B.R. Wells

RICE RESEARCH STUDIES 1999

R.J. Norman and C.A. Beyrouty, editors

ARKANSAS AGRICULTURAL EXPERIMENT STATION
Division of Agriculture University of Arkansas
August 2000 Research Series 476

B.R. Wells
R I C E
Research Studies
1 9 9 9

R.J. Norman and C.A. Beyrouty, editors

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

Technical editing and cover design by Robin Bodishbaugh

Arkansas Agricultural Experiment Station, University of Arkansas Division of Agriculture, Fayetteville. Milo J. Shult, Vice President for Agriculture and Director; Charles J. Scifres, Associate Vice President for Agriculture. PS1.20800PM65. The Arkansas Agricultural Experiment Station follows a nondiscriminatory policy in programs and employment.

ISSN:0099-5010 CODEN:AKAMA6

DEDICATED IN MEMORY OF

Bobby R. Wells

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

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

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

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

FEATURED RICE COLLEAGUE

Dr. Roy J. Smith, Jr.

November 25, 1929–

Dr. Roy J. Smith, Jr., was born in Covington, Louisiana. He was raised on a hill farm near Decatur, Mississippi, and received an Associate of Arts Degree in Agriculture at East Central Junior College in Decatur in 1949. He received a B.S. degree in Agronomy–Soils in 1951 from Mississippi State University and an M.S. degree in Agronomy–Weed Science in 1952 from the same university. Dr. Smith received a Ph.D. degree in Agronomy–Weed Science from the University of Illinois in 1955. Immediately after graduating, Dr. Smith was employed by the Agricultural Research Service of the U.S. Department of Agriculture as a Research Agronomist to lead the weed science research program located at the University of Arkansas Rice Research and Extension Center, Stuttgart. This was a cooperative project between the USDA and the University's Agricultural Experiment Station.

Dr. Smith's pioneering research in weed control in rice has played a major role in the development of weed control technology for rice in the United States. His research developed integrated weed control programs for dry- and water-seeded rice. These improved programs combine standard herbicides such as propanil and molinate in sequential and mixture treatments with other herbicides, including thiobencarb, pendimethalin, fenoxaprop, quinclorac, aciflurofen, and bensulfuron. The integrated systems are used on most of the rice domestically and on millions of acres of rice in the world. Dr. Smith is nationally and internationally recognized for his research in integrated weed management for rice, weed competition in rice, biological control of weeds with plant pathogens, red rice control programs for rice and rotated crops, control of propanil-resistant barnyardgrass, and weed control in conservation tillage systems for rice.

Dr. Smith was with the USDA-ARS for almost 38 years before retiring in 1992. He was a senior research scientist in the USDA-ARS and served as Research Leader and Supervisory Research Agronomist of the Rice Production and Weed Control Research Laboratory at Stuttgart for more than 10 years. He was an adjunct professor with the Agronomy Department of the University of Arkansas for all of his career. He has published about 500 articles on weed science and rotated crops and has advised about 20 M.S., Ph.D., and Postdoctoral students. Dr. Smith has been active in numerous professional societies, especially the Weed Science Society of America (charter member), the Southern Weed Science Society, the Asian Pacific Weed Science Society, the International Weed Science Society (charter member), the Arkansas Agricultural Pesticide Association, and the Rice Technical Working Group.

Dr. Smith has received more than 25 major awards for his research contributions from professional societies, the USDA, and the agricultural community. These awards include the prestigious Superior Service Award in 1967 and the Certificate of Appreciation Award in 1993 from the USDA, the Fellow Award in 1985 from the Weed Science Society of America, Distinguished Service Awards from the Southern Weed Science Society (1996) and the Rice Technical Working Group (1994), the Arkansas Hall of Fame Award in 1997, the Research Award jointly from the WSSA and Ciba-Geigy in 1982, the Weed Scientist of the Year Award in 1989 from the SWSS, WSSA's Outstanding Paper Awards in the Weed Science Journal in 1973 and the Weed Technology Journal in 1989, the John W. White Research Award from the University of Arkansas Division of Agriculture in 1987, the Distinguished Rice Research and Education Awards (1982 and 1998) from the RTWG, and Distinguished Service Awards from the following organizations — the Arkansas Agricultural Pesticide Association (1984 and 1994), the Arkansas Rice Research and Promotion Board (1993), the Rotary Clubs of Pine Bluff and West Pine Bluff (the Harvey W. McGeorge Award in 1994), the Arkansas Association of Cooperative Extension Specialists (1982), and the Grand Prairie Wildlife Federation (1982). Dr. Smith received Certificate of Merit Awards from the USDA-ARS numerous times, and he was promoted to a Senior Scientist in 1983 in the USDA-ARS research scientists category.

Dr. Smith has conducted numerous foreign research projects for the USDA, including weed science projects in cooperation with the International Rice Research Institute in the Philippines, the U.S. Agency for International Development in southeast Asia, the Pakistan Special Project. He was a cooperating scientist on a weed control in rice symposium sponsored by the International Rice Research Institute in the Philippine, as well as a cooperating scientist with the Korean Weed Science Society.

After retiring from the USDA, Dr. Smith established an agricultural consulting business in 1993, which he operates from his home. In addition, he conducts peer reviews of research manuscripts for agricultural journals, including *Weed Science*, *Weed Technology*, and the *Agronomy Journal*. He has also authored and co-authored a number of book chapters and scientific papers on weed science in rice subjects since retiring.

Dr. Smith married Mildred Monroe in 1952, and they have a son, Lex Travis, and a daughter, Vicky Elaine. They have five grandchildren — Brian and Kristin Smith, Nash and Bron Butrimas, and Chelsie Luis.

FOREWARD

The research reports in this publication may represent one year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication dealing with soil fertility also appear in Arkansas Soil Fertility Studies, 1999, Arkansas Agricultural Experiment Station Research Series 471. This duplication is the result of the overlap in research coverage between the two series and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off.

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

All authors are either current or former faculty, staff or students of the University of Arkansas Division of Agriculture. For further information about any author, contact Communication Services, (501) 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 Rice Research and Promotion Board for their vital financial support of these programs.

The Arkansas Rice Research and Promotion Board

Martha Ahrent	Corning
John Andrews	Walnut Ridge
Gregory Baltz	Pocahontas
George Dunklin, Jr.	DeWitt
Marvin Hare	Newport
Jerry Hoskyn	Stuttgart
Jon Lambi	Pickens
Bryan Moery	Wynne
Joe Rennicke	Weiner

CONTENTS

ONGOING STUDIES: BREEDING, GENETICS, AND PHYSIOLOGY

IMPROVING THE PREDICTABILITY OF RICE CROP
DEVELOPMENT WITH THE NEW RICE GROWTH STAGING SYSTEM
P.A. Counce, T.C. Keisling, and D.C. Annis, Jr. 1

USING RICE GROWTH STAGING AS AN AID
TO CROP MANAGEMENT
P.A. Counce, T.C. Keisling, and D.C. Annis, Jr. 9

PERFORMANCE OF RICE CULTIVARS/VARIETIES
SEEDED AFTER HARVESTING WHEAT
R.H. Dilday, J.W. Gibbons, K.A.K. Moldenhauer, and W.G. Yan 15

EVALUATION OF NEW RICE GERMPLASM
FROM FOREIGN COUNTRIES
R.H. Dilday, F.N. Lee, K.A.K. Moldenhauer, W.G. Yan, and R. Guei 19

RICE BREEDING AND GENETICS: DEVELOPMENT
OF SEMI-DWARF LONG- AND MEDIUM-GRAIN CULTIVARS
*J.W. Gibbons, K.A.K. Moldenhauer, F.N. Lee, J.L. Bernhardt,
M. Anders, N. Slaton, R.J. Norman, R.H. Dilday, J.N. Rutger,
M.M. Blocker, J.M. Bulloch, and A.C. Tolbert* 28

BREEDING AND EVALUATION FOR IMPROVED RICE VARIETIES—
THE ARKANSAS RICE-BREEDING AND DEVELOPMENT PROGRAM
*K.A.K. Moldenhauer, J.W. Gibbons, F.N. Lee, R.J. Norman, J.L. Bernhardt,
M.A. Anders, R.H. Dilday, J.N. Rutger, M.M. Blocker, and A.C. Tolbert* 36

PRODUCTION OF TRANSGENIC RICE PLANTS
USING AGROBACTERIUM-MEDIATED TRANSFORMATION
Y. Yang and M. Qi 46

ONGOING STUDIES: PEST MANAGEMENT: WEEDS

A COMPARISON OF NEW GRAMINICIDES IN RICE
N.W. Buehring, F.L. Baldwin, and R.E. Talbert 55

WEED SHIFT IN CROPPING SYSTEMS INVOLVING
TRANSGENIC CULTIVARS
N.R. Burgos, M. Anders, L.R. Oliver, C.C. Wheeler, S. Payne, and M.S. Mobley *60*

VARIABILITY OF ALLELOPATHIC ACTIVITY IN
RICE (*Oryza sativa* L.) WITH WATER-SOLUBLE EXTRACTS
K. Ebana, K. Okuno, R.H. Dilday, W.G. Yan, and H. Namai *66*

GENETIC CHARACTERIZATION OF RED RICE
POPULATIONS USING MOLECULAR MARKERS
L.E. Estorninos, Jr., N.R. Burgos, D.R.Gealy, J.M. Stewart, and R.E. Talbert .. *76*

PROGRESS IN THE USE OF SMALL-VOLUME AGAR ASSAYS
TO DETECT PHYTOTOXIC EXUDATES
PRODUCED BY RICE (*Oryza sativa* L.) ROOTS
D. R. Gealy and Y. Fujii *85*

DIFFERENTIAL RESPONSE OF UNITED STATES *Oryza sativa*
(RED RICE) ACCESSIONS TO RACES OF *Pyricularia grisea*
F.N. Lee, D.R. Gealy, and R.H. Dilday *94*

CHEMICAL ASPECTS OF RICE ALLELOPATHY
FOR WEED CONTROL
J.D. Mattice, B.W. Skulman, R.H. Dilday, and K.A.K. Moldenhauer *102*

ENVIRONMENTAL IMPLICATIONS OF PESTICIDES
IN RICE PRODUCTION
J.D. Mattice, B.W. Skulman, and R.J. Norman *109*

CLOMAZONE FOR CONTROL OF PROPANIL-RESISTANT
AND -SUSCEPTIBLE BARNYARDGRASS IN RICE
E.F. Scherder, R.E. Talbert, L.A. Schmidt, and M.L. Lovelace *116*

NEW STRATEGIES FOR LATE-SEASON WEED CONTROL IN RICE
R.E. Talbert, L.A. Schmidt, E.F. Scherder, and F.L. Baldwin *131*

ONGOING STUDIES: PEST MANAGEMENT: INSECTS

SCREENING RICE LINES FOR SUSCEPTIBILITY TO
DISCOLORED KERNELS: RESULTS FROM THE ARKANSAS
RICE PERFORMANCE TESTS
J.L. Bernhardt and K.A.K. Moldenhauer *136*

TRAPPING ADULT RICE WATER WEEVILS
WITH AQUATIC BARRIER TRAPS AND FLOATING
CONE TRAPS, WITH NOTES ON CHEMICAL ECOLOGY
R.L. Hix, D.T. Johnson, J.L. Bernhardt, J.D. Mattice, and B.A. Lewis *147*

ONGOING STUDIES: PEST MANAGEMENT: DISEASE

REACTION OF RICE CULTIVARS/LINES TO FALSE SMUT,
STEM ROT, AND BLACK SHEATH ROT DISEASE
R.D. Cartwright, F.N. Lee, T. Beaty, E.A. Sutton, and C.E. Parsons *158*

DISEASE MONITORING AND ON-FARM EVALUATION
OF RICE VARIETIES IN ARKANSAS
R.D. Cartwright, F.N. Lee, C.E. Parsons, W.J. Ross, and E.A. Sutton *169*

EFFECT OF NITROGEN FERTILIZER RATE AND APPLICATION
METHOD ON SHEATH BLIGHT AND YIELD OF 'CYPRESS' RICE
R.D. Cartwright, R.J. Norman, and N.A. Slaton *179*

RELATIONSHIP OF RACES, DNA FINGERPRINT GROUPS,
VEGETATIVE COMPATIBILITY GROUPS, AND MATING TYPE
AMONG ISOLATES OF RICE BLAST PATHOGEN
Pyricularia grisea IN ARKANSAS
J.C. Correll and F.N. Lee *189*

STRAIGHTHEAD OF RICE AS INFLUENCED BY
ARSENIC AND NITROGEN
R.H. Dilday, N.A. Slaton, J.W. Gibbons, K.A. Moldenhauer, and W.G.Yan *201*

THE IMPORTANCE AND CAUSES OF
SEEDLING DISEASE PROBLEMS IN RICE, 1999
C.S. Rothrock , S.A. Winters, and R.L. Sealy *215*

INTEGRATING BIOLOGICAL CONTROL OF
NORTHERN JOINTVETCH WITH COLLEGO AND
CHEMICAL CONTROL OF RICE DISEASES AND WEEDS
D.O. TeBeest and C. Guerber *221*

ONGOING STUDIES: RICE CULTURE

HELPING ARKANSAS RICE FARMERS EXPLOIT MARKET OPPORTUNITIES BY IMPROVED USE OF SOYBEAN, WHEAT, AND CORN IN RICE ROTATIONS
M.M. Anders, T.E. Windham, H.D. Scott, K.A. Moldenhauer, R.K. Bacon, R.W. McNew, R.D. Cartwright, and L.O. Ashlock *226*

1999 RICE RESEARCH VERIFICATION PROGRAM
W.B. Koen, N.A. Slaton, C.E. Wilson, Jr., and T.E. Windham *230*

EFFECTS OF USING POULTRY LITTER AS A PREPLANT FERTILIZER IN RICE ON HIGH-pH SOILS
W.B. Koen, C.E. Wilson, Jr., N.A. Slaton, and R.J. Norman *238*

EVALUATION OF SODIUM CHLORATE AS A HARVEST AID FOR RICE
C.E. Wilson, Jr., N.A. Slaton, S. Ntamatungiro, D.L. Frizzell, and R.J. Norman *246*

GRAIN YIELD PERFORMANCE OF RICE CULTIVARS GROWN IN NORTHEAST ARKANSAS AS INFLUENCED BY SEEDING DATE
R.J. Norman, N.A. Slaton, D.C. Cox, and D.L. Boothe *256*

INFLUENCE OF SEEDING DATE ON THE DEGREE DAY 50 THERMAL UNIT ACCUMULATIONS AND GRAIN YIELD OF NEW RICE CULTIVARS
R.J. Norman, N.A. Slaton, K.A.K. Moldenhauer, and D.L. Boothe *261*

GRAIN YIELD RESPONSE OF NEW RICE CULTIVARS TO NITROGEN FERTILIZATION
R.J. Norman, C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Boothe, S.D. Clark, and A.D. Cox *267*

INFLUENCE OF NITROGEN FERTILIZER TIMING AND RATE ON RICE GROWTH
H.J. Pulley, C.A. Beyrouty, R.J. Norman, and N.A. Slaton *278*

ESTIMATION OF SEASONAL RICE EVAPOTRANSPIRATION
F. Renaud, J.A. Ferguson, H.D. Scott, and D.M. Miller *283*

EFFECTS OF PREVIOUS CROP AND
PHOSPHORUS FERTILIZATION RATE ON RICE
N.A. Slaton, S. Ntamatungiro, C.E. Wilson, Jr.,
R.J. Norman, and D.L. Boothe 294

ZINC SEED TREATMENTS FOR RICE
N.A. Slaton, C.E. Wilson, Jr., S. Ntamatungiro,
R.J. Norman, and D.L. Boothe 304

EVALUATION OF NEW VARIETIES TO
STRAIGHTHEAD SUSCEPTIBILITY
N.A. Slaton, C.E. Wilson, Jr., S. Ntamatungiro,
R.J. Norman, and D.L. Boothe 313

ONGOING STUDIES: RICE QUALITY AND PROCESSING

CHARACTERIZATION OF INDIVIDUAL RICE KERNEL MOISTURE
CONTENT AND SIZE DISTRIBUTIONS AT HARVEST
AND DURING DRYING
R.C. Bautista, T.J. Siebenmorgen, and P.A. Counce 318

FISSURE FORMATION CHARACTERIZATION IN
RICE KERNELS DURING DRYING USING VIDEO MICROSCOPY
R.C. Bautista, T.J. Siebenmorgen, and J.W. Fendley 325

DETERMINING MINIMUM TEMPERING DURATIONS
WHILE MAINTAINING HEAD RICE YIELD
A.G. Cnossen and T.J. Siebenmorgen... 331

EFFECT OF GLASS TRANSITION TEMPERATURE ON
DRYING RATES AND TEMPERING DURATION OF ROUGH RICE
A.G. Cnossen, T.J. Siebenmorgen, and W. Yang... 340

EFFECT OF DRYING AND TEMPERING TREATMENT
ON MOISTURE ABSORPTION KINETICS OF RICE
J. Diederen, A.G. Cnossen, T.J. Siebenmorgen, and Y.-J. Wang 347

EFFECT OF TEMPERATURE, EXPOSURE DURATION,
AND MOISTURE CONTENT ON THE YELLOWING OF RICE
A.L. Dillahunty, T.J. Siebenmorgen, and A. Mauromoustakos 355

EFFECTS OF STORAGE DURATION AND
LOCATION (WITHIN BIN) ON RICE QUALITY FACTORS
T.A. Howell, Jr., M.S. Slape, and J-F.C. Meullenet 363

EFFECTS OF COMMERCIAL PROCESSING ON ANTIOXIDANTS FOUND IN RICE BRAN
B.J. Lloyd, T.J. Siebenmorgen, and K.W. Beers 370

CORRELATING FISSURE OCCURRENCE TO HEAD RICE YIELD FOR VARIOUS DRYING AND TEMPERING TREATMENTS
M.J. Jiménez, A.G. Cnossen, T.J. Siebenmorgen, and R.C. Bautista 378

RICE PROTEIN PREPARATION, THERMAL PROPERTIES, AND DENATURATION
Z.Y. Ju, N. Hettiarachchy, and T.J. Siebenmorgen 387

MILLED RICE SURFACE LIPID AND DEGREE OF MILLING DETERMINATION BY DIFFUSE REFLECTANCE FOURIER TRANSFORM INFRARED SPECTROSCOPY
G. R. Reddy and A. Proctor 393

PREDICTION OF RICE SENSORY TEXTURE ATTRIBUTES USING MULTIPLE INSTRUMENTAL PARAMETERS FROM A SINGLE COMPRESSION TEST, MULTIVARIATE REGRESSION AND A STEP-WISE MODEL OPTIMIZATION METHOD
A. Sesmat and J-F. Meullenet 400

RICE KERNEL DRYING BEHAVIOR IN NEAR-COMMERCIAL DRYING CONDITIONS AS DEPICTED IN A GLASS TRANSITION STATE DIAGRAM
W. Yang, T.J. Siebenmorgen, T.A. Howell, and A.G. Cnossen 411

ONGOING STUDIES: ECONOMICS

ARKANSAS GLOBAL RICE MODELING PROJECT
G. L. Cramer, E. J. Wailes, E. C. Chavez, and J. M. Hansen 417

RATE OF RETURN FOR SOUTHERN RICE PUBLIC RESEARCH
G.L. Cramer, E.J. Wailes, and J.M. Hansen 427

ECONOMIC ANALYSIS OF ON-FARM RICE DRYING AND STORAGE
G. L. Cramer, E. J. Wailes, and K. B. Young 436

A WHOLE-FARM INVESTIGATION OF PRECISION AGRICULTURE: IMPACTS OF RISK AVERSION OPTIMAL CROP MIX
M.P. Popp and C.A. Oriade 441

ECONOMIC IMPACTS ON ARKANSAS RICE
FROM GROUNDWATER DEPLETION
E.J. Wailes, G.L. Cramer, K.B. Young, J. Smartt, and P. Tacker 448

COMPLETED STUDIES

EFFECTS OF FALL RICE STUBBLE MANAGEMENT
AND WINTER FLOODING ON SUBSEQUENT CONVENTIONAL-
AND NO-TILL IRRIGATED AND RAINFED SOYBEANS
*M.M. Anders, T.E. Windham, J.F. Robinson,
R.W. McNew, and K. Reinecke* 454

INTERFERENCE BETWEEN RED RICE AND
RICE IN A REPLACEMENT SERIES STUDY
L.E. Estorninos, Jr., D.R. Gealy, and R.E. Talbert 463

SILICON SOIL AMENDMENTS DO NOT INCREASE
ROUGH RICE YIELD OR REDUCE
RICE SHEATH BLIGHT SEVERITY
*F.N. Lee, R.D. Cartwright, N.A. Slaton, S. Ntamatungiro,
C.E. Parsons, B.L. Candole, and E. Gbur*.. 469

CHARACTERISTICS OF *Pyricularia grisea*
“MICROSCLEROTIA” PRODUCED IN SHAKE CULTURE
F.N. Lee, M.A. Jackson, and N.R. Walker... 475

TECHNOLOGY FOR RAPID DETECTION, IDENTIFICATION, AND
QUANTIFICATION OF THE RICE BLAST FUNGUS *Pyricularia grisea*
R. Nannapaneni, R.C. Gergerich, and F.N. Lee 480

YIELD RISK FOR ARKANSAS RICE PRODUCTION
L.D. Parsch and M. Becerra 486

PREDICTION OF COOKED RICE TEXTURE PROFILES USING
INSTRUMENTAL SPECTRAL EXTRUSION DATA
MODELED WITH PARTIAL LEAST SQUARES REGRESSION
AND ARTIFICIAL NEURAL NETWORKS
C. Sitakalin and J-F.C. Meullenet 496

IMPROVING THE PREDICTABILITY OF RICE CROP DEVELOPMENT WITH THE NEW RICE GROWTH STAGING SYSTEM

P.A. Counce, T.C. Keisling, and D.C. Annis, Jr.

ABSTRACT

The rice growth staging (RGS) system allows precise and meaningful timing of production practices and the application of research treatments. The RGS is also related to the thermal time clock for rice. We identified three cardinal temperatures for rice development: minimum, optimum, and maximum. The minimum temperature is the lowest temperature for a process to take place. The optimum temperature is one at which maximum rates for a process occur. The maximum temperature is the highest temperature at which a process can occur. Using previously developed methodologies, we calculated thermal time for growth stages based on these cardinal temperatures. We recorded rice growth stages for 'Drew' in several different situations. We present growth stages for Drew in several situations including a standard in which the rice was grown under controlled climate conditions. We then demonstrate how growth staging can be presented over thermal time and how the use of RGS can improve thermal time accuracy.

INTRODUCTION

A primary key for increasing rice grain yields is "management input" timing. Rice plant growth staging has the potential to provide a practical method to improve management input timing. A rice plant develops vegetatively in discreet units (phytomers). These units can be enumerated as cumulative leaf number. The associated plant time increment is measured from one leaf to the next (phyllochron). Similar plant time increments were defined for reproductive growth stages (Counce *et al.*, 2000b). Thus, a plant development time line can be associated directly with crop management inputs (Counce *et al.*, 2000a).

The key to developmental rate is the temperature of the growing point, i.e. the meristem where cell division and differentiation are occurring for the main stem (Ritchie and Nesmith, 1991). Researchers for other crops have found that they can determine the cardinal temperatures that govern developmental rates by plotting any physiological rate (for a particular species and cultivar) versus temperature. On searching the literature, we found one experiment in which a growth rate for rice was measured at several temperatures (Chaudhary and Ghildyal, 1969) and one report of the base temperature (T_b) of 8°C and the temperature above which growth is arrested (T_x) of 41°C (Alocilja and Ritchie, 1991). A more complete delineation of the method is provided by Reddy *et al.* (1997) and by Olivier and Annandale (1998). These data are shown in Fig. 1a. The two lines were fitted through the data using regression and the cardinal temperatures read directly from the graph. The third cardinal temperature, T_p, is defined as the temperature at which the two lines intersect and was read as 37°C. The T_p is the optimum temperature for development.

The thermal time, τ, is calculated as follows:

$$\tau = 0 \text{ when } T_b > T_{average} \text{ or when } T_{average} > T_x \text{ for } \Delta t \quad (1)$$

$$\tau = (T_{average} - T_b)\Delta t \text{ when } T_b < T_{average} < T_x \text{ for } \Delta t \quad (2)$$

$$\tau = [(T_x - T_{average})(T_p - T_b)/(T_x - Tp)]\Delta t \text{ when } T_p < T_{average} < T_x \text{ for } \Delta t \quad (3)$$

where $T_{average}$ is the average of the maximum and minimum temperatures for the time increment Δt. Usually, daily time steps are taken for Δt as in thermal time calculations for rice (Keisling *et al.*, 1984). The other terms are defined as above. Note that using Eq. 1 results in no thermal time accumulation below T_b or above T_x; using Eq. 2 results in linear thermal time increases between T_b and T_p; and using Eq. 3 results in linear thermal time decreases between T_p and T_x.

The data reported in this paper are intended to illustrate the relationship between RGS and thermal time accumulated (calculated as described above).

PROCEDURES

Several experiments were conducted in 1998 and 1999 with the rice cultivar Drew grown in each experiment. Data collected were date, RGS (vegetative), and daily temperatures as appropriate for each experiment. The particulars concerning the location, observation dates, and general environmental setting for each experiment are presented in Table 1. Thermal time was computed using Eq. 1, 2, and 3 and standard daily air temperatures.

The resultant cumulative thermal time was adjusted by (1) fitting a straight line through the first few data points near the origin by regression, and (2) subtracting the intercept value from all cumulative thermal times so that at growth stage zero, thermal time is zero. This method of zero thermal time adjustment is commonly utilized in thermal time calculations.

RESULTS AND DISCUSSION

The method for computing thermal time in Arkansas is compared to the newly proposed system, as shown in Fig. 1b. The main problems will occur at temperatures below T_b or above T_x. It is apparent that they are fundamentally different and will result in dramatically different computations at the higher temperature ranges. The most obvious change in the proposed system reduces τ accumulated at higher temperatures while the old system remains constant.

The thermal time versus vegetative stage (v stage) obtained in the growth chamber is treated as a standard. The temperature of the growing point was assumed to be the same as the air temperature, since the plants were grown in isolated pots. The standard can be used to compare phenological measurements obtained from various growing conditions (Fig. 2). It is apparent that very similar growth patterns occurred in 1998 and 1999, as indicated by the closeness of the two lines. The distance of the field line below the standard line increased steadily until after the V9 growth stage. From V9 to V12, the distance between the graphs and the standard lessened. At V13 to V14, the slope was the same as the standard. The observations of changes in the rate of accumulation coincided with the changes in the environment of the growing point or mainstem meristem. The mainstem environment coincided with major cultural changes, as shown at the top of Fig. 2.

The change in planting dates from early May to mid- to late June usually results in substantial differences in developmental rates. In Fig. 3, it is seen that the field-grown rice at Keiser developed quite a bit faster than the standard. Fig. 2 demonstrates that the later-planted rice at Keiser developed faster than the rice planted early at Stuttgart. As the environment of the mainstem meristem changes, so does the morphological developmental rate of the mainstem (Fig. 3). Since these segments of the graph were linear, a slope was calculated. When the rice was young, it required 75 thermal units per node compared to the standard of 106.5 thermal units per node. The developmental slope (when the growing point was above the water and in the air) was parallel to the standard.

SIGNIFICANCE OF FINDINGS

Cardinal temperatures for minimum, optimum, and maximum development of Drew rice have been identified, and a rice crop growth staging system has been developed that increases the accuracy of management input timing. The combined use of the RGS and thermal time has the potential to improve timing of rice management practices and thereby increase yields and profitability.

ACKNOWLEDGMENT

We thank Arkansas rice producers for their support through rice checkoff funds administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Alocilja, E.C. and J.T. Ritchie. 1991. A model for the phenology of rice. *In:* T. Hodges (ed.). Predicting crop phenology. pp. 181-189. CRC Press, Boca Raton, FL.

Chaudhary, T.N. and B.P. Ghildyal. 1969. Germination response of rice seeds to constant and alternating temperatures. Agron. J. 61:328-330.

Counce, P.A., T.C. Keisling, and D.C. Annis, Jr. 2000a. Using Rice Growth Staging as an Aid to Crop Management. *In:* R.J. Norman and C.A. Beyrouty (eds.). B.R. Wells Rice Research Studies 1999. University of Arkansas Agricultural Experiment Station Research Series 476:9-14.

Counce, P.A., T.C. Keisling, and A.J. Mitchell. 2000b. A uniform, adaptive and objective system for expressing rice development. Crop Science 40 (in press).

Keisling, T.C., B.R. Wells, and G.L. Davis. 1984. Rice management decision aids based upon thermal time base 50°F. Arkansas Cooperative Extension Service Technical Bull. No. 1.

Olivier, F.C. and J.G. Annandale. 1998. Thermal time requirements for the development of green pea (Pisum sativum L.). Field Crops Research 56:301-307.

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1997. Crop modeling and applications: a cotton example. Advances in Agronomy 59:225-289.

Ritchie, J.T. and D.S. Nesmith. 1991. Temperature and crop development. pp. 5-29. *In:* J. Hanks, and J.T. Ritchie (eds). 1991. Modeling Plant and Soil Systems. American Society of Agronomy, Madison, WI.

Table 1. Experimental descriptions including location, experimental conditions, dates, and number of plants observed.

				Date of Observations		Number of plants observed	
Experiment	Location	Experimental Conditions	Growth Stage	Beginning	Ending	Initially	Final
1	Stuttgart	Growth chamber	V1	11/19/1998	04/19/1999	22	12
2	Stuttgart	Field grown	V1	05/18/1998	08/16/1998	20	11
3	Stuttgart	Field grown	V1	05/18/1998	08/16/1998	20	16
4	Stuttgart	Field grown	V4	08/13/1998	11/11/1998	24	12
5	Stuttgart	Field grown	V2	06/02/1999	10/04/1999	20	20
6	Keiser	Field grown	V1	07/03/1999	09/19/1999	20	18

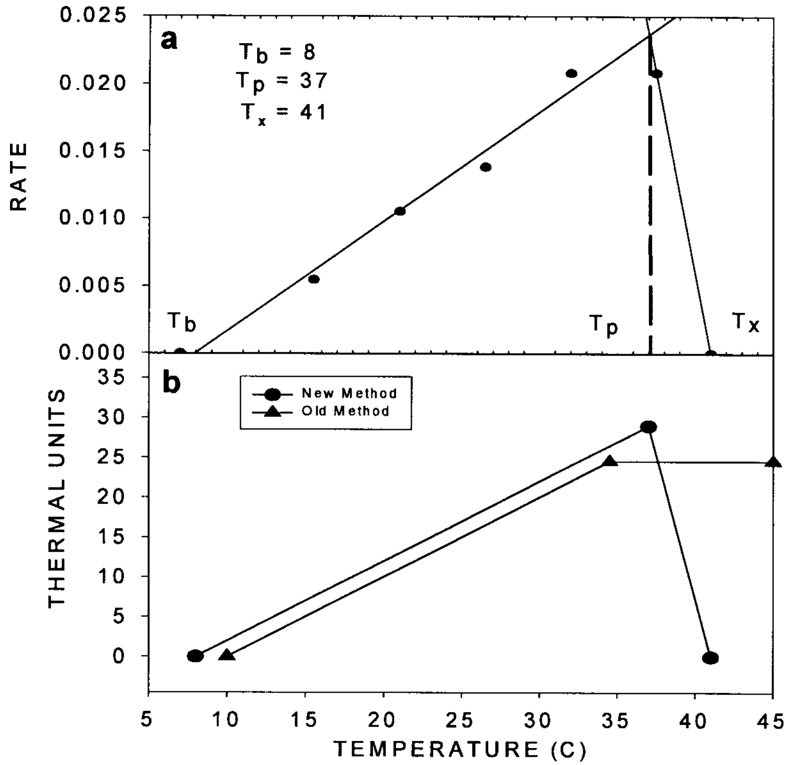


Fig. 1. (a) Graphical determination of the cardinal temperatures for rice phenological growth [data extracted from Chaudhary and Ghildyal (1969) and Alocilja and Ritchie (1991)] and (b) Comparison of newly proposed method of computing thermal time to that which has been used in the past. See Introduction for definitions of T_b, T_x, and T_p.

