambodia	980	996	1,004	1,188	1,320	1,404	1,518	1,619	1,743	1,962	2,105	2,141
China	-38	99	155	248	231	270	240	270	236	234	227	155
Egypt	40	545	477	470	461	463	432	420	405	391	393	383
India	2,800	6,500	7,995	7,557	8,070	8,001	8,791	8,632	8,134	8,446	8,515	8,542
Myanmar (Burma)	750	721	1,034	1,117	1,189	1,337	1,477	1,637	1,804	1,940	2,026	2,064
Pakistan	3,150	3,555	3,404	3,503	3,245	3,379	3,325	3,396	3,401	3,479	3,559	3,454
Thailand	10,300	7,531	7,446	9,076	9,410	9,406	9,392	9,480	9,449	9,480	9,330	9,370
United States	2,905	2,149	2,323	2,428	2,164	2,182	1,924	1,969	1,901	2,001	2,032	2,141
Uruguay	995	898	857	886	909	921	933	941	949	972	984	987
Vietnam	6,500	6,137	7,367	7,470	7,828	7,895	7,966	8,001	8,280	8,387	8,590	8,240
Total Net Exports[a]	**29,222**	**30,116**	**33,034**	**34,882**	**35,745**	**36,206**	**36,918**	**37,288**	**37,257**	**38,283**	**38,764**	**38,502**
Net Importers												
Bangladesh	1,560	624	1,595	2,366	2,362	2,417	2,605	2,694	2,716	2,882	2,695	2,671
Brazil	-650	-253	-97	-79	-258	-415	-623	-732	-768	-858	-905	-1,091
Brunei Darussalam	28	36	36	36	37	37	38	39	40	41	42	42
Cameroon	320	354	341	371	402	423	440	455	463	477	492	492
Canada	327	356	356	366	388	415	429	441	456	464	471	474
China - Hong Kong	410	419	422	428	436	438	442	443	444	444	441	440
Cote d'Ivoire	826	1,141	900	1,084	1,189	1,254	1,342	1,403	1,460	1,493	1,530	1,541
European Union-27	900	821	847	855	850	842	860	876	888	892	906	901
Ghana	560	552	508	494	495	517	525	587	598	611	624	633
Guinea	240	293	279	317	361	374	402	407	403	417	444	416
Indonesia	2,775	1,274	2,428	2,191	1,783	1,551	1,330	1,174	988	1,016	1,240	1,369
Iran	1,300	1,546	1,631	1,686	1,749	1,806	1,850	1,882	1,823	1,897	2,021	2,076
Iraq	1,150	1,203	1,262	1,314	1,295	1,341	1,405	1,452	1,496	1,526	1,555	1,589
Japan	500	532	532	532	532	532	532	532	532	532	532	532
Kenya	300	427	358	391	406	405	450	469	479	500	527	492

continued

Table 1. Continued.

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(thousand metric tons											
Net Importers (cont.)												
Laos	40	57	-44	-45	-46	-30	-36	-28	-33	-31	-25	-13
Malaysia	1,039	1,127	1,226	1,117	1,114	1,107	1,109	1,103	1,102	1,113	1,122	1,136
Mali	125	249	195	142	144	146	157	179	168	191	237	239
Mexico	788	771	764	756	787	788	796	813	817	853	876	893
Mozambique	360	410	421	458	478	500	507	519	529	547	574	547
Nigeria	2,400	2,544	2,436	2,576	2,631	2,646	2,763	2,860	2,950	3,088	3,172	3,122
Philippines	1,500	1,640	2,811	2,755	2,915	3,005	3,119	3,144	3,068	3,187	3,374	3,474
Saudi Arabia	1,080	1,156	1,181	1,196	1,223	1,247	1,283	1,317	1,348	1,379	1,399	1,413
Senegal	790	876	702	824	852	881	911	944	978	1,012	1,050	1,084
Sierra Leone	120	157	137	136	144	150	160	173	177	189	193	199
Singapore	310	312	318	324	331	336	342	347	350	357	362	373
South Africa	735	888	687	832	856	866	902	927	953	977	995	1,018
South Korea	367	362	368	388	409	409	409	409	409	409	409	409
Taiwan	120	123	106	106	106	106	106	106	106	106	106	106
Tanzania	90	158	126	151	169	154	168	163	150	153	168	126
Turkey	219	205	326	313	302	311	327	342	353	364	387	382
Rest of World	7,168	9,963	10,068	10,693	11,510	11,869	12,090	12,079	12,056	12,321	12,018	11,693
Residual	1,425	-207	-194	-192	-209	-222	-220	-231	-241	-266	-266	-276
Total Net Imports	**29,222**	**30,116**	**33,034**	**34,882**	**35,745**	**36,206**	**36,918**	**37,288**	**37,257**	**38,283**	**38,764**	**38,502**
Prices	(U.S. dollars/metric ton)											
International Reference Price	518	449	500	495	461	484	458	454	448	448	455	457
U.S. FOB Gulf Ports	539	510	507	495	474	502	511	477	501	490	487	476
U.S. No. 2 Medium FOB CA	825	869	828	881	913	932	908	894	895	911	909	888

[a] Total net exports are the sum of all positive net exports and negative net imports.

Table 2. Projected world rice supply and utilization over the next 10 years, 2010/11 to 2021/22.