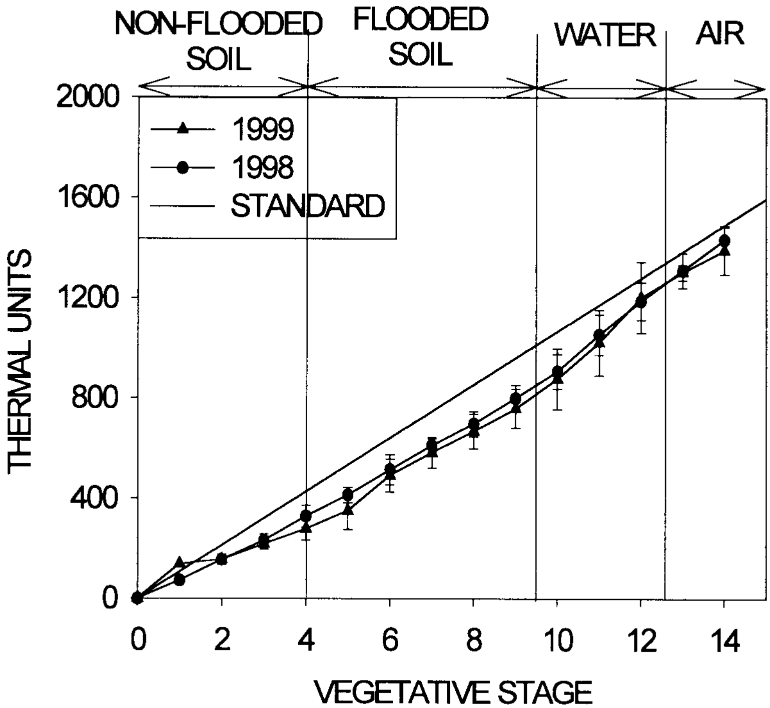


Fig. 2. Thermal time units versus vegetative stage for field-grown Drew rice planted in early May 1998 and 1999 at Stuttgart. Thermal units computed using standard air temperature from a class 'A' weather station. Note the standard derived from growth chamber data.

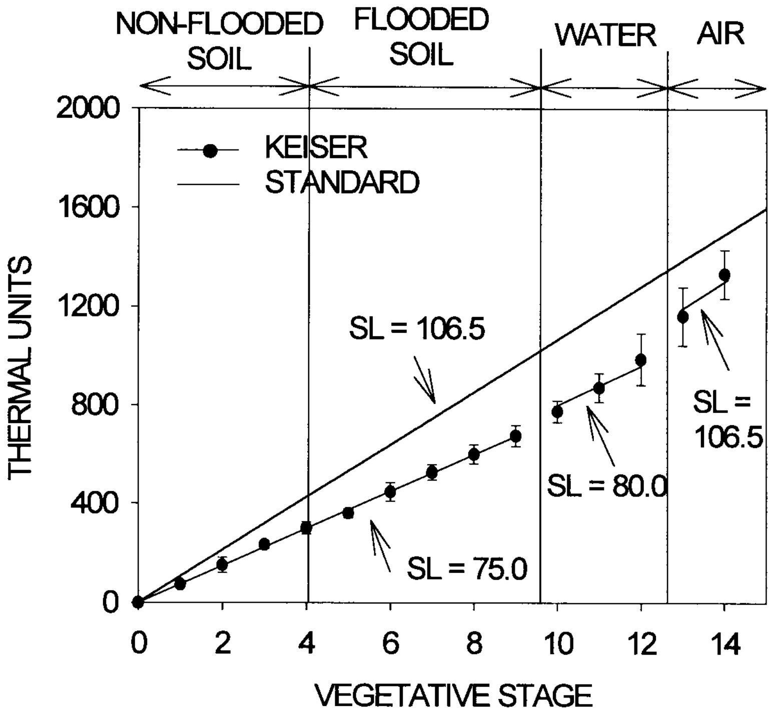


Fig. 3. Thermal time versus vegetative stage for field-grown Drew rice planted at Keiser, in late June 1999.

USING RICE GROWTH STAGING AS AN AID TO CROP MANAGEMENT

P.A. Counce, T.C. Keisling, and D.C. Annis, Jr.

ABSTRACT

The rice growth staging (RGS) system will allow precise and meaningful timing of production practices and the application of research treatments. We present the new RGS as a time line, with plant developmental events noted along that time line. The timing of these distinctive developmental events supports the idea that the RGS is consistent with the physiological age of the plant. Subsequently, we post fertilization and irrigation management practices along the time line as well. The result is a way to precisely time these rice management practices (Counce *et al.*, 2000).

INTRODUCTION

Rice crop management practices are keyed to the rice growth stages. This is evident in pesticide labels that specify that the chemical be applied at certain growth stages to be legal. In rice, we time flooding at the four-leaf stage, apply nitrogen (N) fertilizer at the panicle initiation stage, measure plant area at the mid-tillering stage, etc. (Helms, 1994). Growers schedule their work around calendar days, not RGS. A procedure that links calendar days to RGS would be useful.

Physiological plant age can be denoted by listing in temporal order the sequence of growth events that occur as the plant develops. The physiological growth stage of rice is identical to the rice growth stage from Counce *et al.* (2000) presented in Fig. 1. From Fig. 1 it is apparent that crop management calendars are constructed on the basis of physiological crop age (Hoshikawa, 1989). The physiological crop age is genetically coded and varies only within the limits of the genetic code (Wolpert *et al.*, 1998).

In crops, the two major factors that influence the rate at which plants progress in physiological age are temperature and light (usually length of day). Since commercially grown rice in Arkansas is not photoperiodic, temperature is left as the major factor affecting the rate of physiological aging or phenological development (Alocilja and Ritchie, 1991). To be even more precise, the temperature of the plant parts that are actively undergoing cell division and differentiation is the primary factor in determining the length of time a physiological aging step takes (Ritchie and Nesmith, 1991). The objective of this paper is to show how to develop a management calendar based on RGS.

PROCEDURES

A comprehensive relationship between RGS and potential management practices was constructed (Table 1). The basis for this construction was RGS (Counce *et al.*, 2000) and the DD50 Extension Program for rice (Keisling *et al.*, 1984). Briefly, the RGS is presented below. We propose a rice developmental staging system divided into three main phases of development—seedling, vegetative, and reproductive. Seedling development consists of four growth stages—unimbibed seed (S0), radicle and coleoptile emergence from the seed (S1, S2), and prophyll emergence from the coleoptile (S3). Vegetative development consists of stages V1, V2 . . . VN with N being equal to the final number of leaves with collars on the main stem. Reproductive development consists of 10 growth stages based on discrete morphological criteria: panicle initiation (R0), panicle differentiation (R1), flag leaf collar formation (R2), panicle exertion (R3), anthesis (R4), grain length and width expansion (R5), grain depth expansion (R6), grain dry down (R7), single grain maturity (R8), and complete panicle maturity (R9).

Observations for the rate of rice plant development are means from several experiments over the years. Otherwise parameters are professional opinion based on experience.

RESULTS AND DISCUSSION

With rice being one of the major crops in Arkansas, management calendars have been developed that summarize in-season management practices and predict their timing. However, historically a comprehensive description of rice growth stages had not been compiled. Recently, a comprehensive system of RGS was developed and is provided in a time line with morphological developmental events (Fig. 1) that take advantage of a rice plant's physiological age.

In Table 1, the timing of fertilizer and water management practices is described in terms of the RGS system. The importance of timing in performing these management practices was shown years ago in a Cooperative Extension Service Survey (Huey, 1973). The survey indicated that the highest yields were obtained with the most timely management inputs and that delays of only a few days resulted in 30 to 40% yield reductions. Production costs (except hauling harvested grain) remained the same regardless of yield.

The Arkansas Cooperative Extension Service's DD50 computer program for scheduling management inputs has been a mainstay for helping growers with timing. The cardinal growth stages are emergence (V1) and panicle elongation (VF-4). When the date of emergence is missed, or not recorded, the crop growth stage has the potential to set the program into motion at the completion of any leaf collar. It can be used as a comparison to check the accuracy of predictions as well. This may be especially useful in situations in which the rice crop has had various stresses or is in an environmental niche (such as water seeding) that influences its development. Environmental conditions may occur that cause (i.) the relationship between temperature and growth to be distorted and/or (ii.) the relationship between air temperature and the temperature of the growing point to be changed (Ritchie and Nesmith, 1991).

To check rice development, all that is needed is to keep track of crop development using RGS. Vegetatively, this means keeping track of the leaf number on the mainstem. This can be easily done by using a surveyor's flag to mark a plant's location, then recording the date of occurrence of a complete collar on a leaf and marking leaf 1 with a dab of red fingernail polish, leaf 3 with purple, leaf 5 with orange, etc. The colors used are irrelevant as long as they can be easily distinguished. (Applications of propanil and other pesticides can cause severe leaf burning and need to be assessed very carefully. The leaves should be observed just before and just after propanil applications to avoid an error in leaf count.) As the rice plant grows, lower leaves usually turn brown and "disappear." There are usually about 4 to 5 leaves on the mainstem of normally spaced rice in the field at any time. Therefore, three marker colors are sufficient and can be used repeatedly. The RGS system allows easy observation of reproductive stages if necessary. New leaves will appear about every 3 to 5 days. Thus, the next week's development can be predicted within a couple of days of a forecasted event.

While it may not be the easiest system to implement for management, RGS is always accurate. The RGS system will provide management information in situations in which other forecasting systems do not apply. Finally, RGS will give users a sense of satisfaction because they will be able to see the actual growth stage.

SIGNIFICANCE OF FINDINGS

The RGS system will allow precise and meaningful timing of production practices. A procedure is provided that accurately describes the timing of rice development regardless of environmental conditions. First, we show the RGS time line with rice developmental events along the time line. We then show management practices keyed to the time line. The result of this presentation is the ability to time management practices with the actual stage of growth and thereby improve timing of production practices, yield, and return.

ACKNOWLEDGMENT

We acknowledge the support of Arkansas rice producers through rice checkoff funds provided to the rice physiology project and administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Alocilja, E.C., and J.T. Ritchie. 1991. A model for the phenology of rice. *In:* T. Hodges (ed.). Predicting Crop Phenology. pp. 181-189. CRC Press, Boca Raton, FL.

Counce, P.A., T.C. Keisling, and A.J. Mitchell. 2000. A uniform, adaptive and objective system for expressing rice development. Crop Science 40 (in press).

Helms, R.S. 1994. Rice Production Handbook. Arkansas Cooperative Extension Service MP 192.

Hoshikawa, K. 1989. The growing rice plant. Nobunkyo, Tokyo.

Huey, B.A. 1973. Outstanding facts from survey of 31 Arkansas rice farmers producing high yields—1972. Arkansas Cooperative Extension Service Rice Information Sheet No. 7.

Keisling, T.C., B.R. Wells, and G.L. Davis. 1984. Rice management decision aids based upon thermal time base 50°F. Arkansas Cooperative Extension Service Technical Bulletin 1.

Ritchie, J.T., and D.S. Nesmith. 1991. Temperature and crop development. pp. 5-29 *In:* J. Hanks and J.T. Ritchie (eds). Modeling Plant and Soil Systems. American Society of Agronomy, Madison, WI.

Wolpert, L., R. Beddington, J. Brockes, T. Jessell, P. Lawrence, and E. Meyerowitz. 1998. Principles of development. Oxford University Press, NY.

Table 1. Fertilizer and irrigation management for rice based on the rice growth staging system presented by Counce *et al.*, 2000.

GROWTH STAGE		WATER AND FERTILIZER MANAGEMENT
S0		
S1		
S2		
S3		FLUSH AS NEEDED TO OBTAIN STAND
V1		
V2		
V3		
V4		FLOOD FOLLOWED BY N FERTILIZER APPLICATION
V5		
V6		MEASURE PLANT AREA
V7		
V8		DRAIN FOR STRAIGHTHEAD
V_{F-4} V9	R0 R1	
V_{F-3} V10		FIRST MID-SEASON N APPLICATION
V_{F-2} V11		
V_{F-1} V12		SECOND MID-SEASON N APPLICATION
V_F V13 R2		
R3		
R4		
R5		
R6		DRAIN ALERT
R7		
R8		HARVEST ALERT
R9		

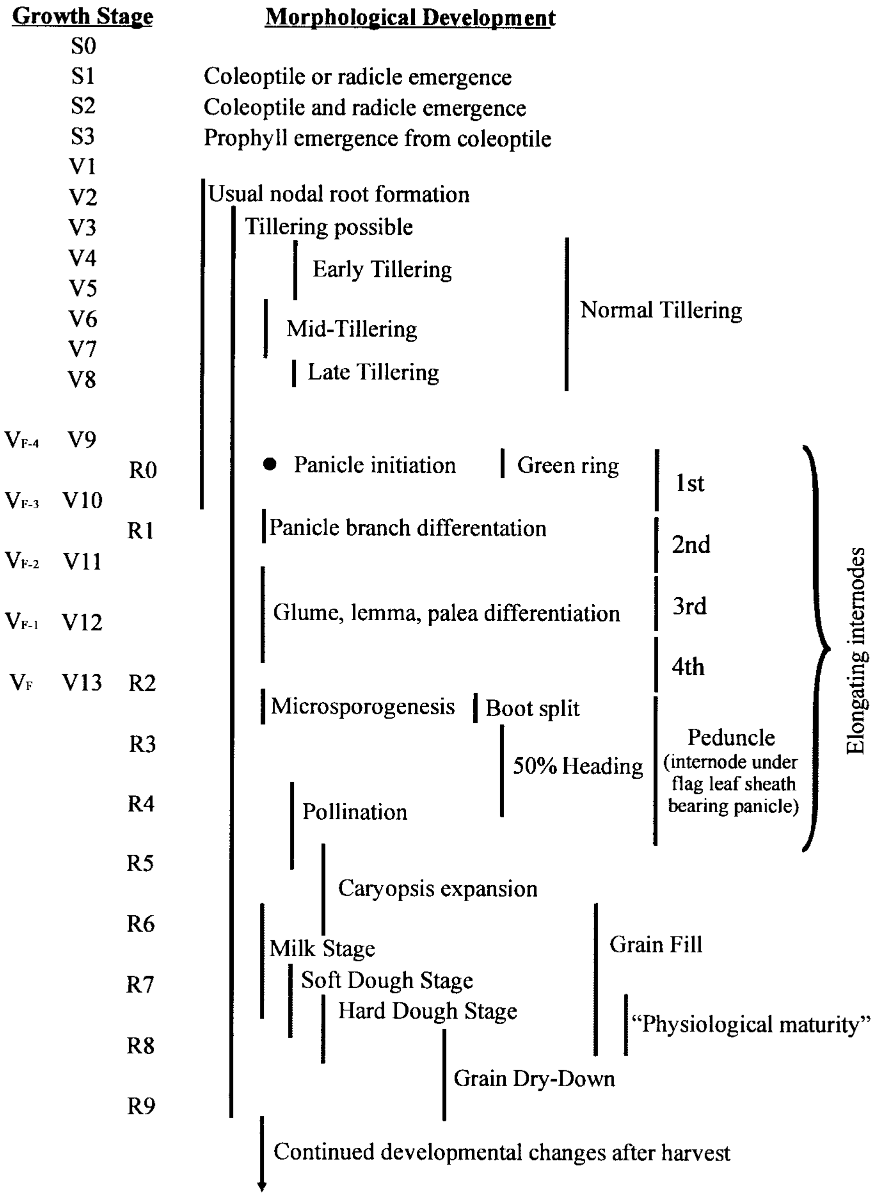


Fig. 1. Time line for rice growth stages and morphological developmental events in the rice plant.

PERFORMANCE OF RICE CULTIVARS/VARIETIES SEEDED AFTER HARVESTING WHEAT

R.H. Dilday, J.W. Gibbons, K.A.K. Moldenhauer, and W.G. Yan

ABSTRACT

In the southern United States, farmers are seeding rice after harvesting wheat, because of low soybean prices and the need for two cash crops per year. Thirty-two entries including 15 cultivars, 10 advanced breeding lines, and 7 germplasm accessions were evaluated on a DeWitt silt loam (Typic Albaqualf) soil on a farmer's field after the farmer had harvested wheat. 'LaGrue' (143 bu/acre) was the highest yielding entry in the test. RU 9801148 (136 bu/acre), an advanced line from Arkansas, was the second highest and 'Kaybonnet' (134 bu/acre) was the third highest yielding entry in the test. These data show that existing cultivars have acceptable yield potential when seeded after harvesting wheat in mid-June in Arkansas.

INTRODUCTION

In the southern United States, farmers are seeding rice after harvesting wheat, because of low soybean prices and the need for two cash crops per year. The normal seeding time for rice on the Grand Prairie of Arkansas is from 15 April to 15 May. Late seeding (about 4 to 6 wk later than normal) may require rice cultivars with both special characteristics and acceptable milling yield. Norman *et al.* (1999) seeded 12 cultivars/varieties on three planting dates (6 April, 11 May, and 10 June) as part of a DD50 study in 1998. They found that most of the cultivars produced the highest grain yield when seeded on 11 May as compared to 6 April or 10 June 1998. Also, most of the cultivars had a greater yield when they were seeded on 6 April than on 10 June. The objective of this study was to evaluate current cultivars, advanced breeding lines from the Arkansas breeding program, and germplasm accessions for grain yield and general adaptability when seeded after harvesting wheat.

PROCEDURES

Thirty-two entries including 15 cultivars (‘Adair’, ‘Alan’, ‘Bengal’, ‘Cocodrie’, ‘Cypress’, ‘Drew’, ‘Jefferson’, Kaybonnet, ‘L204’, LaGrue, ‘Litton’, ‘M202’, ‘Millie’, ‘Priscilla’, and ‘Wells’), 10 advanced breeding lines (RU 9601096, RU 9701041, RU 9801081, RU 9801148, RU 9901030, RU 9901099, RU 9901127, RU 9901133, Stg. 93 M6-104, and Farm Buster), and 7 germplasm accessions (Geumobyeo, Japan 92.09.31, Jouiku 393, Jouiku 394, PI 312777, Shin-Ei, and Zhe 733) were evaluated on a DeWitt silt loam (Typic Albaqualf) soil. The test was located about 0.5 mile north of Highway 146 near Stuttgart on Bill Keller’s farm. The wheat cultivar ‘Coker 9803’ was harvested 7 June 1999 and the rice cultivar Jefferson was seeded on 11 June 1999. Our test was seeded on 14 June 1999 in a completely randomized block design with four replications in the same field that the rice cultivar Jefferson was planted. The plots were 15 ft long and 6 rows wide, with 8-in. spacing between rows. The seedlings emerged on 20 June. Three split applications of urea were applied [preflood: 80 units/acre of nitrogen (N); 0.5-in. internode elongation (IE): 35 units/acre of N; and 7 days after 0.5-in. IE: 35 units/acre of N]. Command herbicide was applied at a rate of 0.5 qt/acre on 11 June. During the first week of July, 1 gal/acre of propanil and 0.375 lb/acre Facet was applied. Heading dates were recorded when 50% of the panicles had emerged. Plant height was measured from ground level to the tip of the panicle at maturity. Two rows in the middle of each plot were hand-harvested at about 17 to 19% moisture and dried to about 12% moisture after thrashing.

RESULTS AND DISCUSSION

LaGrue (143 bu/acre) was the highest yielding entry in the test. RU 9801148 (136 bu/acre), an advanced line from Arkansas, was the second highest yielding entry, and Kaybonnet (134 bu/acre) was the third highest yielding entry in the test. In fact, the six highest yielding entries (LaGrue, RU 9801148, Kaybonnet, RU 9901133, Alan, and Millie) were developed in Arkansas. Jefferson, which was seeded in the farmer’s field, averaged 95 bu/acre dry weight as compared to 76 bu/acre dry weight for Jefferson in the replicated test. Days from emergence to heading ranged from 102 for PI 312777 to 73 for six entries (Farm Buster, M 202, L 204, Jouiku 394, Shin-Ei, and Geumobyeo). Plant height ranged from 107 cm for Adair and Millie to 70 cm for RU 9801081. Table 1 shows plant height, days from emergence to heading, and yield for all 32 entries in the test. Three of the six earliest maturing entries had the lowest grain yield, which suggests that the days from emergence to heading may not be an important characteristic in the selection of rice cultivars to seed following wheat harvest.

SIGNIFICANCE OF FINDINGS

LaGrue, Kaybonnet, Alan, Millie, and selected advanced lines in the Arkansas breeding program appear have acceptable yield potential when seeded after harvesting wheat in mid-June in Arkansas.

ACKNOWLEDGMENT

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

LITERATURE CITED

Norman, R.J., N.A. Slaton, and K.A.K. Moldenhauer. 1999. Development of the DD50 database for new rice cultivars. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:250-256.

Table 1. Grain yield, days from emergence to heading, and plant height of 32 cultivars/varieties and germplasm accessions seeded on 14 June following wheat harvest.

Cultivar	Grain Yield		Heading[z]	Plant Height
	lb/acre	bu/acre	Days	(cm)
LaGrue	6422	143	94	85
RU9801148	6106	136	90	76
Kaybonnet	6020	134	92	82
RU9901133	5834	130	86	82
Alan	5387	120	86	86
Adair	5330	118	86	92
Priscilla	5255	117	88	76
RU9901127	5198	116	86	92
M 202	5080	113	73	81
RU9901030	4925	109	86	79
RU9701041	4738	105	95	70
Cocodrie	4662	104	84	72
Cypress	4586	102	96	68
RU9901099	4476	100	86	78
Wells	4416	98	97	76
Bengal	4347	97	86	82
Litton	4266	95	98	76
RU9801081	4094	91	96	75
Drew	4021	89	95	92
Jouiku 393	3883	86	75	77
Stg93M6-104	3684	82	86	84
RU9601096	3663	81	86	76
Jefferson	3400	76	86	66
Japan 92.09.31	3266	73	87	75
Geumobyeo	3220	72	73	73
L 204	3008	67	73	72
PI 312777	2960	66	102	72
Zhe 733	2920	65	74	70
Millie	2856	64	86	78
Shin-Ei	2648	59	73	78
Jouiku 394	2388	53	73	68
Farm Buster	2166	48	73	68
Mean	4226	94	86	87
LSD (0.05)	1596	36	3	7

[z] Entries were seeded at the RREC and heading dates were recorded.

EVALUATION OF NEW RICE GERMPLASM FROM FOREIGN COUNTRIES

R.H. Dilday, F.N. Lee, K.A.K. Moldenhauer, W.G. Yan, and R. Guei

ABSTRACT

Rice germplasm was recently collected from Bangladesh, China, Hungary, India, Ivory Coast, Japan, Korea, Philippines, Sri Lanka, Taiwan, and Vietnam. The accessions were evaluated for agronomic characteristics such as 50% heading date, plant height, lodging, grain type, field grain yield, and milling yield. 'Wells' was the United States commercial check used in each of the tests, and it generally headed in about 85 days after emergence and had a mean height of 106 cm, with an average grain yield of 7482 lb/acre. The average total milling yield of Wells was 71%, with a head rice yield of 61%. Japan 92.09.31 was the highest yielding (9,141 lb/acre) accession, followed by 'Teshnai' (8,406 lb/acre) from China and IR 50363-61-1-2-2 (8173 lb/acre) from the Philippines. Japan 92.09.31, Teshnai, and IR 50363-61-1-2-2 headed 81, 93, and 81 days after emergence and were 104, 112, and 95 cm tall, respectively. The total milling yield of Japan 92.09.31, Teshnai, and IR 50363-61-1-2-2 was 71, 69, and 70% with a head rice yield of 52, 50, and 60, respectively. 'Karmina', the highest yielding cultivar from Hungary, headed 64 days after emergence or 21 days before Wells and was 108 cm tall, but had a field yield of only 4505 lb/acre. The total milling yield of Karmina was 67%, with a head rice yield of 57%. These accessions may be potential parents for the Arkansas rice variety development program.

INTRODUCTION

The rice portion of the USDA-ARS National Small Grains Working Collection (NSGC) contains 17,167 accessions. In 1990, only 56 genotypes, which can be traced to 13 accessions, had been utilized in developing cultivars in Arkansas, 49 genotypes traced to 12 accessions had been utilized in developing cultivars in Texas, 49 genotypes traced to 16 accessions had been utilized in developing cultivars in Louisiana, and 57 genotypes traced to 23 accessions had been utilized in developing cultivars in California. Furthermore, 10 of the 12 and 13 parental accessions in the Texas and Arkansas breeding programs, respectively, were identical, and 8 of the 13 and 16 accessions in the Arkansas and Louisiana breeding programs, respectively, were identical (Dilday, 1990).

There are about 80,000 accessions of rice at the International Rice Research Institute (IRRI) in the Philippines. China has several rice germplasm collections, with the collection at Beijing having over 50,000 accessions. The national rice collection in India has about 55,000 accessions and is located at multiple storage sites. The Japanese national rice collection contains about 35,000 accessions. The IRRI collection is probably the most genetically diverse in the world, because the acquisition and field collection efforts were implemented in the appropriate places and at opportune times, before advanced genetic erosion occurred (Chang *et al.*, 1989). However, it has been estimated that a total of 100,000 rice cultivars exist in Asia alone (Chang, 1985). Therefore, the collection and acquisition of rice germplasm must be a continual effort. Moreover, the important point is that only a small proportion of the total genetic diversity of rice has been conserved (Chang *et al.*, 1989).

In the past few years, we have collected rice germplasm from 16 foreign countries. This germplasm must pass through the Plant Germplasm Quarantine Office at Beltsville, Maryland, and must be grown in quarantine for one generation before it can be grown in the field and rejuvenated at Stuttgart. After an accession is increased at Stuttgart, it is introduced into the National Plant Germplasm System and assigned a plant introduction number. The ultimate goal is to have rice germplasm used as parents in rice variety development programs in the United States. However, for germplasm to be used it must be shown to be useful. Evaluation of the germplasm identifies useful attributes. The objective of this study was to evaluate new rice germplasm for agronomic characteristics, including field grain and milling yield, in an Arkansas environment.

PROCEDURE

Rice germplasm has been collected recently from Argentina, Bangladesh, China, Colombia, Hungary, India, Ivory Coast, Japan, Korea, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam. The material cleared quarantine and was rejuvenated in the field in 1998. In 1999, the new germplasm was evaluated for field and milling yield, lodging, maturity, grain type, and plant height. The evaluation studies comparing the U.S. cultivar Wells to the cultivars and accessions introduced in the United States were divided into four geographic groups as follows: Group 1 = Bangladesh and Ivory Coast; Group 2 = Japan, China, and Philippines; Group 3 = Korea; and Group 4 = India, Sri Lanka, and Vietnam. The plots were 4.5 ft long and 6 rows wide, with 8-in. spacing between rows. The test was planted on 30 April 1999 in a randomized complete-block design with four replications at the Rice Research and Extension Center near Stuttgart. The seedlings emerged 9 May 1999. Three split applications of urea (45% nitrogen[N]) were applied [preflood: 60 lb/acre of N; 0.5-in. internode elongation (IE): 30 lb/acre of N; and 7 days after 0.5-in. IE: 30 lb/acre of N]. Heading dates were recorded when 50% of the panicles had emerged. Plant height was measured from ground level to the tip of the panicle at maturity. Lodging and grain type were recorded at harvest. Two rows in the middle of each plot were hand-harvested at approximately 17 to 19% moisture and dried to 12% moisture after threshing. Milling yield was determined from a 162-g sample from replications 1 and 2 of each test. Each test included 32 germplasm accessions, including the checks.

RESULTS AND DISCUSSION

The U.S. cultivar Wells was the commercial check in each geographic group in studying the new cultivars and accessions introduced into the United States.

Group 1: Bangladesh, Hungary, and Ivory Coast

Wells headed 85 days after emergence and was 110 cm tall, with a field yield of 7018 lb/acre. The total milling yield of Wells was 71%, with a head rice yield of 62%. Three germplasm accessions—one from Bangladesh and two from the Ivory Coast—were not significantly different in yield from Wells (Table 1). 'BR 6' from Bangladesh headed 99 days after emergence and was 108 cm tall, with a field yield of 7395 lb/acre. The total milling yield of BR 6 was 66%, with a head rice yield of 57%. The two accessions from the Ivory Coast, WAB450-11-1-2-P1 and WAB56-104, headed 74 and 75 days after emergence and were 103 and 116 cm tall with field yields of 6326 and 6463 lb/acre, respectively. The total milling yield of WAB450-11-1-2-P1 was 68%, with a head rice yield of 55%, and WAB56-104 had a total milling yield of 68%, with a head rice yield of 56%. The accessions from Hungary were about 3 wk earlier in maturity (61 to 74 days, mean = 64 days) than Wells (85 days). Karmina, the highest yielding cultivar from Hungary, headed 64 days after emergence and was 108 cm tall but had a field yield of only 4505 lb/acre. The total milling yield of Karmine was 67%, with a head rice yield of 57%.

Group 2: China, Japan and Philippines

Wells headed 85 days after emergence and was 102 cm tall, with a field yield of 7215 lb/acre. The total milling yield of Wells was 71%, with a head rice yield of 61%. There were 18 germplasm accessions—one from Japan, three from China, and14 from the Philippines—that were not significantly different in yield from Wells (Table 2). Japan 92.09.31 headed 81 days after emergence and was 104 cm tall, with a field yield of 9141 lb/acre. The total milling yield of Japan 92.09.31 was 71%, with a head rice yield of 51%. The three cultivars from China (‘Teshni’, ‘Miyang’, and ‘Shanyou’) headed 93, 87, and 93 days after emergence and were 112, 102, and 110 cm tall with field yields of 8406, 6736, and 5294 lb/acre, respectively. The total milling yields of Teshni, Miyang, and Shanyou were 69, 70, and 68%, with head rice yields of 50, 51, and 47%, respectively. The two highest yielding germplasm accessions from the Philippines were IR 50363-61-1-2-2 and ECIA67-S89-1. These two accessions headed 81 and 84 days after emergence and were 95 and 99 cm tall, with field yields of 8173 and 8126 lb/acre, respectively. The total milling yield of IR 50363-61-1-2-2 was 70%, with a head rice yield of 60%, and ECIA67-S89-1 had a total milling yield of 68%, with a head rice yield of 59%.

Group 3: Korea

Wells headed 85 days after emergence and was 104 cm tall, with a field yield of 7803 lb/acre. The total milling yield of Wells was 72%, with a head rice yield of 60%. Four cultivars from Korea were not significantly different in field yield from Wells (Table 3). ‘Suwon 420’, ‘Youngsanbyeo’, ‘Kyehwabyeo’, and ‘Palgongbyeo’ headed 81, 86, 92, and 86 days after emergence and were 99, 94, 107, and 108 cm tall, with field yields of 7329, 6806, 6797, and 6681 lb/acre, respectively. The total milling yields of Suwon 420, Youngsanbyeo, Kyehwabyeo, and Palgongbyeo were 66, 72, 70, and 70%, with head rice yields of 58, 48, 54, and 64%, respectively.

Group 4: India, Sri Lanka, Taiwan, and Vietnam

Wells headed 87 days after emergence and was 108 cm tall, with a field yield of 7893 lb/acre. The total milling yield was 72%, with a head rice yield of 62%. Six germplasm accessions—two from Taiwan, one from India, two from Vietnam, and one from Sri Lanka—were not significantly different in yield from Wells (Table 4). ‘Kaohsiung Sen Yu’ and ‘Taichung Sen Yu’ from Taiwan headed 92 and 93 days after emergence and were 117 and 116 cm tall, with field yields of 7696 and 7382 lb/acre, respectively. The total milling yields of Kaohsiung Sen Yu and Taichung Sen Yu were 67 and 68%, with head rice yields of 59 and 52%, respectively. OR79-21 from India headed 94 days after emergence and was 104 cm tall, with a field yield of 6869 lb/acre. The total milling yield of OR79-21 was 70%, with a head rice yield of 47%. OM 1570 and OM 1704 from Vietnam headed 94 and 91 days after emergence, and they were both 119 cm tall, with field yields of 6681 and 6444 lb/acre, respectively. The total milling yields of OM 1570 and OM 1704 were 71 and 70%, with head rice yields of 62 and 54%, respectively. BG850-2 from Sri Lanka headed 95 days after emergence and was 124 cm tall, with a field yield of 6103 lb/acre. The total milling yield of BG850-2 was 67%, with a head rice yield of 55%.

SIGNIFICANCE OF FINDINGS

Selected rice germplasm from Bangladesh, China, India, Ivory Coast, Japan, Philippines, Sri Lanka, Taiwan, and Vietnam were identified as high-yielding genotypes, and germplasm from Hungary was identified that is about 3 wk earlier in maturity than Wells. These germplasm accessions can be used as parents in the Arkansas rice variety development program

ACKNOWLEDGMENT

This research was partially funded by the rice producers' checkoff fund administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Chang, T.T. 1985. Preservation of Crop Germplasm. Iowa State J. Res. 59(4):365-378.

Chang, T.T., S.M. Dietz, and M.N. Westwood. 1989. Management and Use of Plant Germplasm Collections. Biotic Diversity and Germplasm Preservation, Global Imperatives. Beltsville Symposia in Agriculture Research (13).

Dilday, R.H. 1990. Contribution of ancestral lines in the development of new cultivars of rice. Crop Sci. 30(4):905-911.

Table 1. Agronomic characteristics of new rice germplasm cultivars and accessions introduced into the U.S. from Group 1: Bangladesh and Ivory Coast.

Cultivar / Accession	Country	Yield	Grain Type	Plant Height	Head	Milling Yield (%)		
						Total	Head	Broken
		(lb/acre)		(cm)	(days)	(%)		
BR 6	Bangladesh	7395	M	108.5	99.0	66.5	57.0	9.5
WAB56-104	Ivory Coast	6463	L	116.0	75.0	68.5	56.5	12.0
WAB450-11-1-2-P1	Ivory Coast	6326	M	102.8	74.3	68.0	55.0	13.0
Check								
Wells	United States	7018	L	110.0	84.8	71.5	62.5	9.0
LSD (0.05)		1417		8.5	2.8	3.1	8.4	7.8

Table 2. Agronomic characteristics of new rice germplasm cultivars and accessions introduced into the U.S. from Group 2: Japan.

Cultivar / Accession	Country	Yield	Grain Type	Plant Height	Head	Milling Yield (%) Total	Head	Broken
		(lb/acre)		(cm)	(days)	---------- (%)	----------	----------
Japan 92.09.31	Japan	9141	M	6.8	104.0	81.0	71.0	51.5
TESHNAI	China	8406	M	2.5	112.5	92.8	69.0	50.0
IR 50363-61-1-2-2	Philippines	8173	L	5.5	95.5	81.0	69.5	60.5
ECIA76-S89-1	Philippines	8126	L	4.0	101.5	83.8	68.0	58.5
IR 47310-87-2-1-2	Philippines	7963	L	4.5	115.0	79.5	69.0	55.0
IR 50404-57-2-2-3	Philippines	7318	L	6.5	104.5	81.0	70.5	59.0
BG1639	Philippines	7162	M	1.0	104.0	93.8	64.0	52.5
BR568-15-4-2-2-2	Philippines	6756	M	2.2	105.0	104.3	70.0	61.0
ECIA66	Philippines	6753	L	1.2	105.5	96.0	68.0	61.5
MIYANG	China	6736	M	1.8	102.5	86.8	70.5	51.0
ECIA67-S1-J1-5	Philippines	6706	L	4.0	99.5	83.3	69.0	62.0
BR802-118-4-2	Philippines	6384	M	1.0	111.5	110.0	67.0	57.5
BG915	Philippines	6316	L	8.0	110.5	79.0	70.0	57.0
IR 49442-9-1-1-1-3	Philippines	6296	L	2.8	109.0	97.3	65.5	52.0
BG1219	Philippines	6228	M	1.2	103.5	109.0	71.0	63.0
BOUAKE 189	Philippines	6185	M	1.5	119.0	96.0	66.5	60.0
CL SELECCION56	Philippines	5738	L	1.5	114.5	94.5	69.0	65.0
SHANYOU	China	5293	M	2.5	109.5	93.3	68.0	47.0
Check								
Wells	United States	7215	L	2.0	102.5	84.8	71.5	61.0
LSD (0.05)		1930		3.4	8.5	8.7	2.9	10.2

Table 3. Agronomic characteristics of new rice germplasm cultivars and accessions introduced into the U.S. from Group 3: Korea.

Cultivar / Accession	Country	Yield	Grain Type	Plant Height	Head	Milling Yield (%) Total	Head	Broken
		(lb/acre)		(cm)	(days)	---------- (%) ----------		
Suwon 420	Korea	7329	M	1.0	99.5	80.8	66.0	58.0
Youngsanbyeo	Korea	6806	S	1.0	94.5	86.0	72.0	48.0
Kyehwabyeo	Korea	6797	S	1.0	107.0	91.5	70.0	54.0
Palgongbyeo	Korea	6682	M	1.0	108.5	86.0	70.0	64.0
Check								
Wells	United States	7803	L	1.0	104.0	84.8	72.0	60.5
LSD (0.05)		1275		0.4	6.1	2.0	3.5	8.8

Table 4. Agronomic characteristics of new rice germplasm cultivars and accessions introduced into the U.S. from Group 4: Taiwan, India, Vietnam, and Sri Lanka.

Cultivar / Accession	Country	Yield	Grain Type	Plant Height	Head	Milling Yield (%) Total	Head	Broken
		(lb/acre)		(cm)	(days)	---------- (%) ----------		
TAICHUNG SEN YU	Taiwan	7696	M	117.0	91.8	67.0	59.0	8.0
KAOHSIUNG SEN YU	Taiwan	7382	M	116.0	92.8	68.5	51.5	17.0
OR79-21	India	6869	M	104.0	94.3	70.0	47.0	23.0
OM 1570	Vietnam	6681	L	119.0	93.5	71.0	61.5	9.5
OM 1704	Vietnam	6444	L	119.0	90.3	70.5	54.0	16.5
BG850-2	Sri Lanka	6103	M	124.0	95.0	67.0	54.5	12.5
Check								
Wells	United States	7893	L	108.5	86.8	72.0	61.5	10.5
LSD (0.05)		1808		12.7	6.1	4.3	13.9	11.9

RICE BREEDING AND GENETICS: DEVELOPMENT OF SEMI-DWARF LONG- AND MEDIUM-GRAIN CULTIVARS

J.W. Gibbons, K.A.K. Moldenhauer, F.N. Lee, J.L. Bernhardt, M. Anders, N. Slaton, R.J. Norman, R.H. Dilday, J.N. Rutger, M.M. Blocker, J.M. Bulloch, and A.C. Tolbert

ABSTRACT

Semi-dwarf rice experimental lines have been identified with high yield, stress tolerance, and good grain quality. Lines are in all stages of development, from segregating populations to breeder head rows. New sources of yield, disease, and stress resistance are being used as parents in the breeding program. Semi-dwarf cultivars offer options for Arkansas rice producers.

INTRODUCTION

Since the release of 'Lemont' in the mid 1980s, semi-dwarf rice cultivars have been grown in Arkansas. Lemont, 'Cypress', and 'Bengal', for example, are long- and medium-grain semi-dwarfs that occupy a large proportion of rice area currently and in past years. These cultivars continue to be the base for semi-dwarf cultivar development in Arkansas. Recently, Rutger (1997) induced semi-dwarfism in Arkansas cultivars such as 'LaGrue', 'Orion', and 'Millie'. These mutants provide a source of locally adapted germplasm with a semi-dwarf gene that is non-allelic to the commonly used *sd1* (Rutger *et al.*, 1998). In addition, Lee *et al.* (1999) have characterized as tolerant to both rice sheath blight and blast several recently introduced USDA germplasm accessions. Most of these introductions belong to the indica subtribe of cultivated rice. Indicas have been suggested as sources for yield potential and disease resistance for domestic breeding programs (McClung *et al.*, 1998). Our objective is to develop semi-dwarf long- and medium-grain cultivars that are high yielding with excellent grain, milling, and processing quality that tolerate the common stresses and pests found in Arkansas rice fields.

PROCEDURES

Potential parents for the breeding program are evaluated for the desired objectives. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Use of parents with diverse backgrounds is emphasized. Segregating populations are planted at Stuttgart and the winter nursery at Lajas, Puerto Rico. Selection is based on grain and plant type, spikelet fertility, field and greenhouse disease reaction, and grain quality. Yield evaluations begin with the preliminary yield trial at one location, the Stuttgart Initial Test at two locations, the Arkansas Rice Performance Trials at five locations in the state, and the Uniform Regional Rice Nursery conducted in cooperation with rice-breeding programs in Texas, Louisiana, Florida, and Mississippi.

RESULTS AND DISCUSSION

Over 50 cross combinations were produced in1999. We are attempting to use the winter nursery location to make crosses because of the difficulty in successful pollination at Stuttgart in the winter. Over 980 F2 single plants were selected during the year (Table 1). Panicles from these plants were sent to the winter nursery for advancement of generation. We evaluated a bulk of each selected plant for blast disease in the greenhouse, and selected plants will be grown as F4 rows in 2000. Over 950 F4 and 604 F5 bulk rows were selected to advance. After disease and quality evaluation, the selected lines will be advanced to F5 rows and preliminary yield trials, respectively, next year.

Yields of selected semi-dwarf long-grain lines from the preliminary yield trial are shown in Table 2. Compared to the highly successful Cypress, the four lines designated “A”, “B”, “C”, and “D” from the crosses Rosemont//Newbonnet/Katy, Cypress//Newbonnet/Katy, and Cypress //Katy/Starbonnet, respectively, showed improved blast disease resistance and higher field yield. Tolerance levels to sheath blight disease are near or slightly worse than Cypress, while head rice yields of the experimental lines are inferior to the excellent milling Cypress. Medium-grain lines in the Stuttgart Initial Test designated “A”, “B”, and “C” (“A” and “C” from Bengal/Short-Rico, and “B” from Brazos/Tebonnet/3/164986-4/NV66//Nortai/4/Bengal) produced a higher mean yield at the two locations than the check cultivar Bengal (Table 3). Lines “A” and “B” yielded higher at both locations, while line “C” produced over 200 bu/acre at Rohwer, but less than Bengal at Stuttgart. Grain weight of “C” was larger than that of the other lines, while head rice yield was lower, but acceptable. Each of these lines will be advanced for further testing in 2000.

Two medium-grain and one long-grain semi-dwarf experimental lines will be seeded in breeder head rows for 2000. The lines are designated as “A”, “B”, and “C” in Tables 4 and 5. “A” and “B” are medium grains with the pedigree Brazos/Tebonnet/3/164986-4/NV66//Nortai/4/Bengal. Line “A” is very similar to Bengal in yield, height, and heading date, but has lower kernel weight but higher head rice yield. Line “B” generally has lower yield and milling quality but higher kernel weight than the check Bengal. Compared to the cultivar Cocodrie, Line “C” from the cross Adair/Jodon generally yields as well both in-state and regionally, is slightly shorter, but head and total milling yields are lower.

SIGNIFICANCE OF FINDINGS

Promising semi-dwarf experimental lines have been identified that have good disease resistance, high yields, and good grain and milling quality. Semi-dwarf long- and medium-grain rice varieties with diverse genetic backgrounds offer producers choices of cultivar and management systems for Arkansas rice production.

ACKNOWLEDGMENT

This research is supported by the Arkansas Rice Research and Promotion Board. Thanks also to the Uniform Regional Rice Nursery cooperators from rice-growing states.

LITERATURE CITED

Lee, F.N., R.H. Dilday, K.A.K. Moldenhauer, J.N. Rutger, and W. Yan. 1999. Sheath blight and rice blast resistance in recently introduced rice germplasm. *In:* R.J. Norman and T.H. Johnston (eds.). The B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:195-210.

McClung, A.M., G.C. Eizenga, C. Bastos, B.T. Tillman, and J.N. Rutger. 1998. Yield comparison of indica and U.S. commercial cultivars grown in the Southern U.S. and Brazil. *In:* Proc. Rice. Tech. Work. Group, Reno, Nevada. March 1-4, 1998. pp.59-60.

Rutger, J.N. 1997. Rice genetics and germplasm enhancement. *In:* R.J. Norman and T.H. Johnston (eds.). The B.R. Wells Rice Research Studies 1996. University of Arkansas Agricultural Experiment Station Research Series 456:22-27.

Rutger, J.N., K.A. Gravois, K.A.K. Moldenhauer, F.N. Lee, and R.J. Norman. 1998. Inheritance and performance of six semi-dwarf mutants in Arkansas rice cultivars. *In:* Proc. Rice Tech. Work. Group, Reno, Nevada. March 1-4, 1998. pp.61-62.

Table 1. Number of lines selected in project ARK01542 during 1999.

Evaluation Phase	Number of Lines
F_2 Space Plants	982
F_4 Panicle Rows	958
F_5 Panicle Rows	604
Preliminary Trials	43

Table 2. Results from the 1999 Preliminary Rice Yield Trial for experimental lines and check cultivars.

Cultivar	Grain type	Disease[z] LB(GH)	Disease[z] LB(F)	Disease[z] NB(F)	Disease[z] SB(F)	Height[y] (inches)	50% HD (days)	Grain yield (bu/acre)	Milling yield (% HR : % TOT)
Line A[x]	L	0	1.3	1.5	7.8	38	77	182.00	54 : 73
Line B[w]	L	0	1.3	2.5	8.7	37	80	178.50	59 : 72
Line C[w]	L	0	1	2	8	39	80	173.50	61 : 70
Line D[v]	L	0	2	3	7.5	36	80	164.00	60 : 70
Cypress	L	-	4.3	6.3	7.5	42	84	154.30	65 : 71

[z] Disease data from greenhouse (GH) and field (F) evaluations at Stuttgart and Pine Tree. LB = Leaf Blast, NB = Neck Blast, and SB = Sheath Blight. Ratings on scale of 0 to 9, where 0 = no disease and 9 = plants dead. Average of 4 replications.

[y] Height, days to 50% heading, grain yield, and milling data are from Stuttgart, Arkansas.

[x] Line A from the cross Rosemont//Newbonnet/Katy.

[w] Line B and C from cross Cypress//Newbonnet/Katy.

[v] Line D from cross Cypress//Katy/Starbonnet.

Table 3. Results from the 1999 Arkansas Medium Grain Stuttgart Initial Test (SIT) conducted at the Rice Research and Extension Center (RREC) and the Southeast Branch Experiment Station (SEBES).

Cultivar	Grain type	Location RREC	SEBES	mean	Height[z]	50% HD	100 Grain weight	Milling yield
		---------- (grain yield in bu/acre)		----------	(inches)	(days)	(g)	(% HR : % TOT)
Line A[y]	M	176	196	186	31	84	2.35	63 : 71
Line B[x]	M	174	194	184	33	87	2.22	68 : 73
Line C[y]	M	156	212	184	34	84	2.68	62 : 71
Bengal	M	166	185	176	34	87	2.62	68 : 74

[z] Height, 50% Heading, grain weight, and milling yield from RREC.
[y] Lines A and C from cross Bengal/Short-Rico.
[x] Line B from cross Brazos/Tebonnet/3/164986-4/NV66//Nortai/4/Bengal.

Table 4. Results from the 1999 Arkansas Rice Performance Trials for three experimental lines and two check cultivars.

Cultivar	Grain type	Location[z] SEBES	RREC	PTBES	NEREC	Height[y]	50% Heading	Kernel weight	Milling yield
		(grain yield in bu/acre)				(inches)	(days)	(mg)	(% HR : % TOT)
Line A[c]	M	222	180	171	137	34	86	17.60	73 : 76
Line B[c]	M	195	144	137	133	36	83	19.20	66 : 72
Line C[d]	L	191	185	169	144	34	85	17.85	66 : 73
Bengal	M	209	181	174	174	35	86	18.71	65 : 75
Cocodrie	L	185	176	175	110	41	85	16.90	69 : 73

[z] The 1999 ARPT consisted of three replications at four locations, Southeast Branch Experiment Station, (SEBES), Rowher, Arkansas; Rice Research and Extension Center, (RREC), Stuttgart, Arkansas; Pine Tree Branch Experiment Station, (PTBES), Colt, Arkansas; and Northeast Research and Extension Center, (NEREC), Keiser Arkansas.

[y] Means for height, 50% heading date, kernel weight and milling data are from RREC.

[x] Line A and B are from the cross Brazos/Tebonnet/3/164986-4/NV66//Nortai/4/Bengal.

[w] Line C is from the cross Adair/Jodon.

Table 5. Results from the 1999 Uniform Regional Rice Nursery for three experimental lines and two check cultivars.

Cultivar	Grain type	Location[z] AR	LA	MS	TX	mean	Height[y]	50% Heading	Lodging	Milling yield
		(grain yield in bu/acre)					(inches)	(days)	(%)	(% HR : % TOT)
Line A[x]	M	166	196	208	189	190	38	82	0.00	64 : 71
Line B[x]	M	156	192	179	119	161	34	76	0.00	59 : 69
Line C[w]	L	192	241	222	165	205	35	77	0.00	49 : 66
Bengal	M	161	194	214	194	191	39	81	1.00	62 : 70
Cocodrie	L	182	240	174	177	193	37	78	0.00	55 : 69

[z] AR= Rice Research and Extension Center, Stuttgart, Arkansas; LA= Rice Research Station, Crowley, Louisiana; MS= Delta Research and Extension Center, Stoneville, Mississippi; and TX= Texas Agricultural Research Station, Beaumont, Texas.

[y] Means for height, days to 50% heading, % lodging, and milling data are over all locations.

[x] Lines A and B are from the cross Brazos/Tebonnet/3/164986-4/NV66//Nortai/4/Bengal.

[w] Line C is from the cross Adair/Jodon.

BREEDING AND EVALUATION FOR IMPROVED RICE CULTIVARS—THE ARKANSAS RICE-BREEDING AND DEVELOPMENT PROGRAM

K.A.K. Moldenhauer, J.W. Gibbons, F.N. Lee, R.J. Norman, J.L. Bernhardt, M.A. Anders, R.H. Dilday, J.N. Rutger, M.M. Blocker, and A.C. Tolbert

ABSTRACT

The Arkansas rice-breeding program is an ongoing effort to develop new varieties, test these varieties, and identify important characteristics for further improvement of these varieties. Pest resistance as well as high-yield potential, excellent milling yields, improved plant type (e.g., short stature, semi-dwarf, earliness, erect leaves), and superior quality (e.g., cooking, processing, and eating are all important components in this program. Currently, there are several promising lines with improved plant type, high grain and milling yields, disease resistance, and acceptable cooking quality. New varieties will be released to rice producers in the future for the traditional Southern U.S. long- and medium-grain markets as well as for the emerging specialty markets.

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 the clientele in Arkansas and the Southern United States rice-growing region. Releasing cultivars with standard cooking quality, excellent milling and grain yields, and improved plant type and disease resistance has been and still is the objective of this program. Through the years, improving disease resistance and/or tolerance has been a major goal. Blast resistance has been addressed through research by visiting scholars and graduate students and by the release of 'Katy', 'Kaybonnet', and 'Drew'. Sheath blight tolerance has been an ongoing concern, and the cultivars produced by this program have had the best sheath blight tolerance of any in the United States. A recurrent selection program for increased sheath blight tolerance, which is a long-term approach to increasing resistance, was implemented in 1983. Information on the recurrent selection program was presented at the First Temperate Rice Conference in Australia (Moldenhauer *et al.*, 1994). As interest in specialty rice has increased, the program has taken on the added task of developing agronomically acceptable cultivars that are aromatic or have Japanese quality. Significant yield increases have been realized with the release of the last four long-grain cultivars—'LaGrue', Kaybonnet, Drew, and 'Wells'. Other lines currently in the program have the potential to further increase grain yields, milling quality, and disease resistance.

PROCEDURES

The rice-breeding program continues to utilize the best available parental material from all sources, including other breeding programs in the United States, the USDA World Collection, and international programs such as Centro Internacional deAgricultura Tropical, the International Rice Research Institute, and the West Africa Rice Development Association. Crosses are made each year to incorporate genes for broad-based disease resistance, improved plant type (e.g., short-stature and semidwarf, earliness, erect leaves), superior quality (e.g., cooking, processing, and eating), and efficiency of nitrogen (N)-fertilizer, into highly productive, well-adapted lines. Early-generation selections are chosen from various crosses each year and advanced one generation at the winter nursery in Puerto Rico. As outstanding lines are selected and advanced, they are evaluated extensively for grain yield, milling and cooking characteristics, insect tolerance by the entomologist, and disease resistance by the pathology group. Advanced lines are extensively evaluated for proper timing and rate on N-fertilization practices by the soil fertility group, and for response to recommended weed control practices. The rice-breeding program utilizes all feasible 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, and disease and insect resistance. The winter nursery in Puerto Rico is used to accelerate generation advancement and breeders' seed increases of potential varieties. The statewide rice performance testing program, which includes rice varieties and promising new lines developed in the Arkansas program and from cooperating programs in the other rice-producing states, is carried out each year to select the best materials for future release and to provide producers with current information on rice variety performance. Disease data are collected from ongoing disease-orientated inoculate tests, including inoculated sheath blight; blast, stem rot, and black sheath rot nurseries; general observation tests seeded in problem disease fields; and general observations made during the agronomic testing of entries.

RESULTS AND DISCUSSION

The new variety Wells was released in 1999 and was grown by qualified seed growers for the first time this season. Its experimental designation was RU9601053. Wells performed admirably in the Arkansas Rice Performance Trials (ARPT) and the Uniform Regional Rice Nursery (URRN) in 1998 and 1999. Mean yields across locations in the ARPT for 1998 and 1999 were 150 and 170 bu/acre, respectively (Table 1.). Plant height of Wells averages approximately 3 in. shorter than LaGrue. Milling yields of Wells have tended to be more stable than those of LaGrue. Like LaGrue, Wells is susceptible to the common blast races, but it has significant “field” resistance when good management practices, especially irrigation and fertility, are followed. Blast has not been a problem for this line in the field test plots for the last 2 years across the Southern growing region. Wells originated from the cross ‘Newbonnet’/3/‘Lebonnet’/CI9902//‘Labelle’ (cross no.890481) made in 1989 and was selected from the panicle row STG93L08-93. The documentation has been completed and applications submitted for Plant Variety Protection and a plant utility patent.

Currently, one high-yielding long-grain, line RU9901030 (experimental line—seed not for sale), in the very-short-season ARPT (Table 1) is being considered for foundation seed production and release in 2000. This line had very stable yields across locations, averaging 175 bu/acre at the RREC, 162 bu/acre at the Southeast Branch Experiment Station (SEBES), 173 bu/acre at the Pine Tree Branch Experiment Station (PTBES), and 177 bu/acre at the Northeast Research and Extension Center (NEREC), which compares favorably with ‘Cocodrie’ in the same group. This line has blast resistance and some sheath blight tolerance.

Two short-grain lines [RU9601096 and RU9601099 (experimental lines—seed not for sale)] from the cross ‘Koshihikari’/‘Mars’, which performed well from 1996 to 1998, were also in the ARPT (Table 2) and URRN in 1999. Again, these were high-yielding, excellent milling lines with improved texture and taste for the Oriental market compared to typical southern U.S. medium-grain varieties. Initial sensory evaluation suggests that these lines are closer to the Japanese type of rice than are Mars and ‘Bengal’. In an independent test in Japan, RU9601096 rated 73 and RU9601099 rated 76 on a Japanese taste-testing machine compared to ‘Atitakomachi’ in the same test, which rated 74; Koshihikari was not included in their test. The higher the number on this machine, the better the taste. The Japanese rated the samples lower for other characteristics and were surprised by their good ratings on the taste-testing machine. These lines will again be compared in both sensory and chemical tests to the Japanese cultivars Koshihikari and Akitakomachi. For the past 3 years, backcrosses to Koshihikari have also been made with other selected lines from the program in an attempt to capture the elusive Koshihikari quality. Currently, these lines are being rescreened for quality characteristics. A possible seed increase of RU9601096 or RU9601099 will be grown in 2000. Through this program we hope to develop a high-yielding, agronomically adapted short-grain rice that will be acceptable to the Japanese market.

There were several extremely high yielding lines in the ARPT in 1999 (Table 3). Many were in the very-short-season maturity group. Two of these sister lines from the cross Lebonnet/9902/3/ 'Dawn'/9695//'Starbonnet'/4/LaGrue will be grown in head rows in 2000. These lines have extremely high yield potential. In 1998, the plots approached 200 bu/acre in the Stuttgart Initial Test and again in 1999 in the ARPT (Table 3), and URRN (Table 4) shows both of these lines to be long-grain, short-statured, and early maturing with good yield and milling. Line RU9901081 (experimental line—seed not for sale) yielded 203, 221,154, and 142 bu/acre, at the RREC, Stuttgart; SEBES, Rohwer; PTBES, Colt; and NEREC, Keiser, respectively. Line STG96L-05-078 (experimental line—seed not for sale) had yields of 202, 217,143, and 151 bu/acre at the RREC, SEBES, PTBES, and NEREC, respectively, compared to Cocodrie, a high-yielding variety in the same group, which had yields of 176, 185, 175, 110, bu/acre at the RREC, SEBES, PTBES, and NEREC, respectively.

Lines have also been selected that are extremely early. One of the later-maturing lines in this group, RU9901096 (experimental line—seed not for sale), will also be grown in head rows in 2000. This line did very well at the SEBES (Table 3) and in the URRN in Louisiana, Texas, and Mississippi (Table 4). Other extremely early lines that mature earlier than 'Jefferson' will be evaluated by the University of Arkansas systems agronomist, Dr. Merle Anders, located at the RREC. These lines have maturities of about 100 to 110 days, as well as blast resistance.

Rice blast (*Pyricularia grisea*) can be a devastating disease in Arkansas. Races IB-49 and IC-17 are currently the major races in Arkansas. A program is under way to incorporate the genes for blast resistance from Raminad Strain #3, an international rice blast differential that has resistance to all of the Southern U.S. races, and to utilize adapted material with blast resistance in a backcrossing program with LaGrue. The resistant lines from these backcrossing programs will be utilized as parental material, and all desirable phenotypes will be included in the breeding program and evaluated for cooking quality and agronomic characteristics. Nine lines from the cross LaGrue//'Lemont'/RA73/3/LaGrue/4/LaGrue in the preliminary test at the RREC showed resistance to the major blast races in Arkansas in preliminary field blast testing in 1999. These will be tested in the Stuttgart Initial Test in 2000.

Shown in Table 5 is the number of lines that were in the various phases of this breeding project for the 1999 growing season. There were 133 new cross combinations made in 1999. The 6120 panicles selected from the 53,800 space plants grown in the field in 1999 were seeded in Puerto Rico for generation advance. Panicles selected from these rows will be grown in Puerto Rico as panicle rows in 2000.

SIGNIFICANCE OF FINDINGS

The goal of the rice-breeding program is to develop maximum grain-yielding cultivars with good levels of disease resistance for release to Arkansas rice producers.

The release of Wells to qualified seed growers for the 1999 growing season, the existence of even higher-yielding lines in the program, and the potential releases of new long-grain and Japanese-quality lines are examples of the continued improvement being realized through this program. Improved lines will continue to be released in the future. They will have improved disease resistance, plant type, and grain and milling yields. 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.

LITERATURE CITED

Moldenhauer, K.A.K., and F.N. Lee. 1994. Recurrent selection for sheath blight tolerance in rice. *In:* E. Humphreys, I.S. Murray, W.S. Clampett, and L.G. Lewin (eds.). Temperate Rice—Achievements and Potential. Conference Organizing Committee, C\-NSW Agriculture, Griffith NSW. pp 25-33.

Table 1. Data from the 1997 to 1999 Arkansas Rice Performance Trials for Wells, experimental lines, and check cultivars.

Cultivar	Grain Type[z]	Yield 1997	Yield 1998	Yield 1999	Yield mean[y]	Height	50% Heading	Kernel Weight	Milling
		(bu/acre)				(inches)	(days)	(mg)	(HR:TOT)[x]
Wells	L	171	151	169	164	41	86	18.60	60 : 74
RU9901030[w]	L	--	165	172	168	41	81	16.30	62 : 70
Cocodrie	L	159	146	161	156	38	82	17.50	66 : 73
LaGrue	L	167	158	180	168	44	86	18.00	63 : 72
Kaybonnet	L	146	138	157	147	43	84	15.00	62 : 72

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

[y] 1997 consisted of five locations, Rice Research and Extension Center (RREC), Stuttgart, Arkansas; Pine Tree Branch Experiment Station (PTBES), Colt, Arkansas; Northeast Research and Extension Center (NEREC), Keiser, Arkansas; Southeast Branch Experiment Station (SEBES), Rowher, Arkansas; and Jackson Co. Farmer Field, Tupelo, Arkansas; 1998 and 1999 consisted of RREC, PTBES, NEREC, and SEBES. Lines A and B data from 1998 only.

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

[w] RU9901030 (experimental line - seed not for sale) is from the recurrent selection program for sheath blight tolerance.