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(thousand hectares)											
Area harvested	157,278	160,206	159,858	159,971	160,284	160,163	160,306	160,234	160,160	160,420	160,702	160,557
	(metric tons/ha)											
Yield	2.87	2.9	2.92	2.95	2.99	3.01	3.03	3.05	3.07	3.09	3.11	3.13
	(thousand metric tons)											
Production	451,385	464,625	466,659	471,992	478,922	481,503	485,314	488,646	491,699	496,277	500,466	502,699
Beginning stocks	94,200	97,938	102,797	104,566	107,035	111,536	114,706	116,928	118,689	120,561	122,769	124,689
Domestic supply	545,585	562,563	569,455	576,558	585,957	593,039	600,021	605,574	610,388	616,838	623,235	627,389
Consumption	446,222	460,016	465,084	469,715	474,630	478,555	483,313	487,116	490,069	494,335	498,812	501,043
Ending stocks	97,938	102,797	104,566	107,035	111,536	114,706	116,928	118,689	120,561	122,769	124,689	126,622
Domestic use	544,160	562,813	569,650	576,750	586,166	593,262	600,241	605,805	610,629	617,104	623,501	627,665
Trade	33,690	33,037	36,589	38,441	39,395	39,925	40,718	41,151	41,181	42,237	42,798	42,563
	(%)											
Stocks-to-use ratio	21.95	22.35	22.48	22.79	23.50	23.97	24.19	24.37	24.60	24.84	25.00	25.27

Table 3. Projected U.S. rice supply and utilization over the next 10 years, 2010/11 to 2021/22.

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(thousand hectares)											
Area harvested	1,463	1,059	1,134	1,156	1,164	1,176	1,173	1,192	1,193	1,203	1,207	1,215
	(metric tons/ha)											
Yield	5.19	5.61	5.63	5.67	5.71	5.75	5.80	5.83	5.88	5.92	5.97	6.01
	(thousand metric tons)											
Production	7,593	5,937	6,378	6,551	6,644	6,765	6,797	6,951	7,013	7,129	7,205	7,308
Beginning stocks	1,184	1,514	1,229	1,080	822	794	741	844	942	1,082	1,165	1,215
Domestic supply	8,777	7,451	7,608	7,632	7,466	7,559	7,537	7,795	7,955	8,211	8,370	8,523
Consumption	4,358	4,115	4,205	4,382	4,509	4,636	4,769	4,884	4,971	5,046	5,122	5,149
Ending stocks	1,514	1,229	1,080	822	794	741	844	942	1,082	1,165	1,215	1,233
Domestic use	5,872	5,344	5,285	5,203	5,303	5,377	5,613	5,826	6,053	6,211	6,337	6,382
Net trade	2,905	2,149	2,323	2,428	2,164	2,182	1,924	1,969	1,901	2,001	2,032	2,141

Table 4. Projected per capita rice consumption of selected countries over the next 10 years, 2010/11 to 2021/22.

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(kg)											
Argentina	8.5	8.5	8.6	8.6	8.7	8.8	8.8	8.9	9.0	9.1	9.1	9.2
Australia	14.9	16.0	16.7	17.5	17.5	17.6	17.9	17.9	18.0	17.7	17.7	17.9
Bangladesh	217.8	217.8	215.3	216.1	215.5	212.9	212.7	211.6	211.5	211.3	211.0	210.9
Brazil	41.8	40.1	41.4	41.6	41.7	41.6	41.7	41.7	41.7	41.7	41.6	41.2
Brunei Darussalam	73.4	91.2	90.1	90.1	90.2	89.2	90.4	91.1	91.8	92.1	92.1	91.5
Cambodia	292.0	292.8	288.2	285.2	284.7	284.3	284.2	283.8	283.6	283.4	283.6	283.6
Cameroon	19.4	20.3	20.2	21.6	22.9	23.5	23.9	24.2	24.2	24.4	24.7	24.4
Canada	9.7	10.5	10.4	10.6	11.1	11.8	12.1	12.4	12.7	12.8	13.0	12.9
China	93.0	95.0	95.4	94.8	94.7	94.6	94.3	93.9	93.4	93.1	92.9	92.2
Cote d'Ivoire	59.0	63.6	63.0	63.3	66.3	67.6	69.7	70.6	71.6	71.7	71.9	71.4
Egypt	42.3	46.3	45.6	45.3	45.1	44.9	44.7	44.6	44.5	44.3	44.2	44.1
European Union-27	5.8	5.7	5.8	5.9	5.9	5.8	5.9	5.9	5.9	6.0	6.0	6.0
Ghana	28.8	30.5	30.1	31.0	31.7	32.2	32.3	32.3	32.4	32.5	32.5	32.5
Guinea	121.6	126.4	125.6	126.0	127.9	128.2	129.3	129.0	127.8	127.7	128.3	124.7
China - Hong Kong	57.8	58.8	59.0	59.5	60.5	60.5	60.9	60.8	60.8	60.6	60.2	59.9
India	76.7	79.1	79.0	79.0	78.5	78.4	78.3	78.2	78.2	78.1	77.9	77.7
Indonesia	160.5	161.6	161.4	161.1	161.1	160.6	160.5	160.0	159.2	159.3	159.6	159.2
Iran	37.7	39.0	39.7	40.0	40.5	40.9	41.1	41.2	40.3	40.8	41.8	42.2
Iraq	43.8	43.3	44.9	46.0	45.0	46.1	47.0	47.4	47.7	47.8	47.8	47.8
Japan	63.7	64.4	64.6	64.1	63.5	63.3	63.4	63.4	63.3	62.6	62.4	62.2
Kenya	8.6	9.4	9.1	9.6	9.8	9.8	10.2	10.6	10.6	10.8	11.2	10.7
Laos	288.9	294.1	293.6	294.8	296.3	297.5	298.4	300.0	299.9	300.7	302.4	305.5
Malaysia	94.3	96.4	95.9	95.4	94.8	94.3	94.1	93.4	93.1	92.9	92.7	92.5
Mali	118.4	124.7	124.0	124.1	126.1	126.6	127.7	128.5	128.0	129.2	132.0	132.9
Mexico	7.6	7.8	7.8	8.0	8.0	8.1	8.1	8.2	8.2	8.4	8.5	8.5
Mozambique	21.4	22.9	23.2	24.2	24.9	25.3	25.1	25.1	24.9	25.1	25.5	24.2
Myanmar (Burma)	185.3	185.8	185.4	185.0	184.7	183.9	183.1	181.8	180.1	179.3	178.5	178.2
Nigeria	30.3	29.7	30.4	31.1	31.1	30.9	31.3	31.5	31.7	32.1	32.3	31.7
Pakistan	13.3	15.1	15.3	15.4	15.8	15.9	16.0	16.0	15.9	16.0	16.1	16.0
Philippines	131.4	129.0	128.1	129.3	130.3	129.7	129.6	129.2	127.4	127.6	128.1	127.5
Saudi Arabia	42.7	44.2	44.2	44.3	44.7	44.8	45.5	46.0	46.4	46.8	46.8	46.7