Table 2. Data from the 1996 to 1999 Arkansas Rice Performance Trials comparing two experimental lines from Koshihikari crosses with the medium-grain check cultivar M-202.

Cultivar	Grain Type[z]	Yield 1996	1997	1998	1999	mean[y]	Height	50% Heading	Kernel Weight	Milling
		(bu/acre)					(inches)	(days)	(mg)	(HR:TOT)[x]
M202	M	151	135	135	161	146	39	76	20.70	61 : 72
RU9601099[w]	S	173	160	133	151	154	39	78	18.00	62 : 73
RU9601096[w]	S	169	161	138	148	154	36	77	18.50	55 : 71
Koshihikari	S	---	---	115	136	126	42	81	18.30	60 : 71

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

[y] 1996 consisted of six locations: Rice Research and Extension Center (RREC), Stuttgart, Arkansas; Pine Tree Branch Experiment Station (PTBES), Colt, Arkansas; Northeast Research and Extension Center (NEREC), Keiser, Arkansas; Southeast Branch Experiment Station (SEBES), Rowher, Arkansas; Jackson Co. Farmer Field, Tupelo, Arkansas; and Campbell, Missouri. 1997 consisted of the five locations in Arkansas. 1998 and 1999 consisted of RREC, PTBES, NEREC, and SEBES.

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

[w] Experimental lines - seed not for sale.

Table 3. Data from the 1998 Stuttgart initial test (SIT) and the 1999 Arkansas Rice Performance Trials (ARPT) for three experimental lines and three check cultivars.

Cultivar	Grain Type[z]	Yield 1998 SIT[y]	Yield 1999 ARPT[x]	Yield mean[w]	Height	50% Heading	Kernel Weight	Milling
		(bu/acre)	(bu/acre)	(bu/acre)	(inches)	(days)	(mg)	(HR:TOT)[v]
RU9901081[u]	L	182	180	181	39	82	16.05	65 : 72
STG96l-05-078[u]	L	186	179	181	37	82	17.27	62 : 73
RU9901096[t]	L	173	159	163	40	79	18.35	59 : 74
Cocodrie	L	174	161	165	38	81	16.84	65 : 74
Jefferson	L	167	146	151	36	78	18.71	52 : 71
Maybelle	L	121	146	139	40	74	15.26	39 : 71

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

[y] 1998 SIT consisted of two replications at two locations: Rice Research and Extension Center (RREC), Stuttgart, Arkansas; and the Southeast Branch Experiment Station (SEBES), Rohwer, Arkansas.

[x] The 1999 ARPT consisted of three replications at four locations: RREC, Stuttgart, Arkansas; Pine Tree Branch Experiment Station (PTBES) Colt, Arkansas; Northeast Research and Extension Center (NEREC), Keiser, Arkansas; and SEBES, Rohwer, Arkansas.

[w] Means for yield, height, maturity, kernel weight, and milling data are averaged over locations and years from SIT and ARPT.

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

[u] RU9901081 and STG96L-05-078 (experimental lines - seed not for sale) are from the cross 'Lebonnet'/9902/3/'Dawn'/9695//'Starbonnet'/4/LaGrue.

[t] RU9901096 (experimental line - seed not for sale) is from the cross LaGrue//Katy/Starbonnet.

Table 4. Data from the 1999 Uniform Regional Rice Nursery for two experimental lines and three check cultivars.

Cultivar	Grain Type[z]	Yield[Y] AR	LA	MS	TX	mean	Height	50% Heading	Kernel Weight	Milling
		---------- (bu/acre)				----------	(inches)	(days)	(mg)	(HR:TOT)[x]
RU9901081[w]	L	211	236	243	199	223	39	78	17.90	54 : 68
RU9901096[v]	L	185	246	239	231	225	41	77	20.90	51 : 69
Cocodrie	L	182	240	174	177	193	37	78	17.93	55 : 69
Jefferson	L	153	200	141	173	167	36	76	19.20	54 : 69
Maybelle	L	141	207	—[u]	169	172	40	71	16.00	51 : 69

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

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

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

[w] RU9901081 (experimental line - seed not for sale) is from the cross 'Lebonnet'/9902/3/'Dawn'/9695//'Starbonnet'/4/ LaGrue.

[v] RU9901096 (experimental line - seed not for sale) is from the cross LaGrue//Katy/Starbonnet.

[u] Extensive bird damage decreased the yield of Maybelle in Mississippi.

Table 5. Number of lines in each phase for project ARK01387 in 1999.

Evaluation Phase	Number of Lines
Crosses	133
F_2 Space Plants	53,800
F_3 Panicle Rows Puerto Rico	6120
F_4 P Panicle Rows	4554
L & M Panicle Rows	6340
Preliminary Trials	544
Stuttgart Initial Test & Quality Test	204
Uniform Regional Nursery	200
Arkansas Rice Performance Trials	104
Preliminary Seed Increases	11
Breeder Head Rows	8

PRODUCTION OF TRANSGENIC RICE PLANTS USING AGROBACTERIUM-MEDIATED TRANSFORMATION

Y. Yang and M. Qi

ABSTRACT

Fertile and morphologically normal transgenic rice plants were successfully produced using a simplified *Agrobacterium*-mediated transformation. The transformation of bacterial *GUS* (encoding ß-glucuronidase, a molecular marker) and *NahG* (encoding salicylate hydroxylase, a salicylic acid-degrading enzyme) genes into rice plants was confirmed by polymerase chain reaction, and southern and/or northern analysis. Histochemical stains of leaf segments also detected the expression of ß-glucuronidase in *GUS* transgenic plants. In contrast, the expression of salicylate hydroxylase in *NahG* transgenic plants resulted in degradation of salicylic acid. Since salicylic acid is known to play a key role in signaling host defense responses in dicots, salicylic acid-deficient transgenic rice will be an excellent tool for studying the potential role of salicylic acid in monocot disease resistance.

INTRODUCTION

Development of efficient transformation methods is a prerequisite for the production of transgenic rice and *in vivo* functional analysis of rice genes. The *Agrobacterium tumefaciens*-mediated transformation has been used extensively for gene transfer in various dicotyledonous plants. Recently, the method has been improved for transformation of rice and other monocotyledonous plants (Hiei *et al.*, 1997). In comparison with direct DNA transfer techniques such as bio-ballistic bombardments and electroporation, *Agrobacterium*-mediated rice transformation has several obvious advantages, including the transfer of relatively large segments of DNA with minimal rearrangements, the integration of small numbers of gene copies, and high fertility of transgenic plants. To develop rice transformation capability and facilitate production of transgenic rice in Arkansas, we have conducted the *Agrobacterium*-mediated rice transformation and successfully introduced bacterial ß-glucuronidase and salicylate hydroxylase genes into rice plants, respectively.

PROCEDURES

Gene Constructs and Bacterial Strain

Binary vector pCAMBIA1291Z was used in this study for the gene construct. This vector carries a hygromycin resistance gene and a bacterial ß-glucuronidase gene (*GUS*), a frequently used molecular marker for plant transformation. In addition, the *NahG* gene of *Pseudomonas putina*, which encodes the salicylate hydroxylase for degrading salicylic acid, was placed under the control of 35S promoter and cloned into pCAMBIA1291Z. Gene constructs were then introduced into *Agrobacterium tumefaciens* strain EHA105 by triparental mating (Fig. 1A).

Plant Material and Culture Media

Nipponbare, a japonic rice (*Oryza sativa*) cultivar selected for international rice genome sequencing, was used in this study. Culture media used in rice transformation and plant regeneration were listed in Table 1.

Callus Induction

To initiate callus for transformation, mature seeds were manually dehusked and sterilized with 70% ethanol (1 min) and 50% Clorox (2.6% sodium hypochlorite, 30 min). After rinsing in sterile distilled water three times, seeds were placed on callus induction medium and cultured under continuous light at 30°C in a tissue culture room.

Transformation

The *Agrobacterium* strains carrying gene constructs were streaked on AB medium (Chilton *et al.*, 1974) with appropriate antibiotics and incubated at 28°C for two days. The bacterial cells were collected from plates and resuspended in 30 ml suspension medium to a density of about 3 to 5 x 109 cells/ml. Rice calli (1 to 5 mm in diameter) were soaked in the bacterial suspension for 20 min and blotted on sterilized filter paper to remove excess bacteria. The inoculated calli were then transferred onto cocultivation medium and maintained at 25°C in darkness for two days. After cocultivation and washing, rice calli were transferred onto the selection medium and cultured under continuous light at 30°C for at least 2 wk.

Regeneration of Transgenic Plants

Hygromycin-resistant transgenic calli proliferated on the selection medium were excised and cultured on the regeneration medium in Petri dishes (preferably 10 x 2 cm size) for 2 wk under continuous light at 30°C. Regenerated shoots were then transferred onto the root induction medium for the production of intact transgenic plantlets.

Molecular and Biochemical Analyses

Standard protocols for polymerase chain reaction (PCR) and southern and northern analyses were used to confirm the insertion and expression of bacterial genes in transgenic rice (Sambrook *et al.*, 1989). Histochemical stains of *GUS* activity in transgenic calli and plants were performed using 5-bromo-4-chloro-3-indolylglucuronide (X-Glu) as substrate (Rueb and Hensgens, 1989). Levels of salicylic acid in rice plants were determined by high performance liquid chromatography (HPLC) according to the previously reported methods (Bi *et al.*, 1997; Chen *et al.*, 1997).

RESULTS AND DISCUSSION

Our transformation protocol was similar to the published procedure of *Agrobacterium*-mediated transformation (Hiei *et al.*, 1997). However, we have simplified the tissue culture process by using commercially available, inexpensive media (N6 and MS medium from Sigma Chemical, Milwaukee, Wisconsin. As a result, it greatly reduced the time and labor cost for making stock solutions and tissue culture media. Using this simplified protocol, transgenic rice plants were successfully produced as described below.

One week after culture on callus initiation medium, more than 95% of rice seeds produced calli from the scutellum of embryos. Two to three weeks later, bright yellowish, vigorously growing calli were selected for transformation (Fig. 1B). Alternatively, rice calli may be subcultured in liquid or solid medium for future transformation experiments. By cocultivation with agrobacterial cells carrying gene constructs and subsequent culture on the selection medium for 3 to 4 wk, two dozen hygromycin-resistant calli were obtained. To determine if these calli contained the *GUS* reporter gene, histochemical stains of *GUS* activity were conducted. All of the tested calli were *GUS*-positive (Fig. 1C), suggesting that they were transgenic calli. The hygromycin-resistant calli were then cultured on regeneration medium for shoot production. By transferring shoots onto the root medium, intact rice plantlets were eventually produced (Fig. 1D). A total of 51 regenerated plantlets, including 38 *GUS* transgenic plants and 13 *NahG* transgenic plants, were transplanted into soil and maintained in the greenhouse.

Molecular and biochemical analyses have been carried out to characterize these transgenic plants. The authenticity of all *GUS* transgenic plants was confirmed by PCR analysis as well as histochemical stains of leaves for *GUS* activity (Fig. 2A). Polymerase chain reaction and southern analyses also indicated the presence of the bacterial salicylate hydroxylase gene in *NahG* transgenic plants (data not shown). Furthermore, the expression of *NahG* in transgenic plants was demonstrated by northern analysis (Fig. 3). To determine whether salicylic acid in transgenic rice was degraded by the introduced salicylate hydroxylase, the levels of salicylic acid in rice leaves were measured by HPLC. In contrast to untransformed or *GUS*-transformed rice plants whose levels of salicylic acid ranges from 5 to 10 mg/g fresh weight, the transgenic *NahG* plants contained less than 0.05 mg/g fresh weight of salicylic acid. As a result, salicylic acid-deficient transgenic rice was produced by overexpression of a bacterial salicylate hydroxylase. Currently, rice seeds from both primary and secondary transgenic plants have been harvested. Most of the transgenic plants were fertile and set seeds normally (Fig. 2B).

SIGNIFICANCE OF FINDINGS

Although *Agrobacterium*-mediated rice transformation has been conducted in many labs around the world, this is the first time that transgenic rice plants were successfully produced in Arkansas. The establishment of rice transformation capability using this simplified protocol should greatly facilitate future research on rice functional genomics and biotechnology. To our knowledge, this is also the first report in the world of producing salicylic acid-deficient transgenic rice. Because salicylic acid is known to act as an important endogenous signal in mediating host defense responses in dicots, the salicylic acid-deficient transgenic rice will be an excellent material for studying the potential role of salicylic acid in monocot disease resistance.

ACKNOWLEDGMENTS

We would like to thank Drs. Mark Schell (University of Georgia) and Fleet Lee for providing the *NahG* gene and Nipponbare seeds, respectively. This research was kindly supported by Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Bi, J.L., J.B. Murphy, and G.W. Felton. 1997. Does salicylic acid act as a signal in cotton for induced resistance to *Helicoverpa zea?* J. Chem. Ecol. 23:1805-1818.

Chen, Z., S. Iyer, A. Caplan, D.F. Klessig, and B. Fan. 1997. Differential accumulation of salicylic acid and salicylic acid-insensitive catalase in different rice tissues. Plant Physiol. 114:193-201.

Chilton, M.D., T.C. Currier, S.K. Farrand, A.J. Bendich, M.P. Gordon, and E.W. Nester. 1974. *Agrobacterium tumefaciens* DNA and PS8 bacteriophage DNA not detected in crown gall tumors. Proc. Natl. Acad. Sci. USA 71:3672-3676.

Hiei, Y., T. Komari, and T. Kubo. 1997. Transformation of rice mediated by *Agrobacterium tumefaciens*. Plant Mol. Biol. 35:205-218.

Rueb, S. and L.A.M. Hensgens. 1989. Improved histochemical staining for ß-D-glucuronidase activity in monocotyledonous plants. Rice Genet. Newsl. 6:168-169.

Sambrook, J., E.F. Fritsch, and T. Maniatis. 1989. Molecular Cloning: A Laboratory Manual, 2nd Ed. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY.

Table 1. Media for culture of rice tissue.

Medium	Composition
Suspension medium	Chu (N6) basal salt (C1416, Sigma), Murashige and Skoog (MS) modified vitamin powder (M6896, Sigma), 0.5 g/L casamino acids, 30 g/L sucrose, 10 g/L glucose, 100 mM acetosyringone (added after autoclave), pH 5.2
Cocultivation medium	Chu (N6) basal salt, MS modified vitamin powder, 1 g/L casamino acids, 2 mg/L 2,4-D, 30 g/L sucrose, 10 g/L glucose, 100 mM acetosyringone (added after autoclave), 2 g/L Gelrite, pH 5.2
Selection medium	Chu (N6) basal salt, MS modified vitamin powder, 2 mg/L 2,4-D, 0.5 g/L casamino acids, 2.5 g/L proline, 30 g/L sucrose, 250 mg/L cefotaxime (added after autoclave), 50 mg/L hygromycin (added after autoclave), 2 g/L Gelrite, pH 5.7
Regeneration medium	MS basal salt (M5524, Sigma), MS modified vitamin (M6896, Sigma), 1 g/L casamino acids, 2 mg/L kinetin (or 2 mg/L benzyladenine), 0.1 mg/L NAA, 30 g/L sucrose, 30 g/L sorbitol, 250 mg/L cefotaxime (optional, added after autoclave), 50 mg/L hygromycin (added after autoclave), 3 g/L Gelrite, pH 5.7
Root induction medium	MS basal salt, MS modified vitamin, 30 g/L sucrose, 50 mg/L hygromycin (added after autoclave), 2 g/L Gelrite, pH 5.7

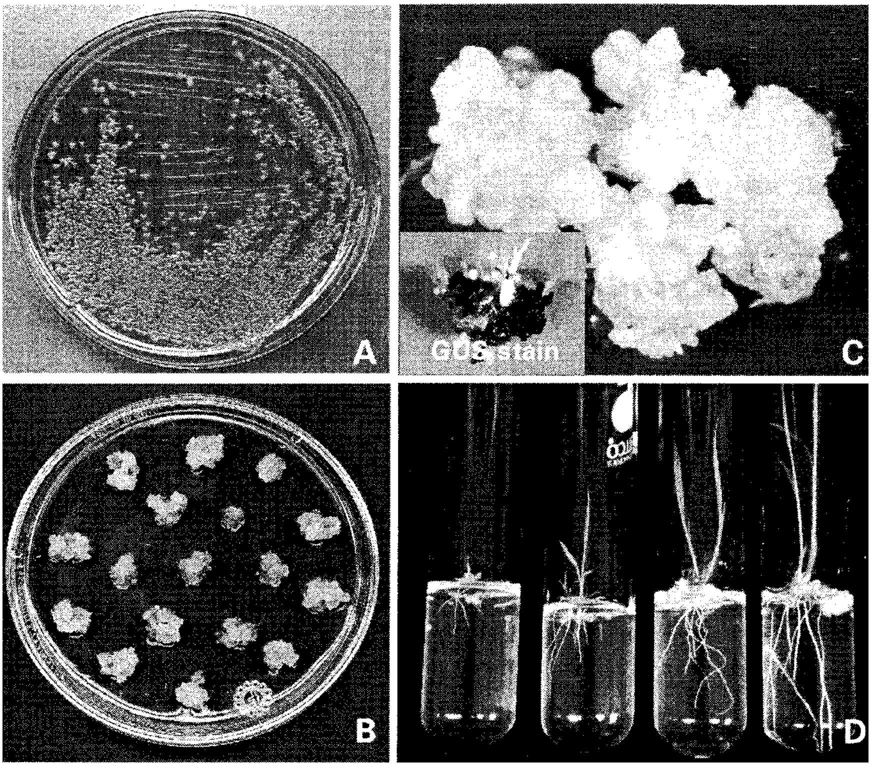


Fig. 1. ***Agrobacterium*-mediated rice transformation. A: *Agrobacterium tumefaciens* carrying gene contruct; B: rice calli used for transformation; C: transgenic calli and histochemical stain of GUS activity; D: regeneration of intact transgenic plantlets.**

Fig. 2. Production of transgenic rice. A: transgenic plants transplanted in soil and histochemical GUS stains of leaf segments; B: morphologically normal transgenic plants setting seeds.

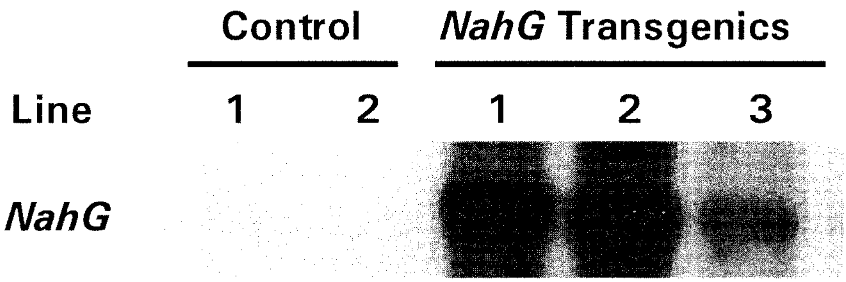


Fig. 3. Expression of bacterial salicylate hydroxylase gene in transgenic rice as demonstrated by northern blot analysis.

A COMPARISON OF NEW GRAMINICIDES IN RICE

N.W. Buehring, F.L. Baldwin, and R.E. Talbert

ABSTRACT

Two studies were conducted in 1999 to compare crop injury and grass control with three new graminicides (clefoxydim, cyhalofop-butyl,and fenoxaprop + safener). Lefoxydim at 0.089 lb ai/acre had the highest injury rating at 31% injury. Fenoxaprop + safener at 0.08 lb ai/acre resulted in 17% injury and cyhalofop-butyl at 0.25 lb ai/acre resulted in 5% injury. Cyhalofop-butyl at 0.125 lb/acre, clefoxydim at 0.067 lb/acre, and fenoxaprop+safener at 0.04 lb/acre provided 98% control of broadleaf signalgrass when applied at two- to three-leaf timing. Cyhalofop-butyl at 0.25 lb/acre and fenoxaprop + safener at 0.08 lb/acre provided 98% control of broadleaf signalgrass when applied preflood. However, clefoxydim at 0.089 lb ai/acre provided only 75% control of broadleaf signalgrass at preflood. None of the compounds showed significant differences in control between propanil-resistant and -susceptible barnyardgrass. Cyhalofop-butyl at 0.25 lb/acre provided 97% control of barnyardgrass, clefoxydim at 0.089 lb/acre provided 90% control of barnyardgrass, and fenoxaprop + safener at 0.06 lb/acre provided 93% control of barnyardgrass when they were applied at two- to three-leaf timing. However, the results were quite different when they were applied preflood. Cyhalofop-butyl at 0.25 lb/acre, clefoxydim at 0.089 lb/acre, and fenoxaprop + safener at 0.08 lb/acre provided only 53 to 59% control when they were applied preflood. Amazon sprangletop control was 98% with cyhalofop-butyl at 0.188 lb/acre, clefoxydim at 0.089 lb/acre, and fenoxaprop + safener at 0.04 lb/acre when they were applied at two- to three-leaf timing. At preflood, cyhalofop-butyl at 0.25 lb/acre provided 70% control, clefoxydim at 0.089 lb/acre provided 91% control, and fenoxaprop + safener at 0.04 lb/acre provided 98% control. A separate trial was established in Lonoke to evaluate these compounds in post-flood conditions. Cyhalofop-butyl at 0.25 lb/acre provided excel-

lent control of broadleaf signalgrass and barnyardgrass (98 and 96%). Fenoxaprop + safener at 0.08 lb/acre provided only 80% control of broadleaf signalgrass and 38% control of barnyardgrass. Clefoxydim at 0.089 lb/acre provided poor control of broadleaf signalgrass and barnyardgrass when applied post-flood (23 and 28%, respectively).

INTRODUCTION

Grasses continue to be serious weeds in rice production. Barnyardgrass (*Echinochloa crus-galli*), broadleaf signalgrass (*Bracharia platypylla*), and Amazon sprangletop (*Leptochloa panicoides*) are the most prominent grasses in rice production in Arkansas. In the past few years, there have been increasing problems because barnyardgrass has become resistant to propanil and quiniclorac, and new control alternatives are needed. Also, there have been problems with herbicide drift damaging adjacent crops. The graminicides—clefoxydim, cyhalofop-butyl, and fenoxaprop + safener—are less hazardous from a drift standpoint.

PROCEDURES

The experiments were located at the University of Arkansas at Pine Bluff (UAPB) farm in Lonoke and the Rice Research and Extension Center (RREC) in Stuttgart. Each experiment was arranged in a randomized complete block with a factorial arrangement (3 graminicides, 3 rates, and 3 timings). Clefoxydim at 0.045, 0.067, and 0.089 lb/acre, cyhalofop-butyl at 0.125, 0.188, and 0.25 lb ai/acre, and fenoxaprop + safener 0.04, 0.06, and 0.08 lb/acre were applied at the two- to three-leaf stage, preflood, and the two- to three-leaf stage followed by a preflood. Standard drill-seeded rice production practices were used, and all treatments were applied with a backpack sprayer at 10 GPA. Also in a separate experiment at the UAPB site, these graminicides were applied post-flood: clefoxydim at 0.89 lb/acre, cyhalofop-butyl at 0.25 lb/acre, and fenoxaprop + safener at 0.08 lb/acre.

RESULTS AND DISCUSSION

Rice injury was rated nine days after application on the two- to three-leaf application timing. Clefoxydim at 0.067 and 0.089 lb/acre had 23 and 31% injury, respectively (Table 1). Cyhalofop-butyl had very minimal injury of 5% at all rates. Fenoxaprop + safener at 0.08 lb/acre had 16% injury.

Clefoxydim at 0.067 lb/acre, cyhalofop-butyl at 0.125 lb/acre, and fenoxaprop + safener at 0.04 lb/acre provided excellent control of broadleaf signalgrass (98%) when applied at the two- to three-leaf timing. At a preflood timing, cyhalofop-butyl at 0.188 lb/acre and fenoxaprop + safener at 0.04 lb/acre provided excellent control of broadleaf signalgrass (93 and 94%, respectively). Clefoxydim at 0.089 lb/acre provided poor control of broadleaf signalgrass (75%). All of the sequential applications provided excellent control of broadleaf signalgrass.

Clefoxydim at 0.089 lb/acre, cyhalofop-butyl at 0.188 lb/acre, and fenoxaprop + safener at 0.04 lb/acre provided excellent control of Amazon sprangletop (98%) when applied at a two- to three-leaf timing. When applied preflood, clefoxydim at 0.089 lb/acre and fenoxaprop + safener at 0.04 lb/acre provided excellent control (91 and 98%, respectively). When cyhalofop-butyl at 0.25 lb/acre was applied at a preflood timing, it provided poor control of Amazon sprangletop (70%). Sequential applications, even at the lowest rate of each graminicide, provided excellent control of Amazon sprangletop.

None of the compounds differed in the control of propanil-resistant and -susceptible barnyardgrass. Clefoxydim at 0.089 lb/acre, cyhalofop-butyl at 0.188 lb/acre, and fenoxaprop + safener at 0.06 lb/acre provided excellent control (90 to 93%) when applied at the two- to three-leaf timing. However, the efficacy of these gramincides was seriously reduced when applied preflood (52 to 60%) with the highest rates. Clefoxydim at 0.067 lb/acre, cyhalofop-butyl at 0.125 lb/acre, and fenoxaprop + safener at 0.06 lb/acre provided excellent control (90 to 98%) when applied sequentially for barnyardgrass control.

In the post-flood trial cyhalofop-butyl at 0.25 lb/acre provided excellent control of broadleaf signalgrass and barnyardgrass (98 and 96%, respectively) (Table 2). Fenoxaprop + safener at 0.08 lb/acre gave only 80% control of broadleaf signalgrass and 38% control of barnyardgrass. Clefoxydim at 0.089 lb/acre provided poor control of both broadleaf signalgrass (23%) and barnyardgrass (28%).

SIGNIFICANCE OF FINDINGS

These graminicides have an excellent potential to be used in rice production, especially around susceptible crops such as cotton, soybeans, and tomatoes. They will have to be used in herbicide programs to control broadleaf weed and sedge control.

ACKNOWLEDGMENTS

This research was funded primarily by the Rice Promotion Board. AgrEvo, BASF, and Dow Agrosciences also supported the project; however, it is the Arkansas Rice Research and Promotion Board that makes the overall program a success.

Table 1. Rice injury, broadleaf signalgrass, Amazon sprangletop, and barnyardgrass control.

Graminicide	Rate	Application timing	Rice injury[z]	Broadleaf signalgrass control[y]	Amazon sprangletop control[y]	Barnyardgras control[y]
	(lb/acre)		(%)			
Clefoxydim	0.045	2-3 lf	5	74	62	69
Clefoxydim	0.045	PF	-	61	74	48
Clefoxydim	0.045	2-3 lf *fb* PF	-	93	98	81
Clefoxydim	0.067	2-3 lf	23	87	70	80
Clefoxydim	0.067	PF	-	71	82	55
Clefoxydim	0.067	2-3 lf *fb* PF	-	98	98	97
Clefoxydim	0.089	2-3 lf	31	98	98	90
Clefoxydim	0.089	PF	-	75	91	59
Clefoxydim	0.089	2-3 lf *fb* PF	-	98	98	98
Cyhalofop-butyl	0.125	2-3 lf	5	98	92	84
Cyhalofop-butyl	0.125	PF	-	76	45	36
Cyhalofop-butyl	0.125	2-3 lf *fb* PF	-	98	91	98
Cyhalofop-butyl	0.188	2-3 lf	5	98	98	91
Cyhalofop-butyl	0.188	PF	-	93	50	48
Cyhalofop-butyl	0.188	2-3 lf *fb* PF	-	98	98	98
Cyhalofop-butyl	0.250	2-3 lf	5	98	98	97
Cyhalofop-butyl	0.250	PF	-	97	70	60
Cyhalofop-butyl	0.250	2-3 lf *fb* PF	-	98	98	98
Fenoxaprop + safener	0.04	2-3 lf	14	98	98	83
Fenoxaprop + safener	0.04	PF	-	94	98	41
Fenoxaprop + safener	0.04	2-3 lf *fb* PF	-	98	98	80
Fenoxaprop + safener	0.06	2-3 lf	16	98	98	93
Fenoxaprop + safener	0.06	PF	-	95	98	51

contir

Table 1. Continued.

Graminicide	Rate	Application timing	Rice injury[z]	Broadleaf signalgrass control[y]	Amazon sprangletop control[y]	Barnyardgrass control[y]
	(lb/acre)		----------	---------- (%)	----------	----------
Fenoxaprop + safener	0.06	2-3 lf *fb* PF	-	98	98	90
Fenoxaprop + safener	0.08	2-3 lf	16	98	98	95
Fenoxaprop + safener	0.08	PF	-	97	98	52
Fenoxaprop + safener	0.08	2-3 lf *fb* PF	-	98	98	95
$LSD_{(.05)}$			15	9	15	8

[z] Rated 9 days from the 2- to 3-leaf application only.
[y] Rated 54 days after preflood application.

Table 2. Rice grain yield and weed control following post-flood application of graminicides.

Graminicides	Rate	Broadleaf signalgrass control[z]	Barnyardgrass control[z]	Yield
	(lb/acre)	---------- (%)	----------	(bu/acre)
clefoxydim	0.089	23	28	85
cyhalofop-butyl	0.250	98	96	142
fenoxaprop+ safener	0.08	80	38	107
bispyibac-sodium	0.02	0	96	54
$LSD_{(0.05)}$		14	17	14

[z] Rated 42 days after post-flood application.

WEED SHIFT IN CROPPING SYSTEMS INVOLVING TRANSGENIC CULTIVARS

N.R. Burgos, M. Anders, L.R. Oliver, C.C. Wheeler, S. Payne, and M.S. Mobley

ABSTRACT

The adoption of herbicide-resistant crops may foster the continuous use or multiple applications of one herbicide and may favor the proliferation of weed species that are more difficult to control. A study was initiated in 1999 at the Rice Research and Extension Center, Stuttgart, to assess the change in weed composition in response to a weed control program for herbicide-resistant crops and various crop rotation schemes. Glufosinate-resistant or Liberty Link (LL) cultivars of rice and soybean were used. Dominant weed species, before postemergence herbicide application, were *Sida spinosa* (prickly sida), *Echinochloa crus-galli* (barnyardgrass), *Cyperus iria* (rice flatsedge), *Sesbania exaltata* (hemp sesbania), *Amaranthus palmeri* (Palmer amaranth), *Mollugo verticillata* (carpetweed), and *Portulaca oleracea* (common purslane). Visual ratings 50 days after planting showed >90 % control of all weeds in nontransgenic rice. Glufosinate (Liberty) provided excellent weed control except for barnyardgrass in LL rice (74%). For LL soybean, glufosinate did not provide sufficient control of prickly sida (65%) and had escapes of barnyardgrass and Palmer amaranth. The conventional herbicide program for soybean provided excellent control of prickly sida (95%) but was poor on Palmer amaranth (39%). Differential weed tolerance to glufosinate was apparent. Nontransgenic rice yielded 5947 kg/ha; the transgenic rice yielded 14% less. There was no significant difference in yield between transgenic and nontransgenic soybean.

INTRODUCTION

The creation of herbicide-resistant crops (HRCs) is a milestone in agriculture. This technology is best suited for herbicides with broad-spectrum activity on weeds.

Crops are now available that are resistant to glyphosate (Roundup), glufosinate, bromoxynil (Buctril), sethoxydim (Poast), and imazethapyr (Pursuit). In rice, this technology is an excellent tool for the management of noxious weeds such as red rice and propanil-resistant barnyardgrass, among others. Before the advent of HRCs, there was no herbicide that could effectively control red rice postemergence in rice. Options for the control of propanil-resistant barnyardgrass were also limited. Glufosinate, like glyphosate, is a nonselective postemergence herbicide. Sequential application of glufosinate at 0.3 kg/ha provided excellent control of red rice with or without flooding (Sankula *et al.*, 1997). Glufosinate-resistant crops contain the bialaphos resistance gene (BAR) that encodes phosphinothricin acetyl transferase (PAT) (Chirstou *et al.*, 1991). Bialaphos is the parent molecule of glufosinate. PAT is the enzyme that detoxifies bialaphos, thereby making the crop resistant to glufosinate (D'Halluin *et al.*, 1992; Droge *et al.*, 1992). Weeds can now be selectively controlled in a previously susceptible crop. Besides providing weed management flexibility, HRCs can potentially increase the use of environmentally benign herbicides such as glufosinate and glyphosate; however, there are critical disadvantages to this technology. One is the possible transfer of resistance genes, by outcrossing, to wild relatives. Rice is predominantly self-pollinated, but chances of hybridization with red rice still exist (Langevin *et al.*, 1990). Flow of resistance genes to weed species is likely to result in increased adaptability of the weed, causing a shift in weed population to more noxious biotypes. Controlled crosses between transgenic rice and red rice showed that hybridization can occur with either one of the rice types as parent (Sankula *et al.*, 1998). Secondly, although glufosinate is nonselective, weed species show differential tolerance to this herbicide (Ridley and McNalley, 1985). Continuous use of glufosinate would greatly favor the dominance of tolerant species, eventually resulting in a population that could not be controlled by this herbicide. If these changes occur, the usefulness of the technology will be nullified and agriculturists will be faced with more serious problems. This study was conducted to determine the change in weed composition in response to a weed control program for herbicide-resistant crops and crop rotation.

PROCEDURES

The choice of crop was based on the availability of seed. The limiting factor was commercially available transgenic rice seed. We used glufosinate-resistant, or Liberty Link (LL), cultivars of rice and soybean. Crop rotation treatments, intended for four seasons, were: (1) continuous LL 'Bengal' rice; (2) continuous conventional Bengal rice; (3) continuous LL soybean; (4) continuous conventional soybean; (5) alternate years of LL rice and LL soybean; (6) alternate years of conventional rice and conventional soybean; (7) alternate years of LL rice and conventional soybean; and (8) alternate years of conventional rice and LL soybean. The experiment was established on 19 May 1999. Seeds of hemp sesbania, a mix of pitted and entireleaf morningglories, and prickly sida were spread uniformly over the experimental area to ensure a more or less homogeneous distribution of weeds. This minimizes extreme variability in weed counts between plots and allows us to measure changes in weed population more accurately. The weed control program for transgenic crops consisted of two applications of glufosinate at 0.40 kg ai/ha. Conventional rice was treated with quinclorac (Facet), 0.42 kg ai/ha, plus propanil, 3.36 kg ai/ha, at one- to three-leaf stage; followed by propanil as needed. Conventional soybean was treated with a premix of imazaquin and pendimethalin (Squadron), 0.98 kg ai/ha, preemergence; followed by fomesafen (Reflex), 0.21 kg ai/ha, and fluazifop (Fusilade), 0.21 kg ai/ha, postemergence. Plot size was 9.14 x 9.14 m, separated by levees. Rice was grown in a flooded culture and soybean was flood-irrigated as needed. The experiment was conducted in a randomized complete block design with four replications. Weed counts were taken from two 1 x 1-m quadrats within each plot. The center of each plot was harvested using a combine. Yields were adjusted to 12% moisture content. Treatments will be placed in the same location every year.

RESULTS

Weed counts before postemergence herbicide application showed that the dominant weed species (no./sq m) were prickly sida (192), barnyardgrass (51), rice flatsedge (30), hemp sesbania (12), Palmer amaranth (10), carpetweed (6), and common purslane (5) (Table 1). Except for prickly sida and hemp sesbania, these were natural populations. The preemergence herbicide Squadron reduced the population of prickly sida, rice flatsedge, barnyardgrass, and Palmer amaranth 89, 88, 80, and 67%, respectively, in conventional soybean plots (data not shown). Visual rating 50 days after planting showed excellent control (>90%) of all weeds in conventional rice (Table 2). Weed control was also excellent, on the average, in LL rice except for barnyardgrass (74%). For LL soybean, glufosinate was weak on prickly sida (65%) and showed some escapes of barnyardgrass and Palmer amaranth. The conventional herbicide program for soybean provided excellent control of prickly sida (95%) but was poor on Palmer amaranth (39%) and barnyardgrass (70%). Postemergence application of fomesafen did not totally control late-emerging Palmer amaranth. Conventional rice yielded 5947 kg/ha on the average; the transgenic rice yielded 14.5% less (Table 3). Competition from barnyardgrass that escaped the second application of glufosinate might have contributed largely to reduced yield of transgenic rice. However, this does not eliminate the possibility of yield penalty as a result of genetic transformation, or hidden stress from glufosinate treatment. The same trend was observed in soybean. Despite unsatisfactory season-long control of Palmer amaranth and barnyardgrass, conventional soybean yielded 2232 kg/ha; transgenic soybean yielded 17% less. This difference in soybean, however, was not significant.

SIGNIFICANCE OF FINDINGS

During the initial year, this study has shown that glufosinate is relatively weak on prickly sida and barnyardgrass. This herbicide also may not sufficiently control weeds with long germination periods such as Palmer amaranth because it lacks residual activity in the soil. It is interesting to see how the crop rotation schemes and herbicide programs affect the weed population in succeeding years. For the cultivars used, there was a tendency of transgenic cultivars to yield lower quantities than the conventional ones.

ACKNOWLEDGMENT

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board for financially supporting this project.

LITERATURE CITED

Chirstou, P.T., L. Ford, and M. Kofron. 1991. Production of transgenic rice (*Oryza sativa*) plants from agronomically important indica and japonica varieties via electric discharge particle acceleration of exogenous DNA into immature zygotic embryos. Biotechnology 9:957-962.

D'Halluin, K., M. De Block, J. Janssens, J. Leemans, A. Reynaerts, and J. Botterman. 1992. The BAR gene is a selectable marker in plant engineering. Methods Enzymol. 216:415-441.

Droge, W., I. Broer, and A. Puhler. 1992. Transgenic plants containing the phosphinothricin-N-acetyl transferase gene metabolise the herbicide L-phosphinothricin (glufosinate) differently from untransformed plants. Planta 18:142-151.

Langevin, S.A., K. Clay, and J.B. Grace. 1990. The incidence and effects of hybridization between cultivated rice and its related weed rec rice (*Oryza sativa* L.) Evolution 44:1000-1008.

Sankula, S., M.P. Braverman, F. Jodari, S.D. Linscombe, and J.H. Oard. 1997. Evaluation of glufosinate on rice (*Oryza sativa*) transformed with the BAR gene and red rice (*Oryza sativa*). Weed Technol. 11:70-75.

Sankula, S., M.P. Braverman, and J.H. Oard. 1998. Genetic analysis of glufosinate resistance in crosses between transformed rice (*Oryza sativa*) and red rice (*Oryza sativa*). Weed Technol. 12:209-214.

Ridley, S.M. and S.F. McNalley. 1985. Effects of phosphinothricin on the isoenzymes of glutamine synthetase isolated from plant species which exhibit varying degrees of susceptibility to the herbicide. Plant Sci. 39:31-36.

Table 1. Weed composition before herbicide application.[z]

Species		
Scientific name	Common name	Density
		(No./m^{-2})
Amaranthus palmeri	Palmer amaranth	10
Brachiaria platyphylla	broadleaf signalgrass	3.3
Cyperus iria	rice flatsedge	30
Cyperus rotundus	yellow nutsedge	0.4
Digitaria sanguinalis	large crabgrass	0.7
Echinochloa crus-galli	barnyardgrass	51
Ipomoea hederacea var. *integriuscula*	entireleaf morningglory	0.7
Ipomoea lacunosa	pitted morningglory	1.8
Mollugo verticillata	carpetweed	6
Portulaca oleracea	common purslane	5
Senna obtusifolia	sicklepod	0.3
Sesbania exaltata	hemp sesbania	12
Sida spinosa	prickly sida	192

[z] Weed counts were taken from 1 m^{-2} quadrats, two/plot. Counts were averaged across all treatments, excluding conventional soybean plots which received preemergence herbicide treatment.

Table 2. Visual weed control rating, 50 days after planting, year one.

	Weed control rating[z]					
Crop rotation[y]	AMAPA	CYPIR	ECHCG	IPOLA	SEBEX	SIDSP
	%					
TRice-TRice-TRice-TRice	98	100	81	100	98	94
Rice - Rice - Rice - Rice	99	96	94	100	100	100
TSoy - TSoy - TSoy - TSoy	90	96	89	99	100	65
Soy - Soy - Soy - Soy	39	99	70	92	96	95
TRice-TSoy-TRice-TSoy	100	100	65	99	84	100
Rice - Soy - Rice - Soy	99	99	86	100	100	100
TRice - Soy - TRice - Soy	99	100	75	100	91	99
Rice - TSoy - Rice - TSoy	94	96	94	100	100	100
$LSD_{0.05}$	20	NS[x]	20	4	13	14

[z] AMAPA = Palmer amaranth, CYPIR = rice flatsedge, ECHCG = barnyardgrass, SEBEX = hemp sesbania, SIDSP = prickly sida.
[y] TRice = Liberty Link® rice, TSoy = Liberty Link® soybean.
[x] NS = not significant.

Table 3. Yield of transgenic and conventional rice and soybean cultivars, year one.

Crop	Yield
	(kg/ha)
Conventional rice[z]	5947
Transgenic rice[z]	5084
$LSD_{0.05}$	435
Conventional soybean[y]	2232
Transgenic soybean[y]	1862
$LSD_{0.05}$	NS[x]

[z] Average of three treatments, four replications.
[y] Average of four replications.
[x] NS = not significant.

VARIABILITY OF ALLELOPATHIC ACTIVITY IN RICE (*Oryza sativa* L.) WITH WATER-SOLUBLE EXTRACTS

K. Ebana, K. Okuno, R.H. Dilday, W.G. Yan, and H. Namai

ABSTRACT

Allelopathic activity of rice to ducksalad and lettuce was studied using crude water-soluble extracts. Ducksalad is a major weed of rice in the southern United States. PI 312777 and 'Rexmont', which are allelopathic and non-allelopathic, respectively, to ducksalad in the field were used in this study. Water-soluble substances were extracted from rice seedlings and adult plants, and were applied to ducksalad and lettuce. Water-soluble extracts of PI 312777 inhibited the root growth of ducksalad and lettuce, while those of Rexmont did not inhibit growth. A significant correlation existed between allelopathic activity to ducksalad and lettuce when water-soluble extracts from six-leaf rice seedlings were used. Use of water-soluble extracts from rice leaves and lettuce as a test plant detected a wide range of allelopathic activity in rice germplasm.

INTRODUCTION

Allelopathy can be a potential tool for natural weed control in the agro-ecosystem. Allelopathic plants release toxic substances into the environment through root exudation, leaching by dew or rain, and volatilization or decaying plant bodies (Rice, 1984). In most cases, allelochemicals released from a plant will inhibit the germination or growth of neighboring plants, although they may stimulate growth. Allelopathic activity to weeds has been found in many crops, such as beets, lupin, corn, wheat, oats, peas, barley, rye, and cucumber (Rice, 1984). Genetic improvement of allelopathic activity through breeding is one strategy that can enhance natural weed control. In the 1970s, the evaluation of germplasm was extensively undertaken to detect allelopathic activity in various crops. Allelopathic landraces and wild relatives of cucumber were screened (Putnam and Duke, 1974). Over 3000 Avena accessions were evaluated, and a number of accessions were found to exude large amounts of an allelochemical, scopoletin (Fay and Duke, 1977). However, genes conferring allelopathic activity or production of allelochemicals have not been detected. A successful breeding strategy to incorporate allelochemical production into advanced cultivars would include large-scale evaluation of a broad array of germplasm, identification of allelochemicals, and mapping the location of gene(s).

Research on allelopathic activity of rice has included the evaluation of germplasm in the field and the laboratory. Several accessions of rice were found to be allelopathic to ducksalad [*Heteranthera limosa* (Sw.) Willd.] (Dilday *et al.*, 1994), which is a major aquatic weed in the southern United States. Ducksalad can cause as much as a 21% reduction in rice yields in direct-seeded cultivation (Smith, 1988). Rice cultivars that are allelopathic to ducksalad can produce a weed-free radius of 10 to 15 cm around individual rice plants, while non-allelopathic cultivars are densely surrounded by ducksalad. Rice cultivars with allelopathic activity to barnyardgrass were screened in the field and laboratory (Olofsdotter and Navarez, 1996). Varietal differences in allelopathic activity were detected by using lettuce (*Lactuca sativa* L.) as a test plant in the laboratory (Fujii, 1992).

Aqueous extracts of decomposing rice residues inhibited the root growth of rice and lettuce seedlings (Chou and Lin, 1976). Six allelochemicals, *p*-hydroxybenzoic, *p*-coumaric, vannilic, syringic, ferulic, and *o*-hydroxyphenyl acetic acids were isolated from decomposing rice straw and paddy soil (Chou, 1980). A total of 16 potential allelochemicals, including the above-mentioned substances have been found in rice (Olofsdotter *et al.*, 1995). However, no allelochemicals are known that are completely responsible for varietal differences in allelopathic activity observed in the field or laboratory experiments. If allelopathic cultivars and the allelochemicals involved are identified, then breeding approaches will be straightforward, but it seems difficult in rice.

The objectives of this study were to develop a simplified method to assess the genetic potential and allelopathic activity of rice to ducksalad.

PROCEDURES

PI 312777 was derived from the cross combination Taichung 65/Taichung Native 1 (TN 1), and Rexmont is a non-allelopathic United States cultivar. These two germplasm accessions were used to develop methods for this study. Ten cultivars including Taichung 65 and TN 1 were also examined using lettuce as a test plant. Their allelopathic activity has been investigated in both the field and laboratory (Dilday *et al.*, 1994; Fujii, 1992; Olofsdotter and Navarez, 1996). One hundred cultivars from the Japanese germplasm collection were examined for allelopathic activity.

Roots, stems (3 cm from the basal node), and total leaf blades were sampled from four- and six-leaf seedlings of PI 312777 and Rexmont grown in the greenhouse. They were also grown in the field, and their roots, stems, and leaves were sampled at the flowering stage and during the grain-filling period. For other accessions, extracts were prepared only from six-leaf seedlings. Samples were freeze-dried and stored at –80°C. The samples were ground to a powder in a mortar and 10 ml of distilled water per 1 g of fresh material was added. The solution was kept in the refrigerator for 2 hr, stirred on a rotary shaker for 1 hr, and then centrifuged at 1500 rpm for 15 min. The supernatant was recovered and stored in the refrigerator until it was used as a crude water-soluble extract.

Two test plants were used to assess allelopathic activity of the water-soluble extracts. One was ducksalad and the other was lettuce, which is often used as a test plant in allelochemical bioassays. Ducksalad was used to investigate the relationship between the inhibitory effect of the extract and allelopathy observed in the field. Lettuce was investigated as a possible substitute species for ducksalad, since it is easier to handle than ducksalad.

To establish a screening protocol, 250 ml of 1.0% agar was poured into 7 x 7 x 7 cm plastic boxes. Fifty ducksalad seeds were placed in agar, and 40 ml (about 1-cm deep) of crude extracts or distilled water (control) was applied to the surface of the agar. The seeds were germinated at 30°C in the light for 7 days. The number of germinating seeds was recorded, and the length of roots and shoots of 10 randomly selected plants was measured. When the original solution of leaf extracts was too toxic to ducksalad, it was diluted 200% with distilled water.

To evaluate a broad range of rice cultivars, 50 seeds of the lettuce cultivar 'Great Lakes 366' were placed on filter paper in a petri dish. Three ml of the crude extract or distilled water as the control was applied. Petri dishes were sealed, and the seeds were germinated at 25°C in the dark for 3 days. The number of germinating seeds was recorded, and the length of roots and hypocotyls of 10 randomly selected germinating seeds was measured.

RESULTS AND DISCUSSION

The relationship between the inhibitory effect of the extract and field allelopathy of rice was investigated by applying leaf, stem, and root extracts from two rice cultivars to ducksalad. There was no difference between the extracts of PI 312777 and Rexmont on germination of ducksalad. Root length of ducksalad treated with the extract from PI 312777 and Rexmont differed in their allelopathic activity. The inhibitory effect of water-soluble extracts from six-leaf rice seedlings on root elongation of ducksalad is shown in Fig. 1. Leaf and stem extracts inhibited root length of ducksalad, but root extract was less effective. The original solution of rice leaf extract was too toxic to reveal cultivar differences using ducksalad. Extracts were diluted 200% to clearly establish the difference between PI 312777 and Rexmont. The results obtained using leaf or stem extracts were the same as the results from allelopathic and non-allelopathic rice to ducksalad in the field.

Lettuce is often used as a test plant, and it has been used in the screening of allelopathic rice germplasm (Olofsdotter *et al.*, 1995). Okuno *et al.* (1997) showed a positive correlation between the allelopathic activity of rice to ducksalad in the field and water-soluble extracts using lettuce as the test plant. A highly significant correlation was found between the inhibitory effect on root length of lettuce and ducksalad in the present study (Fig.2), when leaf extracts of four cultivars—PI 312777, Rexmont, TN1, and Taichung 65—were used. Therefore, these data show that ducksalad can be substituted for lettuce as a test plant in the laboratory for the evaluation of rice allelopathy. The correlation coefficient between the effect of water-soluble extracts on the length of lettuce roots and that of ducksalad roots was 0.91 with leaf extract, 0.58 with stem extract, and 0.24 with root extract. We concluded that leaf extracts from seedlings are the most appropriate test for the evaluation of the allelopathic activity with lettuce. Therefore, we used lettuce for the evaluation of allelopathic activity in this study.

Water-soluble extracts from various tissues and growth stages of two rice cultivars, PI 312777 and Rexmont, were tested to determine the appropriate extract to maximize cultivar differences of allelopathic activity. Leaf, stem, and root extracts all showed inhibitory effects on root elongation of lettuce (Fig. 3). The effect on the hypocotyl elongation of lettuce was variable among replications. Germination of lettuce seeds showed no differences among the extracts. These data show that root length of lettuce can be used to assess allelopathic activity of rice. The extracts isolated from various tissues and growth stages of PI 312777 had differing degrees of inhibitory effects on lettuce (Fig.3). Leaf extracts from six-leaf rice plants inhibited root growth of lettuce more than the other extracts. The extracts caused necrosis on the tip of lettuce roots, and most of the seeds with necrosis could not develop a normal hypocotyl. The inhibitory effects of extracts from rice plants during the grain filling period was low. Stem and root extracts were less effective than leaf extracts. The extracts of Rexmont showed some age-specificity as well as tissue specificity on lettuce growth compared to PI 312777 (Fig. 3).

The variation of allelopathic activity among 10 rice cultivars was investigated using extracts from various tissues (Fig.4). The USDA-ARS Genetic Resources Information Network (GRIN) database states that PI 312777, TN1, and 'Masrai' are allelopathic to ducksalad in the field and Rexmont, Taichung 65, 'Koshihikari', 'Dular', 'Muha', and 'North Rose' are non-allelopathic. 'Nepal No. 18' and 'Musashikogane' are reported to be allelopathic to lettuce (Fujii, 1992), and Musashikogane and TN1 are allelopathic to barnyardgrass (Olofsdotter and Navarez, 1996). Varietal differences found in the present study using water-soluble leaf extracts largely corresponded to the results previously reported. These data show that leaf extracts from six-leaf seedlings are appropriate for evaluating for allelopathic activity.

The Japanese germplasm collection, including the wild relatives of rice, was screened with leaf extracts from six-leaf stage rice seedlings using lettuce as a test plant. A total of 100 cultivars were evaluated for their potential for allelopathic activity. The results showed a wide range in variation of the allelopathic activity in rice (Fig. 5). The most allelopathic cultivar inhibited lettuce root elongation 96%, and the least allelopathic cultivar inhibited root elongation by 39% compared to the control. PI 312777 and Rexmont inhibited root elongation by 90 and 69%, respectively. Cultivars with higher allelopathic activity than PI 312777 were found. Not all of these cultivars may be allelopathic in the field, because field allelopathic activity may result from a combination of the production and secretion of allelochemicals and other factors. However, they are candidates for the development of allelopathic cultivars in the field and can be used for genetic analysis of allelopathic activity.

These studies demonstrated that: (1) water-soluble extracts can be used to evaluate allelopathic activity of rice, (2) lettuce can be used to assess allelopathic activity in rice to ducksalad, and (3) leaf extracts of six-leaf rice seedling were the most effective in detecting varietal differences. Therefore, the method using leaf extracts from six-leaf rice seedlings and lettuce as a test plant is proposed as a tool to evaluate allelopathic activity of rice.

We will use this method in quantitative trait loci (QTL) analysis of allelopathic activity in rice. Based on the QTL analysis, gene(s) conferring allelopathic activity will be mapped and DNA markers located near the gene(s) will be detected. This information will be useful in developing breeding strategies to improve allelopathic activity in rice cultivars.

SIGNIFICANCE OF FINDINGS

These results can be used to evaluate a large number of accessions in the seedling stage in either the field or laboratory for allelopathic activity to ducksalad and possibly barnyardgrass.

LITERATURE CITED

Chou, C.H. 1980. Allopathic researches in the subtropical vegetation in Taiwan. Comparative Physiology and Ecology. 5:222-234.

Chou, C.H. and H.J. Lin. 1976. Autointoxication mechanism of *Oryza sativa* L. I. Phytotoxic effects of decomposing rice residues in soil. Journal of Chemical Ecology. 2:353-367.

Dilday, R.H., J. Lin, and W. Yan. 1994. Identification of allelopathy in the USDA-ARS rice germplasm collection. Australian Journal of Experimental Agriculture. 34:901-910.

Fay, P.K. and W.B. Duke. 1977. An assessment of allelopathic potential in Avena germplasm. Weed Science. 25:224-228.

Fujii, Y. 1992. The potential biological control of paddy weeds with allelopathy—allelopathic effect of some rice varieties. Proceedings of the International Symposium on Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia. 305-320.

Okuno, K., W. Yan, and R.H. Dilday. 1997. Method for testing allelopathic activity in rice using water-soluble extracts. Breeding Science 47 (Supplement 1):223.

Olofsdotter, M., D. Navarez, and K. Moody. 1995. Allelopathic potential in rice (*Oryza sativa* L.) germplasm. Annals Applied Biology 127:543-560.

Olofsdotter, M., and D. Navarez. 1996. Allelopathic rice for *Echinochloa crus-galli* control. Proceedings of Second International Weed Control Congress. 1175-1181.

Putnam, A.R. and W.B. Duke. 1974. Biological suppression of weeds: evidence for allelopathy in accessions of cucumber. Science 185:370-372.

Rice, E.L. 1984. Allelopathy (2nd Edition). Academic Press Inc (London) Ltd.

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

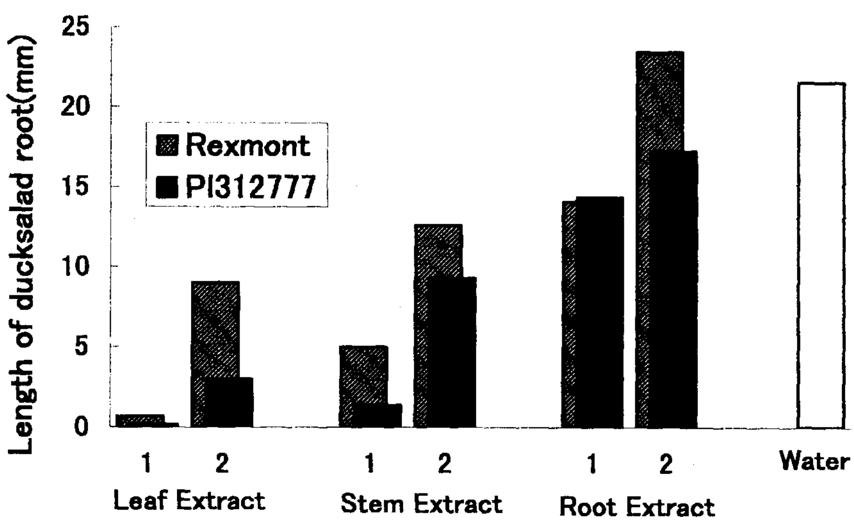
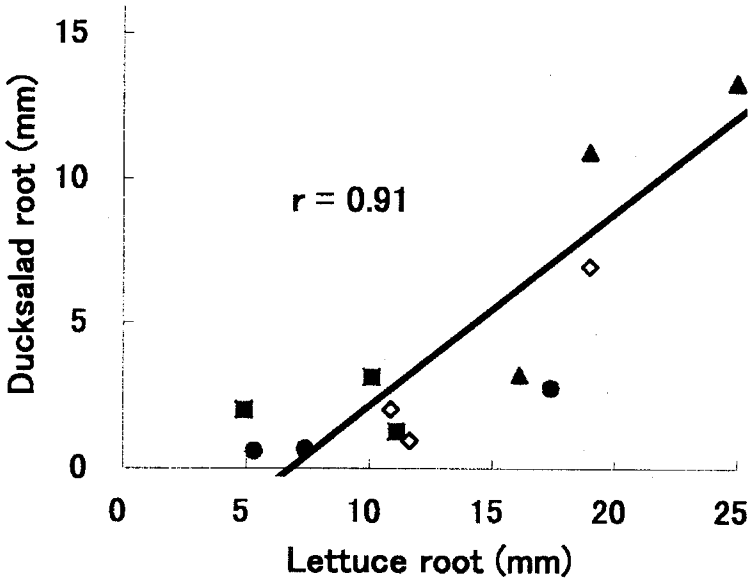


Fig. 1. Rice tissue and variety differences of water-soluble extracts on root elongation of ducksalad.



■ = PI 312777; ▲ = Rexmont; ● = Taichung Native; and ◇ = Taichung 65.

Fig. 2. Relationship between inhibitory effect of water-soluble leaf extracts on lettuce and ducksalad roots.

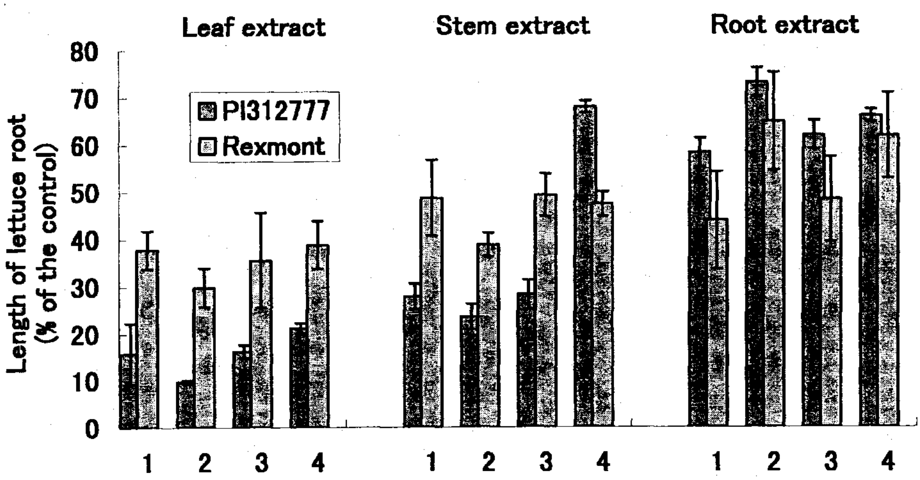


Fig. 3. Rice tissue and variety differences of water-soluble extracts on root elongation on lettuce.

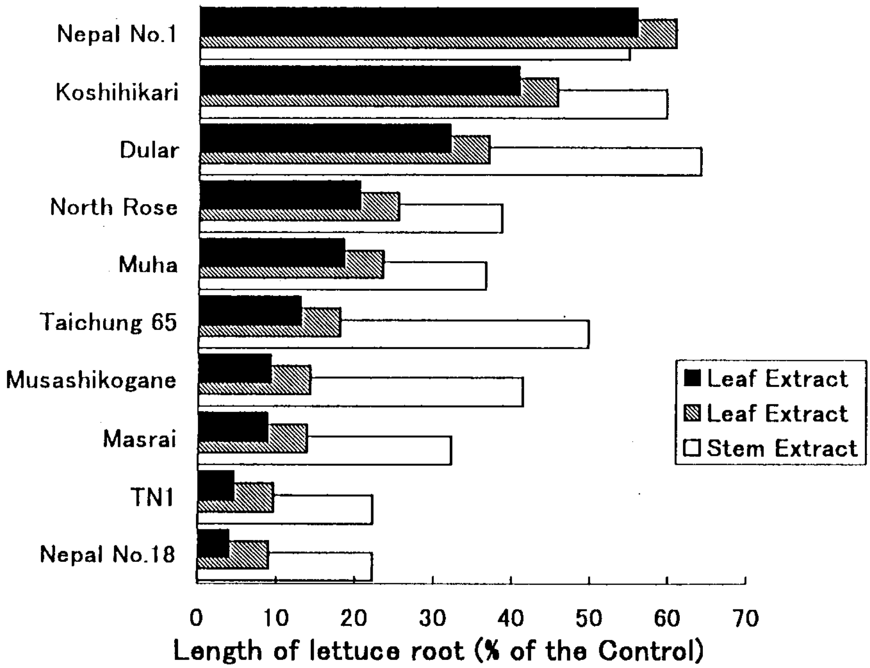


Fig. 4. Varietal differences in allelopathic activity of water-soluble extracts in rice.