continued

Table 4. Continued.

	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22
	(kg)											
Senegal	91.5	92.4	92.3	92.2	92.1	92.1	92.1	92.1	92.2	92.2	92.4	92.6
Sierra Leone	117.8	121.6	120.7	120.8	121.7	122.4	123.7	124.5	124.1	124.8	126.4	126.2
Singapore	60.3	59.5	59.4	59.4	59.4	59.2	59.1	58.9	58.3	58.5	58.3	59.0
South Africa	15.1	15.7	16.1	17.0	17.6	17.9	18.5	19.1	19.6	20.1	20.4	20.9
South Korea	99.5	97.0	98.6	97.6	96.3	95.3	94.8	94.6	94.5	93.6	93.4	93.7
Taiwan	50.4	52.9	50.7	49.6	48.6	47.8	47.4	46.8	46.6	46.3	46.0	45.8
Tanzania	24.0	24.2	24.4	25.1	25.6	25.4	25.8	25.8	25.6	25.7	26.1	25.4
Thailand	158.3	165.1	165.0	162.1	161.4	161.1	160.7	160.3	159.3	159.4	160.1	159.3
Turkey	8.7	8.9	9.2	9.3	9.4	9.4	9.5	9.6	9.7	9.8	10.0	10.0
United States	14.1	13.2	13.4	13.8	14.1	14.4	14.7	14.9	15.0	15.1	15.2	15.2
Uruguay	21.2	21.5	21.6	21.4	21.2	21.0	21.0	21.0	20.8	20.6	20.7	20.2
Vietnam	216.6	218.1	217.4	217.3	217.3	217.0	216.7	216.3	213.8	214.4	214.4	215.3
Rest of World	21.7	23.2	23.3	23.5	23.9	23.9	24.1	24.1	24.1	24.1	24.2	24.0
World	65.0	66.2	66.2	66.2	66.1	66.0	65.9	65.8	65.5	65.4	65.4	65.0

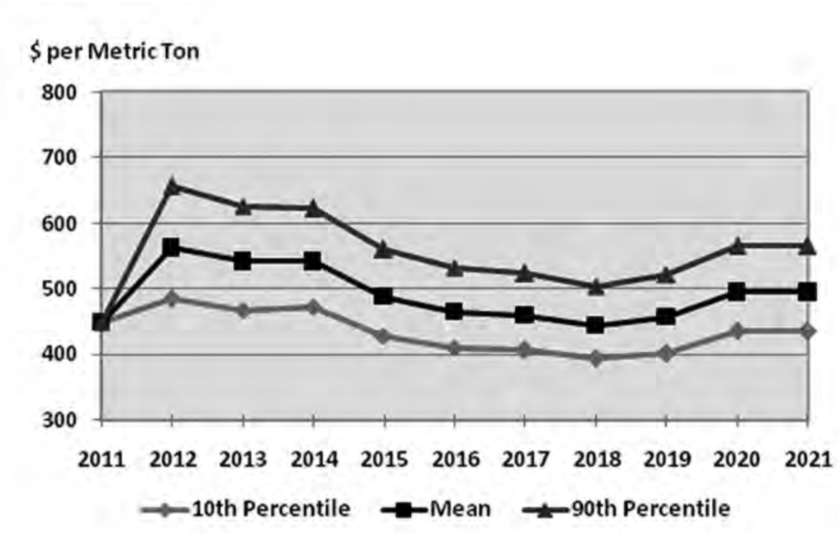


Fig. 1. Long-grain rice international reference price (10-year stochastic projections).

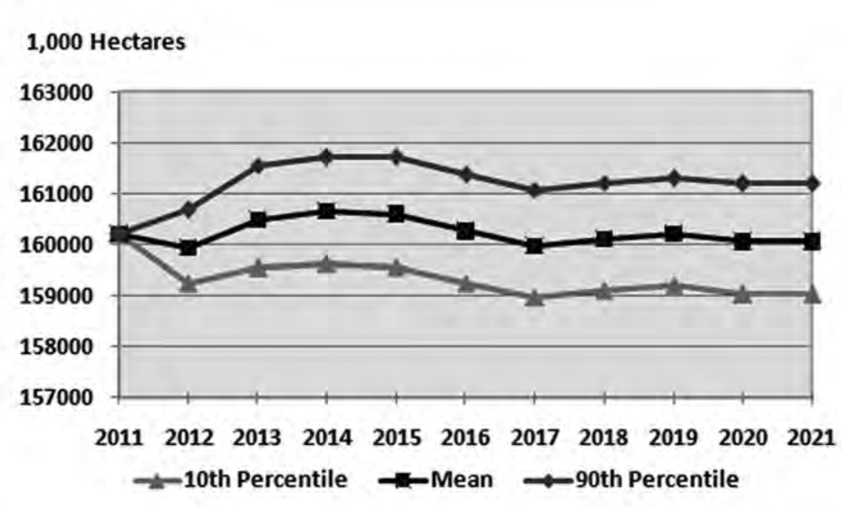


Fig. 2. World rice area harvested (10-year stochastic projections).