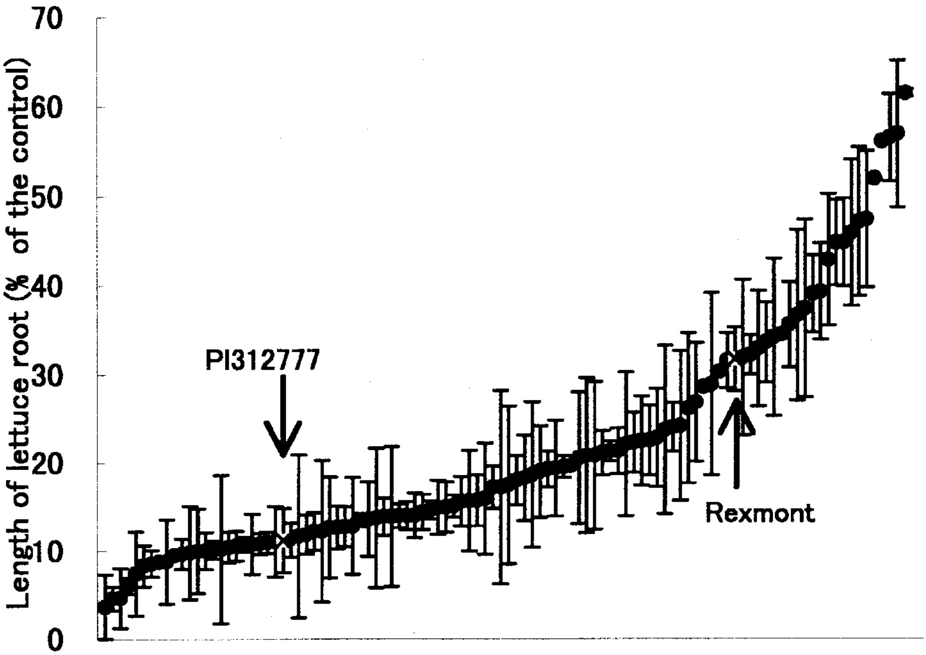


Fig. 5. Inhibitory effect of leaf extract from different cultivars. Each point shows the average of lettuce root length and the bar represents the standard error.

GENETIC CHARACTERIZATION OF RED RICE POPULATIONS USING MOLECULAR MARKERS

L.E. Estorninos, Jr., N.R. Burgos, D.R.Gealy, J.M. Stewart, and R.E. Talbert

ABSTRACT

Low rates of outcrossing between rice and red rice or between red rice ecotypes has long been suspected. A study was initiated to analyze the genetic relationships between red rice populations and cultivated rice by DNA figerprinting. Twenty-three red rice accessions and one rice cultivar, 'Bengal', were grown in the greenhouse, and DNA was extracted from each. Polymerase chain reaction (PCR) with 10-mer primers and genomic DNA template was used to generate random amplified DNA fragments. Polymorphisms among the DNA fragments (RAPDs) were detected by agrose gel electrophoresis.

Preliminary cluster analysis, as shown in multidimensional scaling (MDS) plots, revealed that the 24 accessions could be separated into five groups. Group 1 was Bengal, the only rice cultivar. Group 2 included 'KatyRR' (suspected cross between the cultivar 'Katy' and red rice), which was genetically distant from the other clusters. Group 3 was accession #8. The fourth group comprised the strawhull and awnless accessions consisting of #7, 1995-7, 1995-12, 15-A, 1996-5, and Stuttgart strawhull. The fifth group was the awned-type, strawhull or blackhull accessions, MS-4, LA-3, 11-D, Stuttgart blackhull, TX-4, 1995-4, 1995-14, 10-A, 1996-7, 19-A, and 5-A. Accessions 17-C and 1995-1 were blackhull and awned but were genetically distant from this group. Accessions #8 and 5-A were collected from the same field and were presumed to be the same biotype; however, these results showed that #8 is probably of rice x red rice hybrid origin.

INTRODUCTION

Red rice is among the top problem weeds of rice because it is morphologically similar to domestic rice and because both belong to the same species, *Oryza sativa*, (Hoagland and Paul, 1978). Red rice seeds shatter early and add to the soil seed bank, where many seeds remain dormant and viable for several years. At harvest, red rice contaminates the domestic rice grains and reduces the milling yield and quality because of the red pericarp and because grains are soft and break easily (Smith, 1981).

Hybridization between red rice and domestic rice increases the genetic diversity of red rice as well as its adaptability to different rice cultural environments (Langevin *et al.*, 1990). The genetic diversity may also result in differential tolerances to herbicides, particularly at non-lethal doses. If these hybrids are generated in large numbers, management schemes for the red rice hybrid complex would become more complicated (Gealy *et al.*, 1999). Understanding the genetic characteristics of red rice in relation to rice may enable us to develop better management strategies for red rice control in rice.

PROCEDURES

Plant Materials

Twenty-three red rice accessions and one rice cultivar, Bengal, were supplied by Dr. David Gealy from ARS-USDA, Dale Bumpers National Rice Research Center in Stuttgart. Most of these accessions came from various rice farms in Arkansas and Prairie counties. Additional strawhull types were obtained from Louisiana (three) and Mississippi (two), and blackhull types from Texas, Louisiana, and Mississippi. The seeds were obtained either from individual plants or from bulked seed samples from numerous plants. Twenty to twenty-five seeds of each accession were grown in the greenhouse at the Altheimer Laboratory, University of Arkansas, Fayetteville.

DNA Extraction and Quantification

Two weeks after emergence, leaves were clipped, 0.75 g leaf tissue was ground in liquid nitrogen, and DNA was extracted by the Dneasy Plant Extraction Protocol. The extracted DNA was quantified by ultraviolet absorption at 260 nm wavelength in a spectrophotometer. The protocol gave absorbance readings in the range of 0.1 to 1.0, which is an acceptable range for accurate results.

DNA Analysis

Genomic DNA served as template for PCR amplification using eight random primers, each consisting of 10 base pairs. The reactions were carried out in 20-µl volumes, each containing the following: 10 ng/µl sample DNA, 2.5 µl 10X reaction buffer, 2 µl MgCl2 (25 mM), 2.0 µl dNTPs (25 mM), 0.5 µl of 20 mM of each primer, 0.13 µl Taq DNA polymerase, and 12.87 µl deionized water. Each mixture was placed into a 0.5 ml mini-tray, covered with a drop of mineral oil, and placed in the thermal cycler preprogrammed for: one cycle at 94°C for 2 min to denature the template DNA and 45 cycles at 94°C for 45 sec; 38°C for 5 min; and 72°C for 2 min for amplification. This was followed by a final step at 72°C for 7 min to complete synthesis of partial fragments. The reaction products were held at 4°C until electrophoresis. DNA fragments amplified by PCR were separated by electrophoresis in a 1% agarose gel. The gel was stained with ethidium bromide and photographed using a CCD camera connected to a computer and printer. The procedure was repeated three times to assure reproducibility of each fragment. For each primer, samples were scored for presence (1) or absence (0) of a band. A score of 9 was given when reproducibility could not be determined. Only bands that appeared in at least two of three runs were scored.

RESULTS AND DISCUSSION

The total scorable PCR products (bands) from all eight primers for a given accession ranged from 17 to 54 with an average of 40 scorable bands. Genetic distance based on simple matching coefficients ranged from 0.026 to 0.630 between populations (Table 1). Identical individuals are expected to have a genetic distance close to zero, while unrelated individuals will have a genetic distance close to 1.0. A dendrogram based on linkage cluster analysis facilitates recognition of genetic affinities among the accessions (Figure 1).

Preliminary cluster analysis of the accessions based on common random DNA fragments, as shown in the MDS plots, revealed that the accessions could be separated into five groups (Table 2 and Figure 2). Bengal, the only rice cultivar, was categorized as Group 1 because it was genetically distant from other clusters and appeared not to be related to any red rice population. KatyRR, based on morphological characteristics, is thought to be derived from a hybrid of red rice and the cultivar Katy. Group 2 consisted of this single entry and was genetically distant from the other clusters but closer to 1996-1. KatyRR and 1996-1 were expected to have minimal genetic distance between them because they originated from the same collection of seeds. The estimated genetic distance between KatyRR and 1996-1 indicates that the original seed collection may not have been homozygous. Otherwise, this difference could not be explained. Group 3 also consisted of a single accession, #8, which was genetically distant from the other clusters. The fourth group were the strawhull, awnless-type accessions consisting of #7, 1995-7, 1995-12, 15-A, 1996-5, and Stuttgart strawhull. The fifth group contained awned types consisting of four strawhull and 10 blackhull accessions. The strawhull types were MS-4, LA-3, 11-D, and 1995-14. The blackhull types were Stuttgart blackhull, TX-4, 1995-4, 1995-14, 10-A, 1996-7, 19-A, and 5-A. Accessions 17-C and 1995-1 were blackhull, awned types, but were genetically distant from the group 5.

Accessions #8 (from a bulked sample), and 5-A (from a single plant), were collected from the same field. They were presumed to be the same biotype because both were blackhull and awned, but our results determined that they were relatively distant. Identical individuals are expected to have a genetic distance close to zero, while unrelated individuals will have a genetic distance close to 1.0. The grower who supplied the red rice sample believed that this infestation may have arisen from a single introduction onto his rice farm from rice seed from Louisiana about 10 years prior to collection. The intermediate position of #8 relative to the rice cultivar and the red rice accessions suggests that it may also be derived from a rice x red rice hybrid.

SIGNIFICANCE OF FINDINGS

Preliminary characterization using molecular marker techniques of the various red rice accessions from Arkansas and Prairie counties indicated that several accessions were genetically similar. A few accessions such as KatyRR and #8 were genetically intermediate between the rice cultivar and red rice accessions. It is very likely that these were derived from hybridization events. Further characterization involving cultivars to which these biotypes were associated would determine the extent of genetic movement from domestic rice to red rice.

ACKNOWLEDGMENT

This study was funded in part by the Arkansas Rice Research and Promotion Board. Special thanks to Dr. Clay Sneller for the statistical analysis and to his student, Brian Cornelius, for assistance.

LITERATURE CITED

Gealy, D.R., R.H. Dilday, F.L. Baldwin, and H.L. Black. 1999. Imazethapyr (Pursuit) effect on red rice (*Oryza sativa* L.) biotypes. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. Arkansas Agricultural Experiment Station Research Series 468:79-89.

Hoagland, R.E., and R.N. Paul. 1978. A comparative SEM study of red rice and several commercial rice (*Oryza sativa*) varieties. Weed Sci. 26:619-625.

Langevin, S.A., K. Clay, and J.B. Grace. 1990. The incidence and effects of hybridization between cultivated rice and its related weed red rice (*Oryza sativa* L.). Evolution 44:1000-1008.

Smith, R.J., Jr. 1981. Control of red rice (*Oryza sativa*) in water-seeded rice. Weed Sci. 29:663-666.

Table 1. Genetic distance between populations of red rice ecotypes and rice cultivar based on simple matching coefficients.

Genotype	TX-4	SG-B	11-D	LA-3	96-1	5-A	MS-4	19-A	95-13	95-4	95-14	17-C
TX-4	0.000											
SG-B	0.050	0.000										
11-D	0.098	0.109	0.000									
LA-3	0.143	0.170	0.109	0.000								
96-1	0.381	0.347	0.306	0.311	0.000							
5-A	0.195	0.245	0.125	0.111	0.286	0.000						
MS-4	0.158	0.222	0.133	0.122	0.326	0.048	0.000					
19-A	0.209	0.208	0.212	0.133	0.347	0.128	0.116	0.000				
95-13	0.146	0.188	0.043	0.130	0.320	0.122	0.133	0.200	0.000			
95-4	0.184	0.222	0.133	0.143	0.311	0.068	0.100	0.174	0.091	0.000		
95-14	0.195	0.213	0.065	0.116	0.239	0.130	0.114	0.191	0.109	0.163	0.000	
17-C	0.317	0.289	0.261	0.214	0.333	0.239	0.286	0.227	0.250	0.238	0.214	0.000
95-12	0.238	0.224	0.200	0.191	0.196	0.184	0.255	0.200	0.231	0.250	0.174	0.229
15-A	0.333	0.298	0.300	0.283	0.190	0.234	0.273	0.271	0.286	0.304	0.209	0.205
95-1	0.233	0.220	0.196	0.156	0.340	0.184	0.217	0.146	0.180	0.229	0.191	0.070
SG-S	0.357	0.340	0.308	0.298	0.283	0.265	0.354	0.340	0.314	0.298	0.277	0.250
10-A	0.171	0.191	0.106	0.048	0.255	0.109	0.093	0.208	0.143	0.140	0.068	0.267
95-7	0.326	0.306	0.250	0.239	0.167	0.196	0.250	0.277	0.265	0.273	0.143	0.209
96-5	0.314	0.275	0.256	0.341	0.237	0.250	0.316	0.349	0.279	0.333	0.225	0.359
96-7	0.167	0.194	0.139	0.176	0.289	0.184	0.176	0.300	0.205	0.237	0.200	0.294
#-7	0.207	0.206	0.242	0.129	0.233	0.212	0.172	0.125	0.265	0.265	0.107	0.267
#-8	0.393	0.424	0.471	0.438	0.419	0.455	0.400	0.438	0.471	0.438	0.419	0.464
BGL	0.533	0.563	0.500	0.500	0.400	0.467	0.480	0.548	0.469	0.536	0.483	0.533
KTRR	0.382	0.389	0.342	0.421	0.233	0.405	0.364	0.417	0.395	0.412	0.265	0.333

continued

Table 1. Continued.

Genotype	95-12	15-A	95-1	SG-S	10-A	95-7	96-5	96-7	#-7	#-8	BGL	KTRR
TX-4												
SG-B												
11-D												
LA-3												
96-1												
5-A												
MS-4												
19-A												
95-13												
95-4												
95-14												
17-C												
95-12	0.000											
15-A	0.068	0.000										
95-1	0.176	0.208	0.000									
SG-S	0.133	0.143	0.240	0.000								
10-A	0.255	0.261	0.224	0.340	0.000							
95-7	0.091	**0.026**	0.191	0.116	0.234	0.000						
96-5	0.105	0.167	0.302	0.162	0.310	0.171	0.000					
96-7	0.310	0.324	0.256	0.317	0.184	0.250	0.286	0.000				
#-7	0.125	0.200	0.182	0.242	0.194	0.167	0.240	0.233	0.000			
#-8	0.486	0.516	0.500	0.583	0.387	0.455	**0.630**	0.517	0.500	0.000		
BGL	0.531	0.586	0.531	0.548	0.516	0.448	0.464	0.333	0.474	0.588	0.000	
KTRR	0.294	0.258	0.389	0.412	0.371	0.233	0.357	0.400	0.364	0.304	0.421	0.000

Table 2. Grouping distribution of the 24 accessions based on genetic distances.

Genotype	Group 1	Group2	Group 3	Group 4	Group 5
TX-4					x
SG-B					x
11-D					x
LA-3					x
1996-1				x	
5-A					x
MS-4					x
19-A					x
1995-13					x
1995-4					x
1995-14					x
17-C					x
1995-12				x	
15-A				x	
1995-1				x	
SG-S				x	
10-A					x
1995-7				x	
1996-5				x	
1996-7					x
#-7				x	
#-8			x		
Bengal	x				
KatyRR		x			

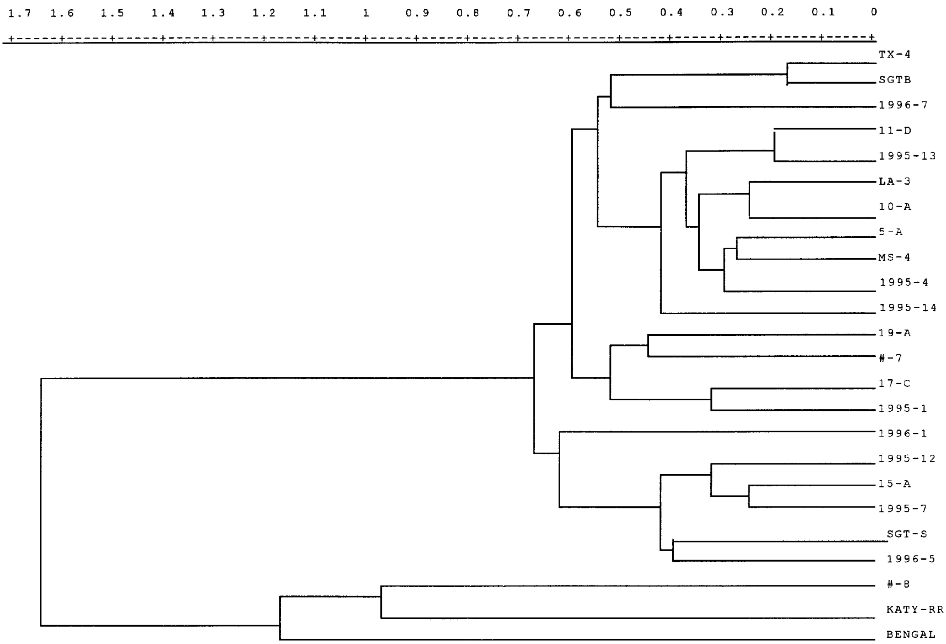


Fig. 1. Dendrogram constructed on the basis of linkage cluster analysis of genetic distance among 23 red rice accessions and a rice cultivar.

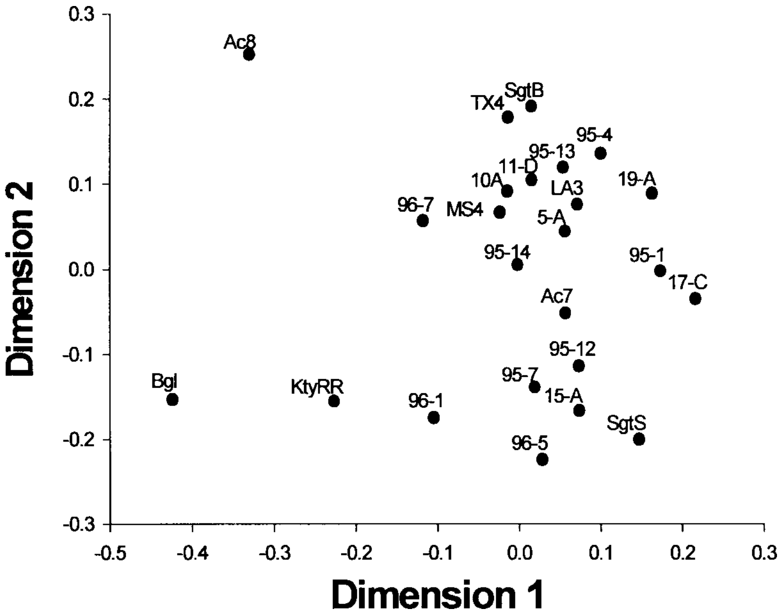


Fig. 2. Distribution of 24 accessions based on multidimensional scaling.

PROGRESS IN THE USE OF SMALL-VOLUME AGAR ASSAYS TO DETECT PHYTOTOXIC EXUDATES PRODUCED BY RICE (*Oryza sativa* L.) ROOTS

D. R. Gealy and Y. Fujii

ABSTRACT

Rice roots produced phytotoxic exudates that were capable of diffusing in agar and inhibiting growth of seedlings of the model plant lettuce planted as much as 40 mm away in standard 250 ml agar assays. Rice cultivars differed in their ability to inhibit lettuce growth, presumably because they produced exudates in differing amounts or of differing phytoxic activity. PI 312777 generally inhibited lettuce more than did ‘Rexmont’. Delaying lettuce seed planting for several days after root exudation began caused greater inhibition of lettuce growth, suggesting that sensitivity may be increased with this modification to the assay procedure. Assays using reduced volumes and amounts of biomass (1/10 or 1/20 that of the standard method) successfully demonstrated that apparent allelopathic activity depended upon the rice cultivar and the mass of rice roots present. Inclusion of known allelochemical standards in agar assays provided a benchmark calibration for apparent allelopathic activity in rice roots. Assays similar to these are being developed to evaluate rice lines against Arkansas weeds.

INTRODUCTION

The long-term goal of this research is to improve the economics of weed control in rice and to improve ground water quality by supplementing herbicide use with weed-suppressive rice cultivars. During a study leave in Japan in June and July 1999, one author (D.R.G.) observed several dramatic examples of weed suppressive (apparently allelopathic) activity in plants. Among these were transplanted rice growing in field plots; *Fagopyrum esculentum* (buckwheat), thought to produce alkaloid allelochemicals;

Licoris radiata, a perennial plant grown on permanent terraces and walkways near rice fields that was introduced into Japan from China several thousand years ago; *Mucuna pruriens* (velvet bean) which produces a highly active, unusual amino acid allelochemical called L-DOPA; *Ficus* (fig) and *Sphenoclea zeylanica*, a perennial weed that is allelopathic to rice. Fields infested with this weed often are incapable of producing healthy rice crops in subsequent years, apparently because of the heavy load of allelochemicals remaining in the soil (N. Hirai, personal communication). Such examples of potent plant-growth suppression by one plant species against another are encouraging and suggest that continued investigations into the genetics, physiological mechanisms, and agronomic optimization of weed-suppressive/allelopathic rice cultivars may be beneficial. Objectives of this project were to evaluate allelopathic activity of various rice lines and known allelochemicals against lettuce seedlings as a target "weed" species, using a standard large-volume agar assay and modified versions of this assay.

PROCEDURES

Standard Plant Box Agar Assay

The standard plant box method for assaying allelopathic activity is summarized as follows. Rice plants were grown in sand culture in pots (16 x 16 cm wide and 12 cm deep) for 4 to 8 wk. Roots were washed extensively with tap water and then with deionized water to remove sand particles. Roots of three rice plants were placed gently into a nylon-mesh-bounded cylinder (3.2 cm in diameter by 6.6 cm tall), which was placed upright in one corner of a clear plastic box 70 x 70 cm wide and 100 cm deep. Rice stems were taped to the corner of the box to stabilize the plants in the box. Hot liquid agar (0.75% w/v; 250 ml per box) was cooled to 40°C and poured into the boxes, covering all root material but not covering stem material. Boxes containing agar and rice plants were cooled on ice until agar had solidified (about 30 min). Immediately after agar had solidified, 31 lettuce seeds were arranged in an equidistant grid pattern across the entire surface of the agar at distances up to 40 mm from the rice roots. Using porcelain forceps, seeds were inserted about halfway into the agar with the germ end down. Boxes were sealed around the rice stems and over the box surface with plastic wrap to minimize water loss, and placed in a fluorescent lighted incubator for 5 days (25°C, 14-hour days: 20°C, 10-hour nights). Lettuce seedlings then were removed and radicle (root) and hypocotyl (shoot) lengths determined to the nearest millimeter for each. Regression analysis was used to estimate lettuce root length at zero distance from rice roots (*y*-intercept), and slope of the inhibition curve. Decreasing inhibition of lettuce growth at increasing distances from rice roots indicates that phytotoxic exudates have diffused away from the rice roots. Small *y*-intercept values in conjunction with either small or large positive slopes are indicative of high levels of phytotoxin exudation from rice roots. Large positive slopes indicate that concentrations of pytotoxins were decreasing at increasing distances from the rice root source.

Modified Agar Assays

In some cases, the standard plant box (250 ml) assay was modified by removing leaves or stems from rice plants immediately before placing the rice roots in agar (data not shown). This procedure reduced water consumption and minimized shrinkage and potential fracturing of the agar bed. In other cases, lettuce seed planting was delayed one to three days after placing rice roots in agar.

In order to minimize the amounts of root material and agar as well as the amount of time required for each assay, some assays were conducted in reduced volumes of 0.75% agar. In these reduced-volume assays, vials were 2.8 cm in diameter x 6 cm deep containing ~25 ml solidified agar, or were 3 cm in diameter x 2.5 cm deep containing ~12 ml solidified agar. A #3 cork borer was used to cut a ~7.5 mm in diameter cylindrical core of solidified agar from the center of each vial that extended to the bottom of the vial. A small clump of rice roots (1/10 to 1/20 the mass used in the standard plant box assays) or 0.75% liquid agar containing known concentrations of various allelochemical inhibitors (e.g., berberine hydrochloride or L-DOPA) was placed into the cylindrical hole. The remaining unfilled volume in the hole was filled with 0.75% liquid agar and agar was allowed to solidify. One day after placing rice roots or inhibitors into the agar, eight lettuce seeds were spaced evenly, about 2 mm from the inside edge of each vial at a radius of about 8 mm from the center of the vial. After 4 days of incubation at 20°C in the dark, lettuce seedlings were removed and measured as described previously. The eight lettuce seedlings in each vial were considered subsamples.

RESULTS AND DISCUSSION

Roots of several rice lines were highly inhibitory to the elongation of lettuce roots in plant box assays conducted with 250 ml agar (Figs. 1, 2, and 3). Allelopathic activity estimated from *y*-intercepts was in the order Akamai 93-10390-1 >> Taichung 65 = PI 338046, and all rice lines reduced lettuce radicle growth by 45% or more compared to the control (Fig. 1). Akamai is a red rice cultivar from Japan, Taichung 65 is a parent of PI 312777, and PI 338046 is a rice line known to suppress ducksalad.

PI 312777 generally inhibited lettuce radicle growth more than did Rexmont (Figs. 2 and 3). PI 312777 inhibited lettuce radicles to about the same degree as did a 100 ppm berberine hydrochloride standard (Fig. 2). In assays that were modified by delaying lettuce planting for 2 to 3 days after rice roots were placed in agar (Figs. 2 and 3), inhibition from rice roots generally was greater (lower *y*-intercepts) than in the standard plant box assays (Fig. 1).

Delaying lettuce seed planting 2 or 3 days after Rexmont and PI 312777 rice roots were placed in the agar medium, caused progressively greater inhibition (decrease in both *y*-intercept and slope of regression curve) of lettuce growth (Fig. 3). The delay in lettuce planting apparently allows more extensive diffusion of allelochemicals away from the rice roots into the agar medium, resulting in earlier and more extensive inhibition of lettuce radicle growth. The greater inhibition recorded in these delayed-seeding assays may allow for sensitive estimates of allelochemical production by small, individual plants, which would be helpful in screening germplasm sources for breeding purposes.

Interestingly, Rexmont inhibited lettuce roots dramatically in the delayed planting studies. These results seem to be inconsistent with the hypothesis that the non-suppressive cultivar Rexmont produces allelochemicals in low quantities or of low activity. Rexmont typically exhibits low weed suppressive activity in the field (Dilday *et al.*, 1995).

In reduced-volume (25 ml agar) rate-response experiments, lettuce radicles were about 10 times more sensitive (I50 values 10 times greater) than hypocotyls to L-DOPA (an alkaloid phytotoxin) (Fig. 4A). This large difference in sensitivity levels of radicles and hypocotyls of lettuce also occurred with exudates from rice roots (Fig. 4B). Together, these data demonstrate that rate-response curves for known allelochemicals may be useful as calibration tools for agar assays with roots of suspected allelopathic rice lines in reduced-volume experiments.

In reduced-volume (12 ml agar) experiments, that used rice root masses of only 5 to 10% of those in the standard root box experiments, allelopathic activity against lettuce radicles increased with increased rice root mass (Fig. 4C). These experiments confirmed that greater rice root mass can result in greater phytotoxicity to lettuce seedlings, indicating that the levels of phytotoxicity measured in agar assays may require adjustments on the basis of the mass of root material present. Presumably, greater root mass results in a greater root surface area from which phytotoxins are released.

Duration of the reduced-volume assays was usually one to several days less than for the standard plant box assays. Therefore, these assays may allow for greater numbers of experiments and greater replication of treatments to be completed more cheaply, and also improve the precision in detecting small differences among treatments. A potential drawback of working with very small root masses and agar volumes, where both the roots and solidified agar are somewhat fragile, is that the method may require an unreasonably high degree of precision, manual dexterity, and visual acuity from the experimenter. These and other technical problems must be overcome before assays with weeds of Arkansas (such as barnyardgrass) can be evaluated efficiently and accurately in reduced-volume agar assays. Presently, it is not clear whether barnyardgrass or other weeds of rice would exhibit sensitivity similar to that of lettuce in such assays. Research is being planned to address this question for barnyardgrass and other weeds of rice in Arkansas. A key to adapting these assays to rice weeds of Arkansas will be to synchronize initial germination and/or radicle growth of the weeds with exudation and diffusion of allelochemicals from rice roots. The natural rate of germination for most weed species is probably too low for optimal use of the existing agar assays.

SIGNIFICANCE OF FINDINGS

These agar assay tests showed that PI 312777 was capable of releasing phytotoxic substances that then migrated a short distance to inhibit root growth of the target plant species, lettuce, thus providing strong circumstantial evidence for the presence of a true allelopathic response. The long-term goal of this cooperative research and future cooperation is to improve the economics of weed control in rice and to improve ground water quality by supplementing herbicide use with weed suppressive rice cultivars. In the future, as molecular mapping approaches to rice research are applied to allelopathy and other weed suppressive mechanisms in rice, weed suppressive genes may be manipulated in a highly targeted and efficient manner, resulting in commercially acceptable cultivars with superior weed suppression characteristics. Overall, this preliminary work demonstrated allelopathic mechanisms at work in some rice lines in agar assays and may lead to a better understanding of the occurrence, significance, and potential exploitation of allelopathy in rice weed suppression systems in Arkansas.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support of the Organization for Economic and Cooperative Development (OECD) and the Arkansas Rice Research and Promotion Board, the total support of all members of the NAIES Allelopathy Laboratory in Tsukuba, Japan, and the technical assistance of Howard Black and numerous part-time assistants.

LITERATURE CITED

Dilday, R.H., R.S. Helms, B.R. Wells, K.A. Gravois, W. Yung, J. Lin, M. Price, M. Jalaluddin, C. Guy, and K.A. Moldenhauer. 1995. Genetic, physiological, and biochemical enhancement of exotic rice germplasm. *In:* B.R. Wells, ed. Arkansas Rice Research Studies. University of Arkansas Agricultural Experiment Station Research Series 446:9-15.

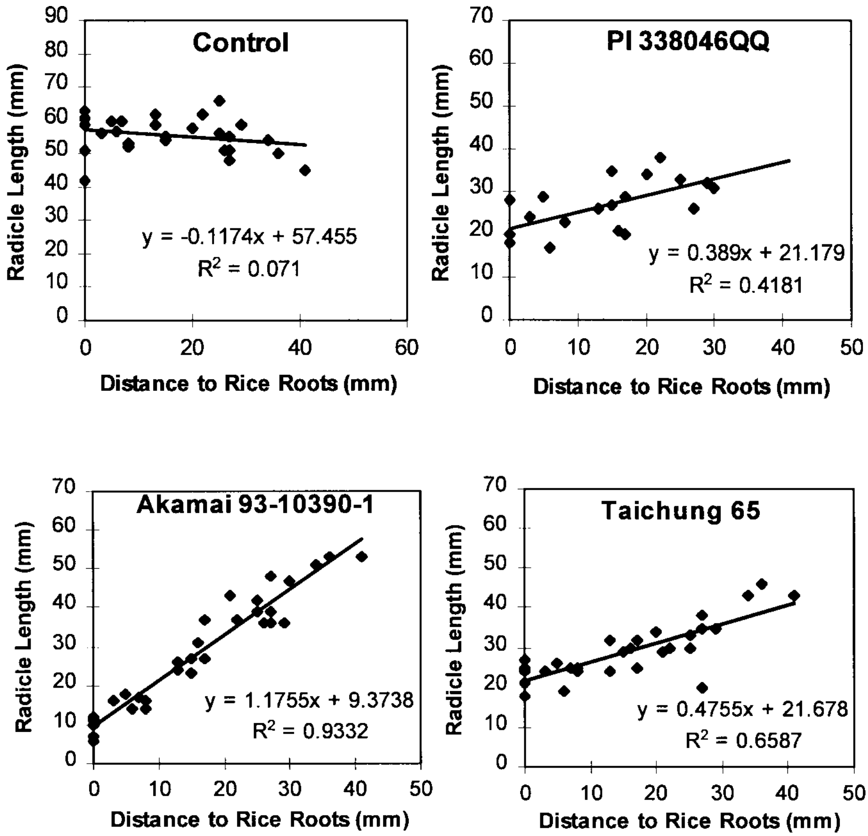


Fig. 1. Inhibition of lettuce radicle growth by roots of various rice lines using standard plant box (250 ml) agar assay.

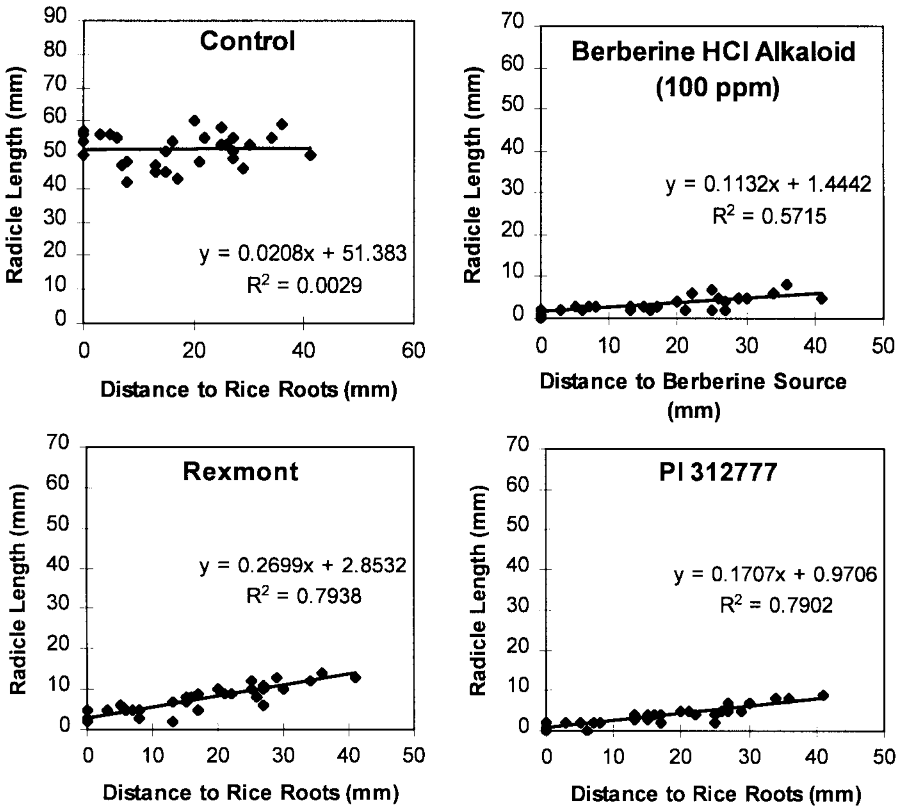


Fig. 2. Inhibition of lettuce radicle growth by PI 312777 and Rexmont rice as compared to water and berberine hydrochloride alkaloid standards—the standard plant box agar assay was modified by delaying lettuce seed planting until 3 days after rice roots were placed in agar.

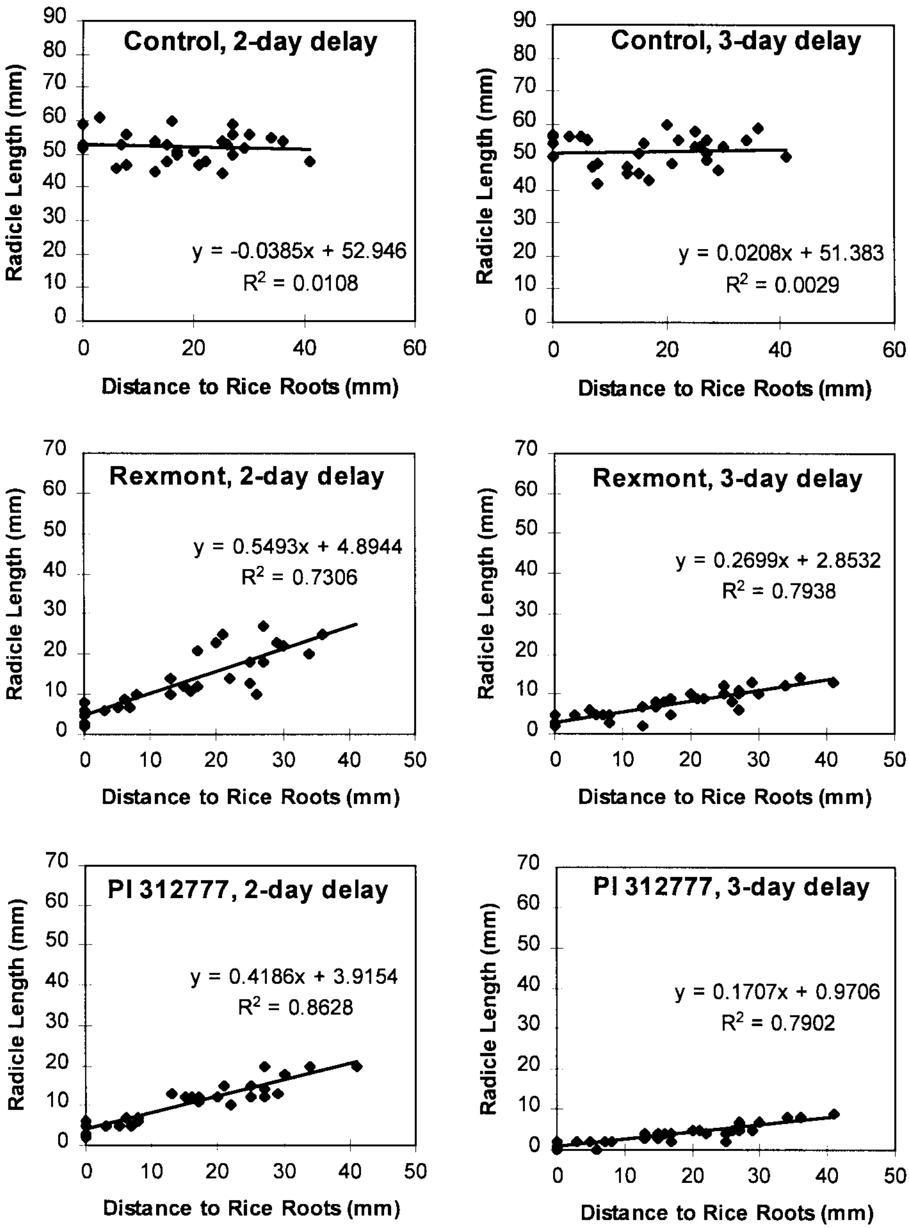


Fig. 3. Effect of delayed lettuce planting on inhibition of lettuce radicles by PI 312777 and Rexmont in modified plant box assays. In the standard plant box method, lettuce seeds are planted the same day that agar is added to the plant boxes.

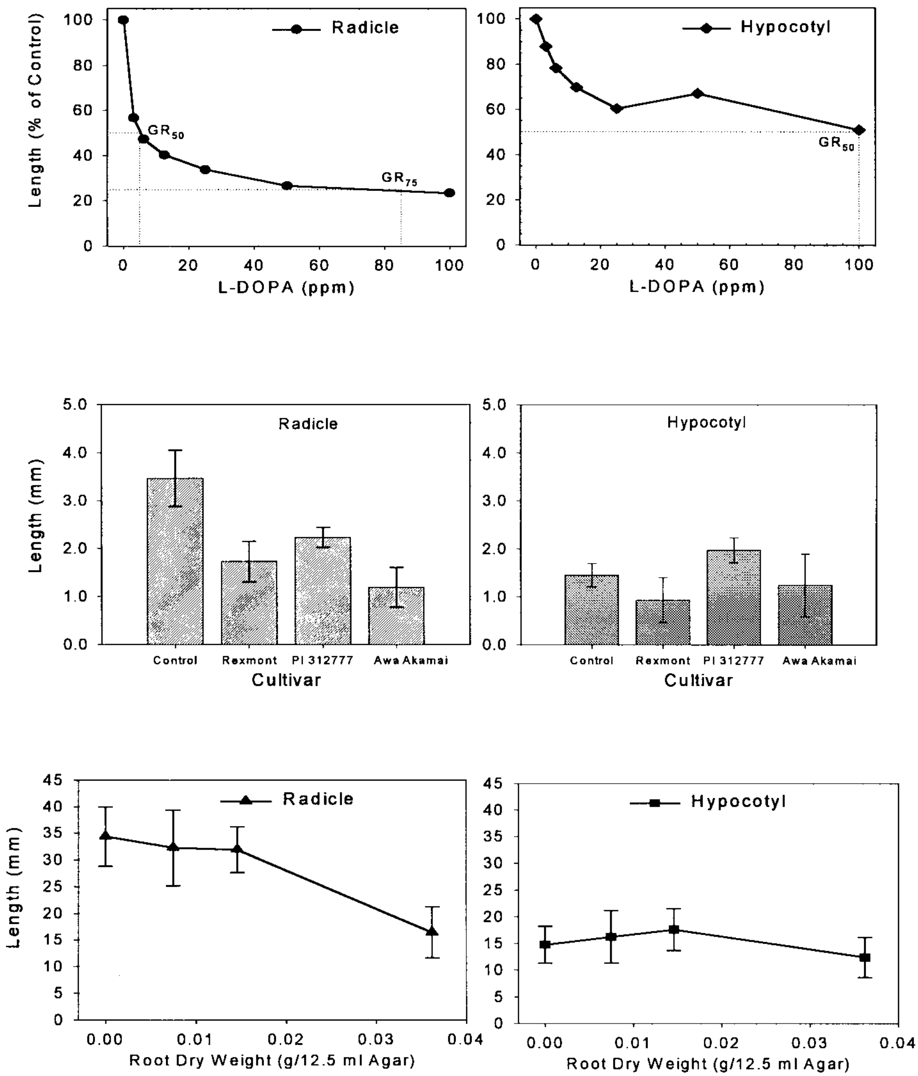


Fig. 4. Effect of (A) L-DOPA (allelochemical standard) concentration, (B) rice cultivars, and (C) rice root mass an growth of the radicle and hypocotyl in lettuce seedlings in reduced-volume agar assays. and Rexmont in modified plant box assays. In the standard plant box method, lettuce seeds are planted the same day that agar is added to the plant boxes.

DIFFERENTIAL RESPONSE OF UNITED STATES *Oryza sativa* (RED RICE) ACCESSIONS TO RACES OF *Pyricularia grisea*

F.N. Lee, D.R. Gealy, and R.H. Dilday

ABSTRACT

On an ongoing basis, we are evaluating various genetic materials in disease nurseries to discover new disease resistance genes for use in developing high-yielding, disease-resistant rice cultivars and to provide data on various production problems commonly encountered in Arkansas. Red rice (*Oryza sativa* L.) is an economically important weed in many rice production areas in the southern United States and, increasingly, throughout the world. It is an especially troublesome weed because it can interbreed at low rates with commercial rice, which is the same species. The current red rice collection consists of approximately 160 entries from Arkansas and other southern rice-producing areas of the United States. Entries of the collection were evaluated for relative susceptibility to races IB-49, IC-17, IE-1K, IG-1, and IH-1 of the rice blast fungus, *Pyricularia grisea*, in greenhouse tests. Four red rice entries tested were resistant to all five races. None of the red rice entries were susceptible to all the blast races. Obvious differences in distribution of major gene blast resistance were evident in that 90, 80, 30, 28, and 14% of the red rice entries were resistant or moderately resistant to races IC-17, IG-1, IE-1K, IH-1, and IB-49, respectively, and suggest either a natural selection for blast tolerance at sites of origin or natural interbreeding with white rice resulting from the close cultural association. Collectively, this and future data may be useful in developing control strategies for red rice, in the eventual identification and transfer of disease resistance genes from red rice into rice, and in acquiring a better understanding about overwintering of the blast fungus and about the natural transfer of genes between wild red and cultivated white rices. Evaluation of red rice resistance to *P. grisea* will be continued to supplement the existing disease data and to determine resistance in the collection to extinct United States blast races or older races which now are recovered only infrequently.

INTRODUCTION

The rice research project Discovery, Identification and Utilization of Resistance Genes for Rice Disease Control in Arkansas, funded in part by the Arkansas Rice Research and Promotion Board, routinely establishes various nurseries as part of the ongoing research activity designed to discover new disease resistance genes and to provide data on various rice production problems commonly encountered in Arkansas. One such problem is red rice, the economically important weed commonly occurring in rice production areas of the southern United States and, increasingly, throughout the world. It is an especially troublesome weed because its growth habits closely mimic those of commercial white rice. Known to be very closely related and classified as being the same species, red rice and white rice can interbreed at low rates.

In the past, disease data from red rice were obtained when seed of individual red rice plants were collected and were included in various disease tests as a matter of general interest about those plants. These infrequent and random evaluations indicated that some of the red rice found in production areas was indeed susceptible to the same diseases as white rice. As a result of a more systematic effort to characterize red rice, approximately 160 entries from Arkansas and other southern rice-producing areas of the United States have been collected and increased and are being evaluated for various agronomic characteristics. These data show the red rice entries vary considerably. For instance, individual entries have shown moderate tolerance to some of the herbicides that will be used with herbicide-resistant rice varieties (Gealy, *et al.*, 1999).

Inoculated field and greenhouse disease tests routinely evaluate resistance to rice sheath blight and rice blast, the two most common and most damaging diseases in U.S. rice production. Because of the inherent lodging tendency of the red rice collection, sheath blight evaluations have been delayed. Data are presented here, however, on the resistance profile of 140 red rice entries to five selected races of the blast fungus, *P. grisea.*

PROCEDURES

Rice blast evaluations were made in standardized greenhouse tests on rice plants ate the three- to four-leaf growth stage that were inoculated with individual *P. grisea* races. Evaluations included known rice test entries and cultivars as standards to confirm isolate purity and estimate test severity. Plants were grown in a DeWitt silt loam soil/sand mixture (3:1) and were under moisture stress, but leaves were not rolled when inoculated with approximately 5 x 105 *P. grisea* spores/mL obtained from petri cultures. Immediately following inoculation, plants were moved into 100%-humidity chambers for 24 hours, then placed onto greenhouse benches for evaluation when lesions on susceptible check cultivars were well formed, usually 7 to 10 days.

Plants were visually rated using the standard 0 to 9 scale to estimate disease reaction. A rating of zero indicates complete disease immunity. A rating of 1 to 3 indicates resistance with limited infection and pathogen growth is severely restricted. Conversely, a 9 rating indicates maximum disease susceptibility with rapid lesion development and little plant response, and typically results in complete plant death when large numbers of infections occur.

RESULTS AND DISCUSSION

Although a number of new molecular techniques are promising, the only currently available method to assay for disease resistance is to grow plants, cause the disease by inoculating with the pathogen under favorable conditions, and evaluate the resulting disease reaction to estimate degree of resistance. The 0 to 9 numerical rating scale is sometimes loosely converted to letter symbols where 0 to 3 = R (resistant), 3 to 4 = MR (moderately resistant), 5 to 6 = MS (moderately susceptible), 7 = S (susceptible), and 8 to 9 = VS (very susceptible). While the lower rice blast disease ratings of R and MR are more desirable; a rating near 5 is usually indicative of acceptable disease resistance when environmental conditions only slightly favor the pathogen. This characterization of disease resistance is not an exact science because results are sometimes variable and the test tends to overwhelm field resistance. However, this approach provides a standardized and reasonably accurate estimation of plant disease susceptibility.

Test isolates of *P. grisea* were selected from our blast race collection according to their perceived relative virulence, and they are believed to represent much of the genetic variability occurring in the current U.S. *P. grisea* population. Races IB-49 and IC-17, although infrequently recovered at the time of release, quickly increased upon the rapid and widespread grower acceptance of the cultivar ‘Newbonnet’. These races, especially IB-49, predominated during the devastating blast epidemics of the 1980s and are now commonly isolated from Arkansas production areas. Race IG-1 now rarely occurs in Arkansas rice fields but was commonly recovered during the period prior to Newbonnet, when the ‘Starbonnet’ cultivar was seeded to a large portion of Arkansas production areas. Race IH-1 was also common in minor cultivars before and during the period Starbonnet was widely grown. Although poorly adapted and seldom found in field collections, race IE-1k represents a potential problem race if substantial acreage in Arkansas is seeded with the cultivars ‘Drew’ and ‘Kaybonnet’.

Approximately four of the red rice entries have excellent resistance to all five blast races tested, and many of the remaining entries are resistant to three or four races (Table 1). The data indicate these and many of the other entries contain major blast resistance genes, many of which may potentially be useful in commercial white rice cultivars. Surprisingly, none of entries are susceptible to all races tested, and only eight of the entries were rated susceptible or very susceptible to both the races IB-49 and IC-17. It is also interesting to note the obvious differences in resistance to individual races in that 90, 80, 30, 28, and 14% of the red rice entries were resistant or moderately resistant to races IC-17, IG-1, IE-1K, IH-1, and IB-49, respectively (Table 2). The very low percentage of entries resistant to race IC-17 is especially bewildering, since this virulent isolate is well established in Arkansas production areas.

Since red rice and commercial white rice are the same species and likely interbreed at low rates in the field, there is an undefined probability that the observed resistance (or susceptibility) genes in red rice originated through the release and use of blast-resistant cultivars. Additional testing of entries using ancient races of the pathogen coupled with DNA analysis and comparison of entries should provide more insight into this intriguing possibility.

The role of red rice in overwintering and/or subsequent dispersion of the blast fungus has not been carefully investigated but must be considered. Knowing the life cycle of the pathogen, we can speculate that blast-infected red rice plants, especially those outside the production field, overwinters the pathogen. Also, susceptible red rice plants would be easily infected to initiate the disease and would serve as an inoculum source within production fields during the growing season. The occasional field observation of blast in red rice lends some support to this theory.

SIGNIFICANCE OF FINDINGS

Arkansas rice growers will benefit greatly over many years as data from this and other ongoing projects in the rice research effort are assessed and assimilated into rice disease control and weed control programs. Research results presented here provide definitive information about the relative blast susceptibility of red rice. However, the data also emphasize unresolved issues concerning the source of blast resistance genes present in red rice, the role of red rice in overwintering and dissemination of the blast pathogen, and more importantly, the role of red rice in the evolution of new *P. grisea* races. Collectively, this information can be useful in developing control strategies for red rice, the identification and transfer of desirable genes from red rice into commercial rice, providing better understanding of the natural transfer of genes between red and commercial white rices, and may result in a better understanding about the overwintering of the blast fungus. The evaluation of red rice for resistance to *P. grisea* will be continued to gather additional disease data and to determine resistance levels to older or extinct blast races from southern rice production areas.

ACKNOWLEDGMENTS

This research was made possible by grower funding through the Rice Research and Promotion Board and funding through the University of Arkansas Agriculture Experiment Station. The talents and significant contributions of Mr. Howard Black and Mrs. Hazel Mullins are also gratefully acknowledged.

LITERATURE CITED

Gealy, D.R., R.H. Dilday, F.L. Baldwin, and H.L. Black. 1999. Imazethapyr (‘Pursuit’) effect on red rice (*Oryza sativa* L.) biotypes. *In:* R.J. Norman and T.H. Johnston (eds.) B.R. Wells Rice Research Studies 1998. Arkansas Agricultural Experiment Station Research Series 468:79-89.

Table 1. Red rice entries arranged according to resistance rating and the relative number of entries resistant to five *Pyricularia grisea* races.

Red Rice Biotype	*Pyricularia grisea* race designation				
	IC-17	IG-1	IH-1	IE-1K	IB-49
	(resistance rating)				
1995-14	R[z]	R	R	R	R
1996-1	R	R	R	R	R
1997-33	R	R	R	R	R
LA3	R	R	MR	R	R
2C	R	R	R	MR	S
20E	R	R	R	MS	MS
1996-6	R	R	R	MS	MS
1995-4	R	R	R	MS	S
1996-5	R	R	R	MS	S
1997-28B	R	R	R	MS	S
2A	R	R	R	MS	S
97RRLib7	R	R	R	MS	S
1997-34	R	R	R	S	R
2B	R	R	R	S	MS
4D	R	R	R	S	MS
1995-5	R	R	R	S	S
20C	R	R	R	S	S
13C	R	R	R	S	S
1997-29	R	R	R	S	S
9A	R	R	R	VS	S
1	R	R	R	VS	S
97RRLib1	R	R	R	VS	S
97RRLib6	R	R	R	VS	S
16B	R	R	MR	S	S
4B	R	R	MR	S	S
16C	R	R	MR	S	S
1995-6	R	R	MR	S	S
1995-7	R	R	MR	S	S
6B	R	R	MR	VS	S
2D	R	R	MS	R	S
17B	R	R	MS	R	S
17D	R	R	MS	R	S
14C	R	R	MS	MS	S
14F	R	R	MS	MS	S
14D	R	R	MS	MS	S
14G	R	R	MS	MS	S
14E	R	R	MS	S	S
4C	R	R	MS	S	S
13F	R	R	MS	S	S

continued

Table 1. Continued.

Red Rice Biotype	*Pyricularia grisea* race designation				
	IC-17	IG-1	IH-1	IE-1K	IB-49
	---------- (resistance rating) ----------				
14B	R	R	MS	S	S
4A	R	R	MS	S	S
11H	R	R	MS	S	S
14A	R	R	MS	S	S
15A	R	R	MS	S	S
15B	R	R	MS	S	S
15C	R	R	MS	S	S
16A	R	R	MS	S	S
1995-3	R	R	MS	S	S
16D	R	R	MS	S	S
17A	R	R	MS	S	S
6A	R	R	MS	VS	S
3C	R	R	MS	VS	S
3D	R	R	MS	VS	S
17C	R	R	S	R	R
1995-1	R	R	S	R	MS
18C	R	R	S	MS	S
1997-20	R	R	S	MS	S
20B	R	R	S	MS	S
3B	R	R	S	S	S
21A	R	R	S	S	S
21B	R	R	S	S	S
1995-2	R	R	S	S	S
11B	R	R	S	S	S
9B	R	R	S	S	S
13G	R	R	S	S	S
3A	R	R	S	S	S
21C	R	R	S	S	S
15D	R	R	S	S	VS
7	R	R	S	VS	S
11D	R	R	VS	R	R
11F	R	R	VS	R	R
13E	R	R	VS	R	R
1997-30	R	R	VS	R	R
1997-46	R	R	VS	R	R
13D	R	R	VS	R	R
11A	R	R	VS	R	MS
12C	R	R	VS	R	MS
13A	R	R	VS	R	MS
199	R	R	VS	R	MS

continued

Table 1. Continued.

Red Rice Biotype	*Pyricularia grisea* race designation				
	IC-17	IG-1	IH-1	IE-1K	IB-49
	---------- (resistance rating) ----------				
1997-40	R	S	S	VS	S
1997-37	R	S	S	VS	VS
1997-35	R	S	S	VS	VS
1997-36	R	S	S	VS	VS
1995-15	R	VS	R	S	S
1996-8	R	VS	R	VS	S
1997-9	R	VS	S	S	S
5A	MS	R	VS	R	S
1997-42	S	R	R	S	MS
11E	S	R	VS	R	R
12A	S	R	VS	R	R
10B	S	R	VS	R	S
1996-3	S	R	VS	R	S
8	S	R	VS	MR	S
1996-11	S	R	VS	MS	S
1997-2	S	R	VS	S	S
1997-6	S	R	VS	S	S
18A	S	R	VS	S	S
1997-41B	VS	R	R	R	R
5B	VS	R	S	R	S
11G	VS	R	VS	R	R

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

Table 2. Rice blast resistance profile observed in 140 red rice biotypes tested for reaction to five races of *Pyricularia grisea*.

	Blast races						
Resistance level	IC-17	IG-1	IE-1K	IH-1	IB-49	Races IC-17 plus IG-1	Races IB-49 plus IC-17
	(% of rice biotypes tested)						
Resistant	90.0	79.3	25.7	23.6	12.9	84.6	51.4
Moderately resistant	0.0	0.7	2.1	6.4	0.7	0.4	0.4
Moderately susceptible	0.7	2.1	11.4	18.6	1.07	1.4	5.7
Susceptible	7.1	15.7	46.4	22.9	70.0	11.4	38.6
Very susceptible	2.1	2.1	14.3	28.6	5.7	2.1	3.9

CHEMICAL ASPECTS OF RICE ALLELOPATHY FOR WEED CONTROL

J.D. Mattice, B.W. Skulman, R.H. Dilday, and K.A.K. Moldenhauer

ABSTRACT

High-performance liquid chromatography (HPLC) chromatograms from methanol extracts of leaf tissue from 10-day-old rice plants (*Oryza sativa*) show that four to six compounds are present either exclusively or in much larger amounts in the extracts from accessions that inhibit growth of barnyardgrass (*Echinochloa crus-galli*) compared to those that do not inhibit growth. An assay has been developed using the HPLC chromatograms to predict whether an accession will inhibit growth of barnyardgrass. A cluster analysis using all the peaks in the chromatograms from 40 different accessions shows that the data are best separated with three clusters. The accessions showing strongest inhibition of barnyardgrass growth are all in the same cluster.

Fractions have been collected from an extract of approximately 3000 PI# 312777 rice plants using prep HPLC. Some fractions appear to contain only one compound. A solid from one of the fractions has been recrystallized.

INTRODUCTION

Some accessions of rice have been shown to inhibit the growth of barnyardgrass and/or ducksalad (*Heterantherea limosa*) (Dilday, *et al.*, 1989, 1991; Navarez and Olofsdotter, 1996; Hasan *et al.*, 1998; and Kim and Shin, 1998). If this trait can be introduced into commercially useful rice, herbicides may be applied at a reduced rate or an application eliminated completely. The net result would be lower production costs and probably less environmental impact.

The observed effect may be due to competition, allelopathy, or a mixture of both. Our goal is to assist the breeders in incorporating this valuable weed control trait into commercially useful rice. We have two objectives that will help us to meet this goal. (1) Develop an assay that can be used to evaluate rice varieties, crosses between varieties, and individual plants for weed control potential. The assay should be applicable to young rice plants and be nondestructive to the plant so that individual plants showing promise of having high weed control activity could be grown to maturity and seed collected. (2) Determine whether the effect is due to allelopathy or competition. If it is allelopathy, identify compounds that are responsible so researchers can better understand how the rice plants are inhibiting the growth of certain weeds.

PROCEDURES

Extraction

There were three replications of 40 accessions. For each replication, all of the leaves were removed from 10 plants that were 7 to 10 days old. The leaves were cut into approximately 1-cm lengths and combined with methanol at a ratio of 10 mg fresh tissue/ml of methanol. The samples were refrigerated overnight, and in the morning 750 µl of extract was combined with 750 µl of deionized water and 47.8 µl of 157 mg simazine/L methanol as an internal standard.

Chromatography

The HPLC conditions were as follows:

Column: Prodigy 25 cm x 4.6 mm C18
Mobile Phase: A—1% acetic acid in deionized water, B—acetonitrile
Program: 10% B for 3 min, increase to 50% B over 27 min and then immediately increase to 80% B over 0.1 min, hold for 1.9 min, decrease to 10% B over 0.1 min and hold for 7.9 min
Injection: 30 µl *Detection:* 320 nm, change to 270 at 20 min
Flow: 1.5 ml/min

Bioassays

Bioassays were performed in groups of 12 to 15 accessions/group. There were 10 replications/accession. In each group, 'Rexmont' was included twice, and either 'Gui Chao' or PI# 312777 was included. Rexmont is the commercial variety that does not inhibit barnyardgrass growth, and Gui Chao and PI# 312777 show strong inhibition of growth.

Greenhouse bioassays were performed by placing 120 ± 1 g of 2 mm mesh-sieved DeWitt silt loam soil in 16-oz plastic cups. Approximately 23 rice seeds were placed around the edge of the cup, and 30 ± 1 g of soil was added. The samples were watered as needed. Barnyardgrass seed was stirred with 1 N nitric acid for 1 hour and then washed with deionized water. The seeds were pregerminated in petri dishes between disks of paper towels. On the fourth day after seeding the rice, any barnyardgrass that was present was removed. A small amount of soil was removed from the center of the cups, and six pregerminated barnyardgrass seeds were grown. Each day the samples were inspected, watered as needed, and thinned to 15 rice plants and 4 barnyardgrass plants.

The number of rice plants and the height of the barnyardgrass plants were measured 11 and 15 days after seeding the rice. Heights of barnyardgrass grown with each accession were recorded as a percent of the height of barnyardgrass growing with Rexmont. Cluster analysis was done using the procedure of Hand (1981).

Isolation of Chemicals

The above-ground portion of approximately 3000 PI# 312777 rice plants (310 g fresh weight) that were 1 month old were extracted overnight with 4.2 L of methanol. The methanol was removed with a rotary evaporator, leaving 108 ml of mostly water and residue. Methanol (250 ml) was added and the mixture was extracted with approximately twenty 50-ml portions of hexane, leaving a gold-colored solution. The methanol was removed, 200 ml water was added, and the mixture was extracted with approximately nine 50-ml portions of ethyl acetate. The remaining aqueous solution was concentrated to approximately 10 ml on a rotary evaporator.

In parallel experiments, fractions were being collected using conventional bench top chromatography with either silica or C18 packing. Isolates from the initial fractions were further isolated using preparative scale HPLC.

In both of the above cases, the mixture was filtered through a 0.22-µ acrodisc, and 200 µL were repetitively injected on a Prodigy 25 cm x 10 mm C18 prep scale column as follows:

Mobile Phase: A—1 % acetic acid, B—acetonitrile

Program: 11% B at 3 ml/min for 0 min. Increase to 7 ml/min over 10 min and hold for 25 min. Increase to 80 % B over 0.1 min and hold for 2.9 min. Decrease to 11% B over 0.1 min and hold for 3.8 min. Decrease to 3 ml/min over 0.1 min.

Fractions were collected with an automatic fraction collector every minute beginning at 4 min.

Solid material from one of the isolated fractions was collected and recrystallized. After further tests for purity, samples will be taken for 13C NMR and mass spectroscopy.

RESULTS

Cluster analysis using all the chromatographic data shows that the samples fall into three clusters, with one cluster further separated from the other two (Figure 1).

Greenhouse bioassay data is available for 28 of the rice accessions. Table 1 shows the accessions and the clusters to which they belong. Also shown is the height of the barnyardgrass that was grown, with that accession as a percentage of the height of barnyardgrass that was grown with Rexmont. Within each group of accessions on which the bioassay was performed, the difference in barnyardgrass height that was required to be significantly different varied, but was typically between 10 and 15%. As an example, barnyardgrass that was grown with 'L204' was 86% as tall as barnyardgrass grown with Rexmont. In some experiments, that might have been significantly different and in others it might not have been. Nine of the accessions fall into the well-separated cluster number 3. Eight of these accessions also show the most control of barnyardgrass in the bioassays. The ninth accession (PI# 338046) has given irreproducible results in bioassays. At times it shows intermediate control as in Table 1, and at other times it shows strong control. There are no accessions that consistently show no control that are in cluster 3. Therefore, if an unknown sample is analyzed and it falls in cluster number 3, there is a very good probability that it will show relatively strong inhibition of barnyardgrass growth.