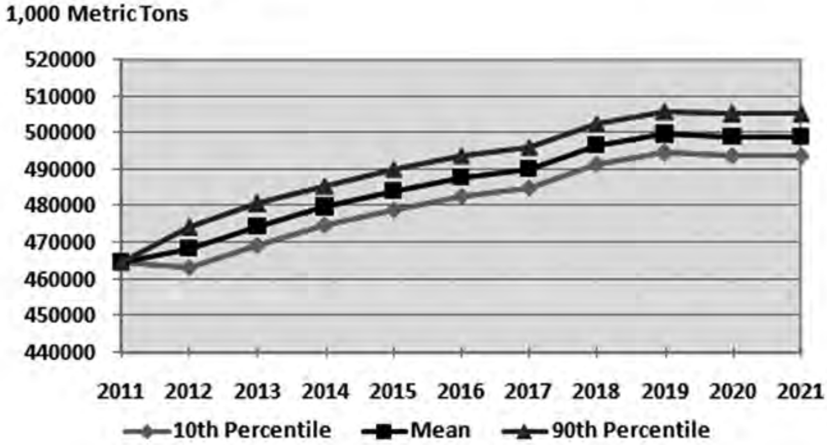


Fig. 3. World rice milled production (10-year stochastic projections).

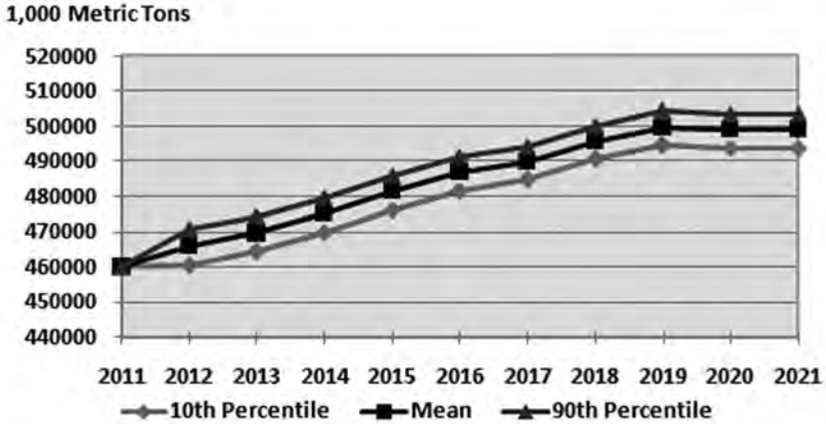


Fig. 4. World rice total consumption (10-year stochastic projections).

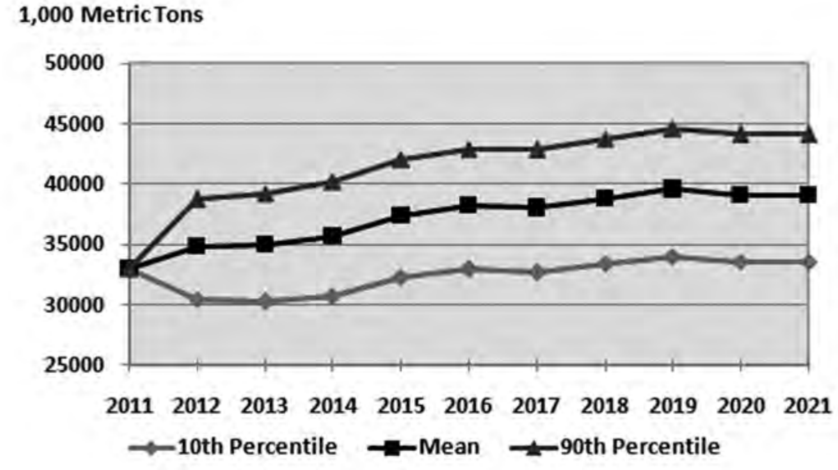


Fig. 5. World rice total trade (10-year stochastic projections).

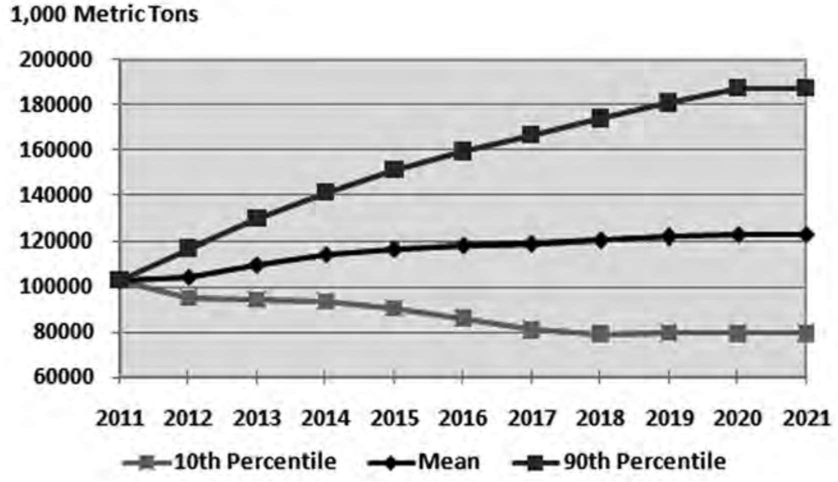


Fig. 6. World rice ending stocks (10-year stochastic projections).

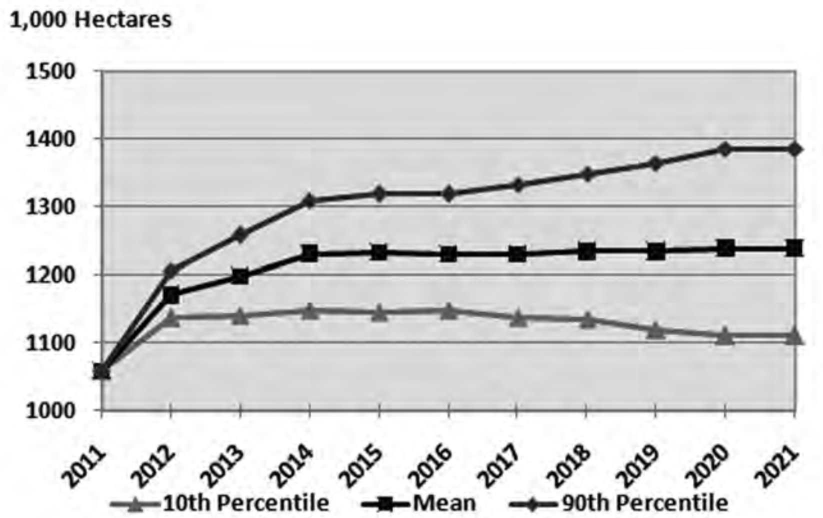


Fig. 7. U.S. rice area harvested (10-year stochastic projections).

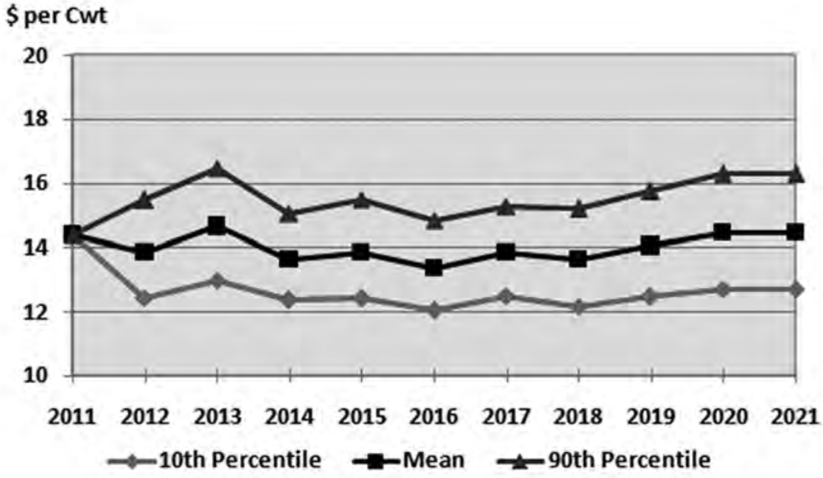


Fig. 8. U.S. rice season average farm price (10-year stochastic projections).

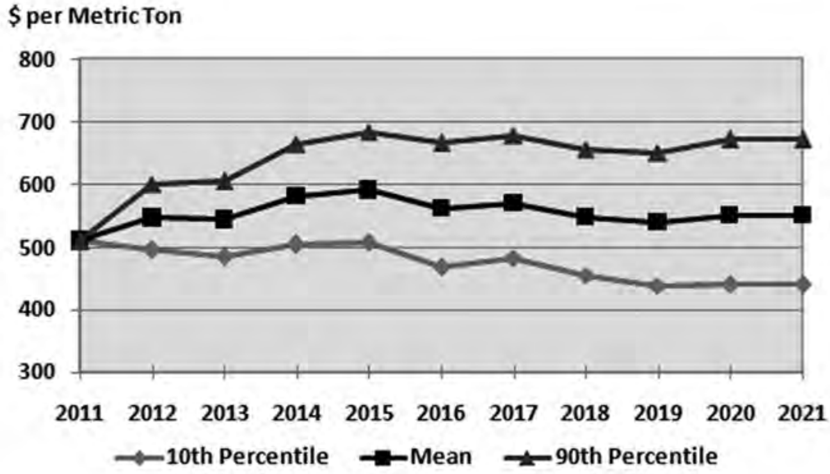


Fig. 9. U.S. long-grain rice export price, fob Gulf (10-year stochastic projections).

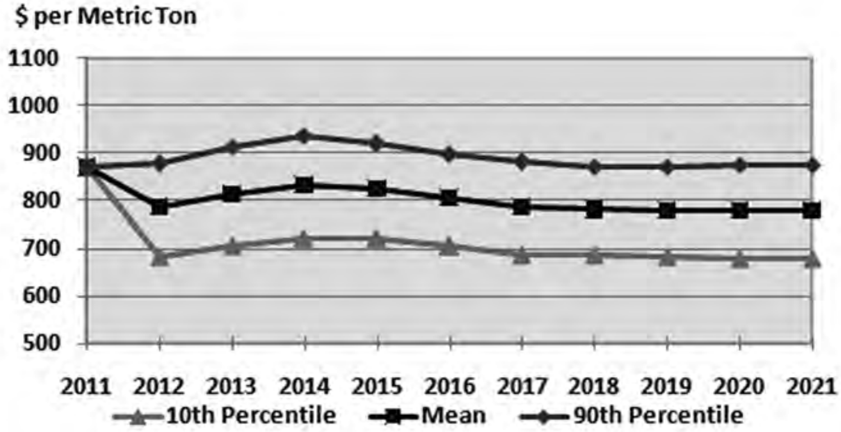


Fig. 10. Medium-grain rice price, fob CA (10-year stochastic projections).

ECONOMICS

Evaluating the Range in Monetary Benefits to Multiple Inlet Irrigation Using Simulation

K.B. Watkins, T. Hristovska, and M.M. Anders

ABSTRACT

Irrigation fuel costs represent a significant portion of rice production expenses. Multiple inlet (MI) irrigation represents a water saving alternative to conventional flood (CF) irrigation in rice production. This study uses simulation to calculate the range of monetary benefits to MI in rice production for a standard well 120 ft or less in depth. Rice yields, rice prices, prices for key production inputs (diesel and fertilizer), and water savings to MI relative to CF are simulated. Rice net returns above variable and fixed expenses are calculated for both MI and CF with and without a modest MI yield boost. Monetary benefits to MI are measured as the difference between MI net returns and CF net returns. Without a modest yield increase, monetary benefits to MI are positive everywhere for water savings of 17% or greater. Water savings to MI relative to CF averaged slightly over 21% across Arkansas field demonstrations for the period 2000 to 2007. These results imply that most Arkansas rice producers irrigating from standard wells would likely achieve positive monetary benefits using MI in place of CF irrigation. A modest yield boost can greatly enhance the monetary payoff of MI, and the monetary benefit can be potentially greatest during periods of both high energy and commodity prices.

INTRODUCTION

Irrigation fuel costs represent a significant portion of rice production expenses. Irrigation fuel costs account for 17% to 18% of total variable production expenses for the crop depending on seed type (Flanders et al., 2011). Most rice acres in Arkansas are irrigated using conventional levee and gate systems. Flooded rice production under these systems uses a well or riser in the highest-elevation portion of the field. Levees are constructed at approximately every 2.33 inch elevation drop, and adjustable spills are placed in the levees. Water released from the well or riser fills the first paddy and then flows over the spills into lower paddies (Vories et al., 2005). Multiple inlet (MI) irrigation represents a water saving alternative to conventional flood (CF) irrigation. Rather than discharging water directly from the well or riser into the first paddy, the riser is connected to a pipe, and gates or holes are placed in the pipe for each paddy. Multiple inlet irrigation allows each paddy to be watered concurrently instead of receiving overflow from a higher paddy. By adjusting the gates, the operator can fill all paddies simultaneously (Vories et al., 2005).

Water savings may be achieved using MI over CF because the field is flooded quicker and irrigation efficiency is increased through reduced pumping time during the season. Reported water savings for MI based on Arkansas rice field demonstration data from 2000 through 2007 ranged from 5% to 44% and averaged 21% across field demonstrations and years (Table 1). Higher grain yields may also be possible with MI. Vories et al. (2005) reported a positive though non-significant numeric rice yield difference of 3.4% for field demonstrations in Arkansas using MI versus CF. The authors speculated the numeric yield difference may be due to shallower depth of water on MI fields relative to CF fields, a reduction in the "cold water" effect of groundwater observed in areas around the well or riser that are typically later maturing and lower yielding than the rest of the field, and improved nitrogen efficiency.

This study uses simulation to measure the monetary benefits of MI given the range in water savings possible as reported in field demonstration studies throughout Arkansas. Rice yields, rice prices, prices for key production inputs (diesel and fertilizer), and water savings from MI relative to CF are simulated using SIMETAR (Simulation and Econometrics to Analyze Risk; Table 2). Per acre net returns above variable and fixed expenses are calculated with and without MI and with and without a 3.4% increase in simulated MI rice yields. Monetary benefits to MI are calculated as the difference between MI and CF net returns.

PROCEDURES

Five hundred iterations of rice yields, rice prices, fuel and fertilizer prices, and water savings from MI relative to CF irrigation were simulated using the Excel Add-In, SIMETAR (Richardson et al., 2008). Water savings to MI were simulated based on field demonstration data for the period 2000 through 2007 (Table 1). Rice yields were simulated using eleven years of historical yield data from a long-term cropping systems study at Stuttgart, Ark., for the period 2000 to 2010 (Anders and Hignight, 2010). Prices for rice and key production inputs (diesel, urea, phosphate, and potash) were simulated based on historical prices obtained from the USDA, National Agricultural Statistics Service for the period 2000 to 2010 adjusted to 2010 dollars using the Producer Price Index (PPI; Table 2). Summary statistics for simulated yields, MI water savings, rice prices, and prices for diesel and fertilizer inputs are presented Table 3.

For a more detailed explanation about the simulation methods used in this analysis, see Watkins et al. (2012).

Direct and fixed expenses for the analysis were based on cost data used in the 2010 Arkansas Rice Research Verification Program (Runsick et al., 2010) and irrigation cost data from Hogan et al. (2007). Direct expenses included expenses associated with fertilizer, pesticides, seed, operator labor, machinery and irrigation fuel, machinery and irrigation repairs and maintenance, and interest on operating capital. Fixed expenses for machinery were composed of both machinery depreciation and interest. Irrigation variable and fixed expenses were obtained from Hogan et al. (2007) and were based on a standard well 120 ft or less in depth. Irrigation fixed expenses were adjusted to 2010 dollars using the PPI and represent expenses associated with depreciation, interest, property taxes, and insurance.

A total of 30 acre-in. of water was assumed for rice under CF irrigation. Applied water under MI was calculated using the following equation:

$$MII_k = CFI * (1 - MISAV_k) \qquad \text{(Eq. 1)}$$

where $k = 1$ to 500 simulated iterations; MII_k = total applied water under MI for iteration k (ac in); CFI = total applied water under CF irrigation (30 acre-in.) and $MISAV_k$ = simulated MI water savings over CF irrigation for iteration k (decimal). The non-diesel installation and removal cost of MI irrigation tubing was $9.52/acre based on costs reported by Hogan et al. (2007) updated to 2010 dollars. Total diesel and labor used to install and remove irrigation tubing was set to 0.291 gal/acre and 0.289 hr/acre, respectively, based on estimates derived from Hogan et al. (2007). Per acre net returns above variable and fixed expenses to rice production with and without MI were estimated both with and without a 3.4% MI rice yield increase. Monetary benefits of MI were calculated as the difference MI and CF net returns.

RESULTS AND DISCUSSION

Summary statistics of MI and CF net returns for Arkansas rice assuming a standard well are presented in Table 3. Net returns to MI without a yield increase reflect the monetary impact of MI water savings net of MI installation and removal costs on rice net returns. The mean, maximum, and minimum net returns to MI are greater than those to CF, reflecting greater profitability for MI resulting from savings in irrigation fuel costs. Net returns to MI with the 3.4% yield boost reflect both the monetary impact of water savings net of MI installation and removal costs and the positive monetary benefit of greater yields resulting from use of MI over CF. The yield boost results in an upward shift in MI net returns averaging approximately $30/acre and ranging from a minimum of approximately $20/acre to a maximum of approximately $43/acre.

Monetary benefits to MI are also reported with and without a 3.4% yield boost in Table 3. Without the yield boost, MI monetary benefits average $7/acre and range from -$7/acre (minimum) to $77/acre (maximum). The negative minimum MI monetary benefit means that MI installation and removal costs can exceed the value of MI water savings in some instances. With the 3.4% yield boost, the average MI monetary benefit is increased to $38/acre, and the likelihood of a negative MI monetary benefit is removed, as is reflected by the minimum monetary benefit of $77/acre with the yield increase.

Simulated MI monetary benefits assuming no MI yield increase are mapped against simulated water savings to MI irrigation for a standard well in Fig. 1. Monetary benefits to MI increase as MI water savings increase due to savings in irrigation pumping costs. Monetary benefits to MI are negative (cost of MI installation and removal exceeds value of water savings) when water savings are 10% or less. With MI water savings between 10% and 17%, MI monetary benefits may be positive or negative depending on the diesel price. As diesel prices increase, the likelihood of achieving positive monetary benefits to MI increases within the 10% to 17% MI water savings range. Monetary benefits to MI are positive for MI water savings of 17% or greater, and the magnitude of the monetary benefit increases as diesel prices increase.

Simulated MI monetary benefits assuming a 3.4% MI yield increase are mapped against simulated water savings to MI irrigation for the standard well scenario in Fig. 2. The yield boost results in positive monetary benefits to MI across all MI water savings. Monetary benefits to MI are again positively related to MI water savings. However, the size of the MI monetary benefit for a given level of water savings depends on both the fuel and the rice price. As both prices increase, the size of the MI monetary benefit increases for a given level of MI water savings. Similarly, as both the rice price and the fuel price decrease, the size of the MI monetary benefit decreases for a given level of MI water savings. Thus, monetary benefits to MI are potentially greatest during periods of both high energy and commodity prices.

SIGNIFICANCE OF FINDINGS

Our analysis indicates that monetary benefits to MI are positive everywhere for MI water savings of 17% or greater when no yield increase occurs and water is pumped from a standard well 120 ft or less in depth. Water savings to MI averaged slightly over 21% across Arkansas field demonstrations and years (Table 1). These results imply that most Arkansas rice producers irrigating from standard wells would likely achieve positive monetary benefits using MI irrigation in place of CF irrigation even in the absence of a modest yield increase. A modest yield boost can greatly enhance the monetary payoff of MI irrigation. With a modest yield boost, monetary benefits to MI can be potentially greatest during periods of both high energy and commodity prices.

ACKNOWLEDGMENTS

This research was funded by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Anders, M.M. and J.A. Hignight. 2010. Environmental impact, soil quality, grain yield, and economic viability of a rice-soybean rotation. *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 581:237-247. Fayetteville.

Flanders, A., C. Dunn, S. Stiles, C. Grimes, S. Kelley, K. Lawson, R. Mazzanti, B. McClelland, and S. Runsick. 2011. 2012 crop enterprise budgets for Arkansas crops planted in 2012. University of Arkansas, Division of Agriculture, Cooperative Extension Service, AG-1272, December 2011.

Hogan, R., S. Stiles, P. Tacker, E. Vories, and K.J. Bryant. 2007. Estimating irrigation costs. Little Rock, Arkansas: University of Arkansas Cooperative Extension Service, Fact Sheet No. FSA28.

Richardson, J.W., K.D. Schumann, and P.A. Feldman. 2008. SIMETAR, Simulation & Econometrics to Analyze Risk. College Station: Agricultural And Food Policy Center, Department of Agricultural Economics, Texas A&M University.

Runsick, S., R. Mazzanti, C. Wilson, and B. Watkins. 2010. University of Arkansas Rice Research Verification Program. University of Arkansas Cooperative Extension Service. http://www.aragriculture.org/crops/rice/Verification/RRVP10.pdf

Vories, E.D., P.L. Tacker, and R. Hogan. 2005. Multiple inlet approach to reduce water requirements for rice production. Appl. Eng. Agri. 21:611-616.

Watkins, K.B., T. Hristovska, and M.M. Anders. 2012. Measuring the stochastic monetary benefits of multiple inlet irrigation in Arkansas rice production. Selected paper presented at the 2012 Southern Agricultural Economics Association Annual Meeting, February 4-7, 2012, Birmingham, Alabama. http://ageconsearch.umn.edu/bitstream/119655/2/Watkins%202012.pdf

Table 1. Rice field demonstration water savings data for multiple inlet compared with conventional flood by county, soil texture, and year, 2000 to 2007.

Year	County	Soil texture	MI water savings[a]
			(decimal)
2000	Poinsett	Clay	0.1750
2000	Ashley	Clay	0.1800
2001	Arkansas	Silt Loam	0.2100
2001	Crittenden	Clay	0.2900
2001	Crittenden	Silt loam	0.1700
2001	Cross	Silt Loam	0.1600
2002	Crittenden	Sandy Loam	0.0900
2002	Desha	Silt Loam	0.2600
2002	Poinsett	Clay	0.4400
2002	Poinsett	Clay	0.4200
2002	Poinsett	Silt Loam	0.1700
2003	Drew	Silt Loam	0.1300
2003	Lonoke	Silt Loam	0.2500
2004	Crittenden	Clay	0.2300
2004	Poinsett	Silt Loam	0.2200
2004	Poinsett	Silt Loam	0.2800
2005	Craighead	Clay	0.1800
2005	Cross	Silt Loam	0.2900
2005	St. Francis	Silt Loam	0.1900
2005	White	Silt Loam	0.2700
2006	Poinsett	NA[b]	0.1300
2006	Poinsett	NA	0.0800
2006	Cross	NA	0.1900
2006	Cross	NA	0.2200
2007	Arkansas	NA	0.1800
2007	St. Francis	NA	0.2300
2007	White	NA	0.0500
Mean			0.2106

[a] Multiple inlet (MI) water savings represent the percent reduction in applied water from multiple inlet relative to conventional flood irrigation on each field demonstration.

[b] NA = not available.

Source: Tacker P. and Tacker et al. (2000 to 2008). Rice irrigation-water management for water, labor, and cost savings. *In:* B.R. Wells Rice Research Studies, University of Arkansas Agricultural Experiment Station, Research Series 485, 495, 504, 517, 529, 540, 550, and 560.

Table 2. Summary statistics of simulated rice yields, water savings of multiple inlet relative to conventional flood irrigation, rice prices, and key production input prices.

Stochastic variable	Mean[a]	SD	CV[b]	Minimum	Maximum
Rice yield (bu/acre)	184	12	7	160	199
MI savings (decimal)	0.2106	0.0861	41	0.0499	0.4401
Rice price ($/bu)	5.42	0.93	17	4.14	6.94
Diesel ($/gal)	2.46	0.48	20	1.64	3.51
Urea ($/lb)	0.2155	0.0251	12	0.1698	0.2636
Superphosphate ($/lb)	0.2362	0.0650	28	0.1774	0.4203
Potash ($/lb)	0.2505	0.0735	29	0.1710	0.3979

[a] Summary statistics calculated from 500 simulated iterations.

[b] Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation (SD) divided by the mean.

Table 3. Summary statistics of multiple inlet net returns, conventional flood net returns, and multiple inlet monetary benefits for Arkansas rice assuming a standard well.

Variable	Mean[a]	SD[b]	CV[c]	Minimum	Maximum
	------($/acre)-------			------------($/acre)-----------	
Without a MI yield increase					
MI[d]	355	147	41	88	656
CF	347	145	42	82	637
With 3.4% MI yield increase					
MI	385	153	40	108	699
CF	347	145	42	82	637
Without a MI yield increase					
MI monetary benefit	7	8	104	-7	38
With 3.4% MI yield increase					
MI monetary benefit	38	11	29	15	77

[a] Summary statistics calculated from 500 simulated iterations.

[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] MI = multiple inlet; CF = conventional flood.

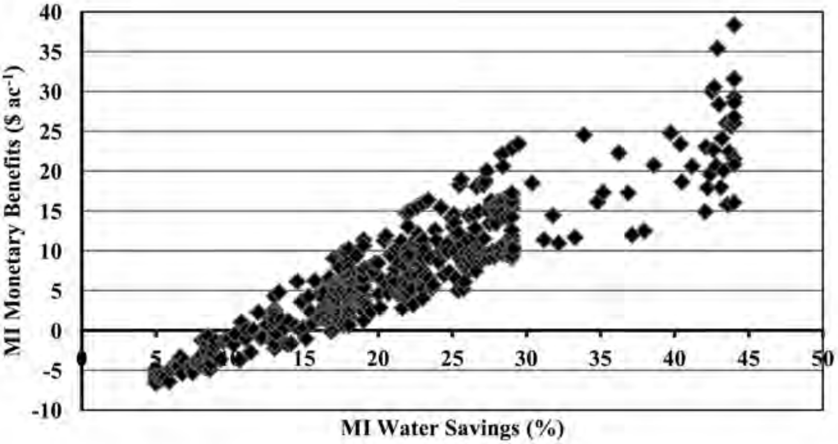


Fig. 1. Multiple inlet (MI) monetary benefits as a function of water savings to MI irrigation over conventional flood (CF) irrigation in Arkansas rice production assuming a standard well and no multiple inlet yield increase.

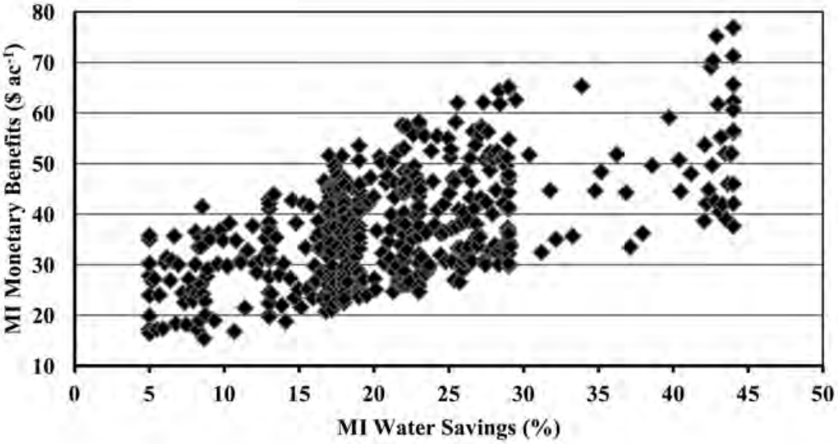


Fig. 2. Multiple inlet (MI) monetary benefits as a function of water savings to MI irrigation over conventional flood (CF) irrigation in Arkansas rice production assuming a standard well and a 3.4% MI yield increase.

NOTES

NOTES

NOTES

NOTES

NOTES

U of A
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

B.R. Wells Rice Research Studies 2011

Norman and Moldenhauer

AAES