Isolation of Chemicals

Analysis of the isolated fractions from the prep column using the analytical column showed that some of the fractions appeared to have only one compound. One compound has been isolated and recrystallized. Further testing will be necessary to ensure that they are pure enough for mass spectral and 13C NMR analysis.

DISCUSSION

HPLC Assay

We were able to successfully use the assay to identify eight of nine accessions that inhibit barnyardgrass growth. We are in the process of testing to see whether the assay will work to predict activity against barnyardgrass from crosses between accessions. Each individual plant from a cross between the two accessions may or may not contain the weed control property, and the ones that do contain it may do so in varying degrees. In order to perform a bioassay, the seed supply from each F2 plant must be multiplied by growing the plant to maturity, collecting and planting the seed, and repeating the process. This would require up to two growing seasons in the field to multiply all the seed from progeny from the initial cross. It would be 2 years before we would know which of the progeny from the original cross had weed control potential. The assay we have developed should allow us to evaluate each original progeny when it is approximately 10 days old and keep only those showing promise. We would know the weed control potential of each of the initial progeny within a month, as opposed to waiting 2 years, and it would require much less space and other resources.

We have obtained HPLC results from 288 progeny from a cross between PI# 312777 and Rexmont and have processed the results from 140 of them. We can make predictions as to which would show weed control. We are now in the process of multiplying the seed so that we can test our predictions with bioassays.

Isolation of Chemicals

Once the chemicals are isolated and identified we can work on testing them for activity against barnyardgrass. If they are shown to be allelochemicals, knowing what they are will make it possible to determine how they work. Knowing how they work will make it possible to determine whether their effect can be enhanced.

ACKNOWLEDGMENTS

We acknowledge the Arkansas Rice Research and Promotion Board, USDA, and IRRI for funding this project.

LITERATURE CITED

Dilday, R.H., P. Nastasi, and R.J. Smith, Jr. 1989. Allelopathic observation in rice (*Oryza sativa* L.) to ducksalad (*Heteranthera limosa*). Proceedings of the Arkansas Academy of Science. 43:21-22.

Dilday, R.H., P. Nastasi, J. Lin, and R.J. Smith, Jr. 1991. Allelopathic activity in rice (*Oryza sativa* L.) against ducksalad [*Heteranthera limosa* (Sw) Willd.]. *In:* J.N. Hanson, M.J. Shaffer, D.A. Ball, and C.V. Cole, (eds.). Proceedings of Sustainable Agriculture for the Great Plains. Beltsville, MD: Department of Agriculture, Agricultural Research Services. pp. 193-201.

Hand, D.J. 1981. Discrimination and classification. New York: John Wiley & Sons. p. 174.

Hasan, S.M., I.R. Aidy, A.O. Bastawisi, and A.E. Draz. 1998. Weed management using allelopathic rice varieties in Egypt. *In:* M. Olofsdotter (ed.). Allelopathy in rice. Proceedings of the Workshop on Allelopathy in Rice, 25-27 Nov 1996. Manila, Philippines: International Rice Research Institute. pp. 27-38.

Kim, K.U., and D.H. Shin. 1998. Rice allelopathy research in Korea. *In:* M. Olofsdotter (ed.). Allelopathy in rice. Proceedings of the Workshop on Allelopathy in Rice, 25-27 Nov 1996. Manila, Philippines: International Rice Research Institute. pp. 39-44.

Navarez, D.C., and M. Olofsdotter. 1996. Relay seeding technique for screening allelopathic rice (*Oryza sativa*). Second International Weed Control Congress, Copenhagen. pp. 1285-1290.

Table 1. Height of barnyardgrass grown with rice accessions as a percent of the height of barnyardgrass grown with Rexmont and the cluster to which the rice accession belongs.

Cultivar / Variety	%	Cluster	Cultivar / Variety	%	Cluster
Millie	124	2	Drew	91	1
Lagrue	121	2	Orion	90	2
Lemont	111	1	Bengal	88	nd[z]
Katy	110	1	L204	86	2
STG94L-42-130	106	1	Lacassine	80	2
Cypress	103	1	Wells	79	1
Jackson	101	1	TN-1	78	3
Rexmont	100	1	Jasmine	77	3
Newbonnet	100	2	PI 373026	73	3
Dixiebelle	100	1	PI 312777	71	3
Delrose	95	1	PI 350468	65	3
Mars	93	1	Teqing	65	3
PI 338046	92	3	Gui Chao	63	3
Kaybonnet	92	2	ZHE733	63	3

[z] nd = not determined.

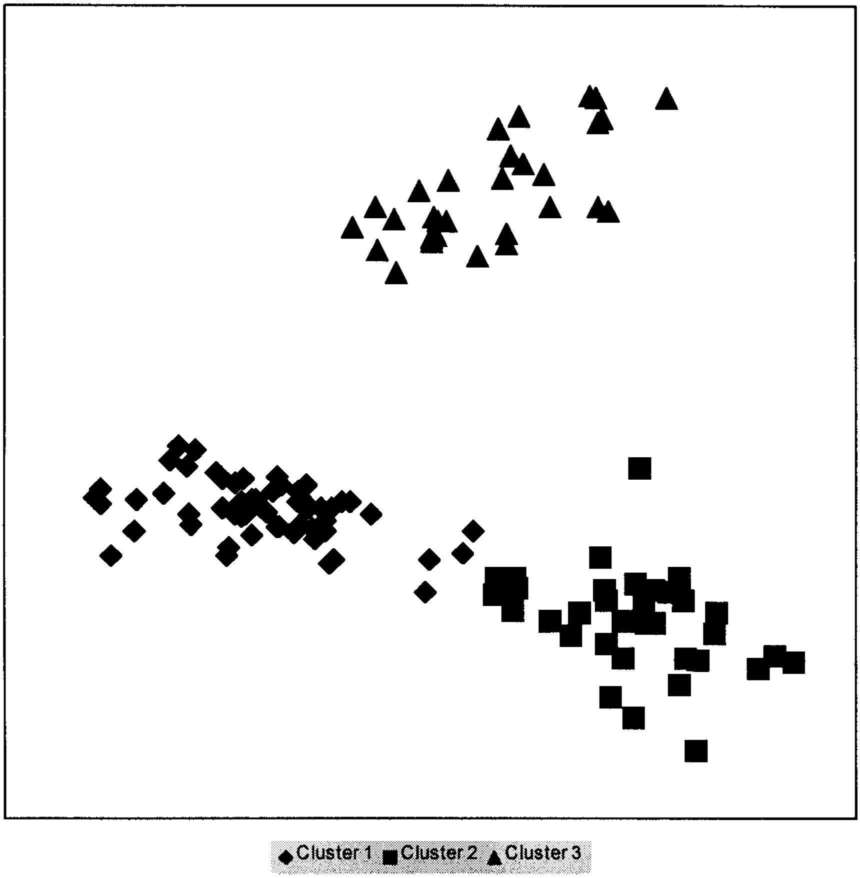


Fig. 1. Two-dimensional representation showing three clusters with each point determined from 20 peaks from the HPLC chromatogram for that replication, 40 accessions with 3 replications per accession.

ENVIRONMENTAL IMPLICATIONS OF PESTICIDES IN RICE PRODUCTION

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

ABSTRACT

Water samples have been collected from six sites in the rice-growing region in Arkansas in 1997, 1998, and 1999. Concentrations of pesticides greater than 2 parts per billion (ppb) were found in 1.8% of the possible cases where they could be found. Molinate was the most frequently found pesticide in 8.4% of the samples and was also found in the highest concentration at 22.5 ppb in 1997. Molinate was not found in any consecutive samples from the same site in 1997 but was found in two consecutive samples in Lee County in 1998 and three consecutive times at the same site in 1999. A total 73% of the detections came from the two sampling sites that were the smallest rivers.

INTRODUCTION

Some rice pesticides have been found to persist in surface waters in California. The objective of this project is to determine whether there is a persistence problem with rice pesticides in Arkansas waters. Monitoring for pesticides in water may allow us to detect a potential problem and address it before it becomes a major problem.

PROCEDURES

Sampling Sites

Six separate locations were monitored for rice pesticides in Arkansas during 1997, 1998, and 1999. The collection sites are given in Table 1. Two Mississippi River sites were monitored to assess water quality as it entered and left the major rice-growing region of the state. Each site was selected as a point through which major watersheds flow from rice production areas.

Sampling Procedure

Sampling was performed at approximately 2-wk intervals during the rice production season. A duplicate sample was taken at each collection site and fortified with a mixture of the pesticides. The samples were transported to the lab on ice and extracted using Empore C18 disks. Analysis was done using both high-performance liquid chromatography (HPLC) and gas chromatography mass spectrometry (GCMS). Pesticides selected for monitoring were Benlate (benomyl), Bolero (thiobencarb), Facet (quinclorac), Furadan (carbofuran), Grandstand (triclopyr), Londax (bensulfuron methyl), malathion, methyl parathion, Ordram (molinate), Prowl (pendimethalin), Rovral (iprodione), Sevin (carbaryl), Stam (propanil), Tilt (propiconazole), Whip (fenoxaprop-ethyl), 2,4-D, and MCPA. Command (clomazone), Karate (lambda-cyhalothrin), and azoxystrobin were added in 1999.

Analysis Procedure

A 250-ml aliquot of each sample was extracted in the laboratory using conventional C18 disk technology. Samples were then analyzed by GCMS and HPLC.

RESULTS AND DISCUSSION

Most of the 1999 samples have been analyzed. Some of the analytical techniques have changed since the beginning of the study. In order to make comparisons from year to year, the original limits of detection of 2 ppb are used, although for some compounds we can detect lower levels. Since these are river water samples, not drinking water, the 2-ppb level would be reasonable for making comparisons. Results for each sample that contained at least one detection of a pesticide in 1997, 1998, and 1999 are given in Tables 2 and 3.

There have been 33 detections out of 1876 possible detections if every compound had been detected in every sample, which equates to 1.8% detections. The most frequently detected compound was molinate, which was detected in 8.4% of the samples. Molinate was also detected in the highest concentration (22.5 ppb on 15 July 1997 at site D, Table 2).

There were 9 detections greater than 2 ppb in 1997, 8 in 1998, and 16 in 1999. One of the 16 was clomazone, which was a new compound for 1999.

The two most frequently detected compounds were molinate and quinclorac as shown in Table 4. There appears to be no change in the frequency of molinate detections, although the frequency of quinclorac detections may be increasing. The *concentrations* of quinclorac have not been increasing. The highest concentration was 9.2 ppb in 1997 and has been between 2.0 and 5.3 ppb when detected in 1998 and 1999 (Table 2).

Table 3 shows that 20 samples contained only one compound, 5 samples contained two compounds, and 1 sample contained three compounds. Table 3 also shows that the two sites that produced the most detections were in Lee county at sites D and E.

The frequency of detections for each site by year are given in Table 5. Sites A,B,C, and F are all large rivers, which would draw water from watersheds outside the rice-growing agricultural region and would also tend to dilute any compound that was present. The two smaller rivers with sampling sites, D and E, would probably be more sensitive barometers of changes occurring in the rice-growing region. Over the 3-year period, 73% of the detections have occurred at these two sampling sites. These two rivers are both in Lee County and show differing results over time. The number of detections on the D'Anguille River has remained constant over the last 3 years, but there was an increase in the detections on the St. Francis River in 1999 compared to the preceding 2 years. Four of the five detections in 1997 and 1998 were of molinate. In 1999, three of eight detections were of molinate and three were of quinclorac.

The frequency of detections for three concentration ranges by year are given in Table 6. There has been an increase in the low-level detections over the 3 years, no difference in the middle-level detections, and an increase in the high-level detections. This could be explained either by increasing amounts of compounds entering the water or by low levels of water in some of the rivers. This would have the consequence of concentrating the compounds and cause their concentration to increase from one range into the next or higher concentration ranges. This could account for the increased detections in the >10 ppb range.

Detection of the same compound at the same site on consecutive sampling intervals could indicate that the compound is continually being introduced into the water as opposed to a limited, intermittent introduction. There have been three instances, each at site E, where the same compound was detected in consecutive sampling periods at the same site. Molinate was found at site E at 2.4 ppb on 30 June 1998 and again at 8.0 ppb on 14 July 1998. It was also found in three consecutive samplings on 15 June 1999 (5.8 ppb), on 29 June 1999 (12.7 ppb), and again on 13 July 1999 (15.7 ppb). Site E also had quinclorac at 2.3 ppb on 13 July 1999 and at 2.1 ppb on 26 July 1999.

SIGNIFICANCE OF FINDINGS

It is not surprising to find some pesticides in surface water in an agricultural area during the growing season. With few exceptions, the detections have been of low level and sporadic.

There were increases in the number of detections in general and the number of detections of quinclorac in 1999, but at this point it is not clear whether that is due to increased pesticide usage, increasing amounts moving off the land, or simply a concentration effect due to a dry year lowering water levels, especially in the smaller rivers. Results in future years should answer this question.

Most of the detections occur in the two smallest rivers, the D'Anguille and St. Francis. Both of these rivers have their watersheds essentially all in the rice-growing region. This, plus the fact that they simply contain less water to dilute any pesticides present, may make them the best indicators of changes in concentrations or frequency of detections as a result of pesticide usage and management practices.

ACKNOWLEDGMENTS

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

Table 1. Sample collection sites.

Code	River	County	Nearby town
A	Mississippi	Chicot	Lake Village
B	Arkansas	Desha/Arkansas	Backgate
C	White	Arkansas/Monroe	Saint Charles
D	L'Anguille	Lee	Marianna
E	Saint Francis	Lee	Cody
F	Mississippi	Mississippi	Blytheville

Table 2. Results for samples that contained at least one detection of a pesticide. Limit of quantitation of 2 ppb.

		Pesticides[z]							
Date	Site	carbar	molin	propic	fenox	quinc	carbo	propa	clom
6/3/97	A	-	-	7.1	-	-	-	-	-
	D	2.2	5.5	-	-	9.2	-	-	-
	E	4.2	2.2	-	-	-	-	-	-
	F	16.7	-	-	-	-	-	-	-
7/15/97	D	-	22.5	-	-	-	-	-	-
	E	-	9.9	-	-	-	-	-	-
6/2/98	A	-	-	-	-	2.0	-	-	-
	D	-	2.3	-	-	5.3	-	-	-
	F	-	6.8	-	-	-	-	-	-
6/30/98	E	-	2.4	-	-	-	-	-	-
7/14/98	E	-	8.0	-	-	-	-	-	-
8/3/98	D	-	2.8	-	-	-	-	-	-
8/25/98	D	-	-	-	-	3.4	-	-	-
5/11/99	B	-	-	-	5.9	-	-	-	-
	E	-	-	10.1	-	-	-	-	-
6/1/99	C	-	-	-	-	-	-	-	2.6
	E	-	-	-	-	-	-	5.8	-
6/15/99	B	-	-	-	-	-	-	2.5	-
	D	-	-	-	-	3.7	4.2	-	-
	E	-	5.8	-	-	3.8	-	-	-
6/29/99	E	-	12.7	-	-	-	-	-	-
7/13/99	D	-	9.5	-	-	-	-	-	-
	E	-	15.7	-	-	2.3	-	-	-
	F	22.2	-	-	-	-	-	-	-
7/26/99	E	-	-	-	-	2.1	-	-	-
9/8/99	F	-	-	-	-	-	-	13.9	-

[z] carbar (carbaryl), carbo (carbofuran), molin (molinate), propic (propiconizole), fenox (fenoxaprop-ethyl), quinc (quinclorac), propa (propanil), and clom (clomazone).

Table 3. Detections of pesticides as a function of date and sampling site.

	Sampling site					
Date	A	B	C	D	E	F
6/3/97	propic[z]			carbar molin quinc	carbar molin	carbar
7/15/97				molin	molin	
6/2/98	quinc			molin quinc		molin
6/30/98					molin	
7/14/98					molin	
8/3/98				molin		
8/25/98				quinc		
5/11/99		fenox			propic	
6/1/99			clom		propa	
6/15/99		propa		quinc carbo	quinc molin	
6/29/99					molin	
7/13/99				molin	molin quinc	carba
7/26/99					quinc	
9/8/99						propa

[z] carbar (carbaryl), carbo (carbofuran), molin (molinate), propic (propiconazole), fenox (fenoxaprop-ethyl), quinc (quinclorac), propa (propanil), and clom (clomazone).

Table 4. Distribution by year of the two most frequently detected compounds.

	Pesticide	
Year	Molinate	Quinclorac
	------------ (no. of detections) ------------	
1997	4	1
1998	5	3
1999	4	4

Table 5. Frequency of detections at each site by year.

	Site					
Year	Site A	Site B	Site C	Site D	Site E	Site F
	(no. of detections)					
1997	1	0	0	4	3	1
1998	1	0	0	4	2	1
1999	0	2	1	3	8	2
Total	2	2	1	11	13	4

Table 6. Frequency of detections by year for three concentration ranges.

	Concentration ranges		
Year	2 to 5 ppb	5 to 10 ppb	> 10 ppb
	(no. of detections)		
1997	3	4	2
1998	5	3	0
1999	7	4	5

CLOMAZONE FOR CONTROL OF PROPANIL-RESISTANT AND -SUSCEPTIBLE BARNYARDGRASS IN RICE

E.F. Scherder, R.E. Talbert, L.A. Schmidt, and M.L. Lovelace

ABSTRACT

Clomazone has been used in a number of agricultural crops for its excellent grass activity as well as for control of certain broadleaf weeds. A crisis exemption permit was granted in 1999 for use in rice without federal label approval. Researchers in Arkansas continue to evaluate clomazone activity in rice. In studies in 1999, clomazone at 0.3 to 0.5 lb ai/acre provided >90% control of barnyardgrass and broadleaf signalgrass at a preplant incorporated (PPI), preemergence (PRE), or delayed preemergence (DPRE) application timing while maintaining acceptable crop tolerance. Clomazone was effective in a herbicide program by providing grass control when tank-mixed or followed with a broadleaf herbicide to maintain a weed-free environment all season long. Growers may fail to control weeds on levees if ample moisture creates a conducive environment for weed growth. Clomazone will need to be utilized as part of a multi-faceted herbicide program to minimize weed escapes on the levee. With many previous herbicides in rice, such as triclopyr and fenoxaprop, crop tolerance has been an important concern of growers. Cultivars appear to have similar tolerance levels to clomazone, with other factors such as rate, soil type, and environmental conditions having more impact on injury.

INTRODUCTION

Rice production has relied heavily on the use herbicides, cultural practices, and flood management to maintain control of a wide spectrum of weeds common to rice (Street *et al.*, 1994). Weed spectrum, tillage, and overall water management are some factors that must be considered when choosing a herbicide program for rice production. Smith (1988) states that many environmental and edaphic conditions that are favorable for rice production also favor weeds common to rice. This is why such weeds as barnyardgrass, broadleaf signalgrass, ducksalad, ammania, nutsedge, and sprangletop species are ranked in the top 10 worst weeds in Arkansas rice (Baldwin, 1997).

Propanil has been widely used in rice since the early 1960s because it can effectively control a wide spectrum of weeds. Propanil is also considered an environmentally friendly herbicide with a short half-life in the soil. Because of the widespread use of this herbicide, propanil-resistant barnyardgrass was documented in 1990 in Poinsett County (Carey *et al.*, 1992). Currently, the University of Arkansas has 180 documented cases of propanil-resistant barnyardgrass in over 20 counties.

There are herbicides currently on the market to combat the problem of propanil-resistance barnyardgrass. Pendimethalin, thiobencarb, and quinclorac are the main soil-applied herbicides used for control of grasses in rice. However, they may fail to give season-long weed control if flood management is not maintained properly or rain does not fall early in the growing season (Street and Mueller, 1993). These three herbicides have also proven to be less effective on sprangletop species, which may evolve into a late-season problem requiring a salvage treatment (Baldwin and Boyd, 1999). Other postemergent herbicides like fenoxaprop have injured rice and may cause yield loss, depending on environmental conditions at application (Snipes and Street, 1987). For the reasons above, an alternative herbicide needs to be found for consistent control of barnyardgrass under varying conditions.

The following studies had multiple objectives: (1) evaluation of clomazone at various application timings, rates, and under variable moisture conditions for weed control efficacy; (2) evaluation of crop tolerance of several widely grown cultivars to applications of clomazone; and (3) determination of optimal use of clomazone in a herbicide program for effective weed control on levees and in the field.

PROCEDURES

General Methods

The procedures outlined here will be used throughout the following studies unless otherwise specified. All studies were conducted at the Rice Research and Extension Center at Stuttgart on a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) with 1% organic matter and pH of 5.3. The rice cultivar ‘Drew’ was planted on 12 May 1999 and was used in all trials except that of cultivar tolerance, which had multiple cultivars. Rice was seeded in plots nine rows wide (7-in. spacing) and 16 ft in length. Propanil-resistant and -susceptible barnyardgrass, northern jointvetch, hemp sesbania, and palmleaf morningglory seed were sown in singular rows perpendicular to the rows of rice, with evaluations made on the natural population of weeds (if present) and seeded weeds. Visual ratings of chlorosis, biomass reduction, injury, and weed control were taken at 7, 14, 21, 28, 42, and 56 days after emergence (DAE). Yield was taken on the four center rows and adjusted to 12% moisture. All data were subjected to anaylsis of variance with means separated at the 0.05 level using Fisher's Protected Least Significant Difference.

Clomazone Evaluation of Application Timings, Rates, and Moisture Regimes

Clomazone (Command 3 ME) was evaluated in two separate but adjacent experiments to observe the effects of application rate, timing, and water management on barnyardgrass control. Clomazone was evaluated at 0.2 and 0.4 lb ai/acre PPI, PRE, and DPRE. Comparison treatments were quinclorac (Facet) 0.375 lb ai/acre, pendimethalin (Prowl) 1.0 lb ai/acre, and thiobencarb (Bolero) at 4.0 lb ai/acre. Flushing was delayed in one experiment to evaluate the effects of water management on the efficacy of barnyardgrass control. Visual ratings were taken on percentage of control of propanil-resistant and -susceptible barnyardgrass, and rice tolerance. Data from the two experiments were combined and analyzed as a split plot with main plot factor as water management (flush and delayed flush) and the subplot factor as individual herbicide treatments.

Herbicide Programs Using Clomazone for Broad-Spectrum Weed Control

Clomazone was evaluated at 0.2 and 0.5 lb/acre PRE and DPRE for its activity on barnyardgrass and broadleaf signalgrass. Herbicides tank-mixed with clomazone included quinclorac, thiobencarb, and pendimethalin. Sequential programs included clomazone followed by (*fb*) carfentrazone, propanil, bensulfuron, and propanil + molinate with a standard comparison treatment of quinclorac *fb* propanil. Visual ratings were taken on percent control of barnyardgrass, broadleaf signalgrass, palmleaf and pitted morningglory, hemp sesbania, northern jointvetch, and rice tolerance. The experimental design was a randomized complete block.

Weed Management on Levees Following Use of Clomazone at Seeding

Clomazone was applied at 0.4 lb/acre at PRE prior to levee formation. Levees were formed using a levee plow, and rice was sown between the second and third pass at 150 lb/acre. Propanil-resistant and -susceptible barnyardgrass were sown in rows on the crest of the levees to ensure a weed population. Clomazone was then applied at 0.2 lb/acre after levees were formed for those programs requiring a second application. Therefore the total clomazone rate per area of land is 0.6 lb/acre (the maximum use rate by the proposed label). Sequential programs included propanil, fenoxaprop + safener, quinclorac, and bispyribac-sodium. Visual ratings were taken on barnyardgrass control as well as crop tolerance. The experimental design was a randomized complete block.

Aquatic Control with Clomazone

Aquatics can be a problem in rice production because of interference with proper water management in the field. Clomazone was evaluated in the absence of rice in this experiment to encourage a population of aquatics. Clomazone at 0.3 and 0.5 lb/acre PRE and imazethapyr at 0.63 lb ai/acre PPI and early post (EPOST) were evaluated for their control of ducksalad. Flooding of this experiment coincided with other trials established at the same time. Ratings were taken mid-season for ducksalad control. The experimental design was a randomized complete block.

Cultivar Tolerance with Clomazone

Rice cultivars vary in their tolerance to such herbicides as triclopyr and fenoxaprop (Pantone and Baker, 1992; Griffin and Baker, 1990). This study evaluated the tolerance of 18 rice cultivars to clomazone at 0.3 and 0.6 lb/acre DPRE. Visual ratings were taken on chlorosis, biomass reduction, overall crop injury, time to 50% heading, percent lodging, and yield. The experimental design was a split plot with cultivar as the main plot factor with subplots of an untreated check (kept clean with propanil) and the two rates of clomazone. Plot dimensions were 5 x 15 ft for main plots and 5 x 5 ft for subplot factors.

RESULTS AND DISCUSSION

Clomazone Evaluation of Application Timings, Rates, and Moisture Regimes

Water management did have a significant effect on clomazone at 0.2 lb/acre (Table 1). Little difference was seen with clomazone at 0.4 lb/acre; this may be attributed to early-season rainfall prior to flooding, which overshadowed the effects of delayed flushing. Clomazone applied at 0.2 lb/acre showed a trend toward less control of both propanil-resistant and -susceptible barnyardgrass as compared to the 0.4 lb/acre rate. This level of control was comparable to the standards of pendimethalin and thiobencarb. Overall, clomazone at 0.4 lb/acre provided the highest numerical control of both biotypes DPRE, with 99 and 96% control of propanil-resistant and -susceptible barnyardgrass, respectively. Yields did not differ among herbicide treatments.

Herbicide Programs Involving Clomazone for Broad-Spectrum Weed Control

Clomazone at 0.2 and 0.5 lb/acre gave >83% control of propanil-resistant and -susceptible barnyardgrass prior to sequential applications of postemergence herbicides. At 56 DAE, barnyardgrass control was >95% for all treatments (Table 2).

Control of palmleaf and pitted morningglory was limited to programs involving quinclorac, bensulfuron, and carfentrazone. Hemp sesbania and northern jointvetch control was also dependent on the herbicide program used. Programs utilizing quinclorac at 0.38 lb/acre, carfentrazone, and propanil provided >85% control.

Yield differences were seen among programs. Those programs that contained quinclorac, propanil, and carfentrazone gave higher yields. This research supports the use of clomazone in a program approach for overall effective weed control.

Weed Management on Levees Following Use of Clomazone at Seeding

When clomazone was applied at 0.4 lb/acre prior to levee formation, with no additional herbicide or sequential program, grass control was not maintained throughout the growing season (Table 3). A second application of clomazone at 0.2 lb/acre or another postemergence grass herbicide consisting of quinclorac or bispyribac-sodium was needed to control propanil-resistant and -susceptible barnyardgrass.

Yields were very low with all treatments. This is partially due to a poor stand of rice throughout the trial and does not reflect poor weed control.

Control of Aquatic Weeds With Clomazone

Clomazone had little effect on ducksalad (Table 4). Programs of imazethapyr and bensulfuron gave adequate control of this aquatic weed; however, residual activity of these two herbicides did not give season-long control. At 90 DAE, only imazethapyr had any activity on this weed species with 40 to 50% control .

Cultivar Tolerance With Clomazone

On the 18 cultivars evaluated, the highest amount of visual chlorosis observed (38%) was with clomazone at 0.6 lb/acre 7 DAE (Table 5). All cultivars were tolerant to clomazone at 0.3 lb/acre, with chlorosis <13% at 7 DAE. Chlorosis ratings were <6% for all varieties by 28 DAE regardless of rate. Minor differences were observed visually between the cultivars, with all cultivars evaluated showing acceptable levels of tolerance.

Time to 50% heading was recorded to evaluate the potential delaying of maturity. Differences in the time to 50% heading were seen among cultivars. This would be expected as a result of the differing maturity dates of the cultivars evaluated. When clomazone rates were compared to the untreated check within a cultivar, no delay in maturity was observed.

There were no significant differences within a cultivar for an effect on yield that could be attributed to the application of clomazone.

SIGNIFICANCE OF FINDINGS

Clomazone can provide excellent control of grass species as a stand-alone herbicide. When broadleaf weeds are present, clomazone can be tank-mixed or followed by a broadleaf herbicide to provide an effective weed control program. Cultivar tolerance differences with clomazone do not appear to be a factor that needs to be considered. From the cooperative effort of universities and industry, a label for the use of this herbicide should be approved in the future.

ACKNOWLEDGMENTS

These studies were supported in part by rice grower checkoff funds through the Arkansas Rice Research and Promotion Board. We gratefully acknowledge the men and women at the Rice Research and Extension Center for their help and guidance in these studies.

LITERATURE CITED

Baldwin, F.L. 1997. Weed Survey—Southern States: Grass crops subsection. Proc. South. Weed Sci. Soc. 50:237.

Baldwin, F.L., and J.W. Boyd. 1999. Recommended chemicals for weed and brush control. Arkansas Cooperative Ext. Ser. MP-44. Little Rock, Arkansas.

Carey, V.F. III., R.E. Talbert, A.M. Baltazar, and R.J. Smith, Jr. 1992. propanil-tolerant barnyardgrass in Arkansas. Proc. South. Weed Sci. Sco 45:296.

Griffin, J.L., and J.B. Baker. 1990. Tolerance of rice (*Oryza sativa*) cultivars to fenoxaprop, sethoxydim, and haloxyfop. Weed Sci. 38:528-531.

Pantone, D.J., and J.B. Baker. 1992. Varietal tolerance of rice (*Oryza sativa*) to bromoxynil and triclopyr at different growth stages. Weed Technol. 6:968-974.

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

Snipes, C.E., and J.E. Street. 1987. Rice (*Oryza sativa*) tolerance to fenoxaprop. Weed Sci. 35:401-406.

Street, J.E., R.L. Allen, and H. Teresiak. 1994. Rice weed control with quinclorac. Mississippi Agricultural and Forestry Experiment Station, 1008. Mississippi State University, Agricultural and Forestry Experiment Station.

Street, J.E., and T.C. Mueller. 1993. Rice (*Oryza sativa*) weed control with soil applications of quinclorac. Weed. Technol. 7:600-604.

Table 1. Barnyardgrass control 56 DAE[z] and rice yield influenced by rate, application timing, and water management, Stuttgart, 1999.

Herbicide Treatments	Rate	Application Timing[y]	Propanil-Resistant		Propanil -Susceptible		Rice Yield	
			Flush	Delay	Flush	Delay	Flush	Delay
	(lb ai/acre)		(% barnyadgrass control)				(lb/acre)	
Untreated check			0	0	0	0	4660	5350
Clomazone	0.2	PPI	99	68	98	79	7020	7310
Clomazone	0.4	PPI	84	80	78	83	7120	6500
Quinclorac	0.375	PPI	100	87	99	90	6360	7390
Clomazone	0.2	PRE	100	80	100	89	6530	6690
Clomazone	0.4	PRE	100	93	100	93	7220	7530
Quinclorac	0.375	PRE	100	76	100	82	7540	7010
Clomazone	0.2	DPRE	80	80	81	90	6490	7580
Clomazone	0.4	DPRE	100	98	100	91	6835	6360
Quinclorac	0.375	DPRE	99	89	96	93	7230	7760
Pendimethalin	1.0	DPRE	97	84	83	88	7230	7900
Thiobencarb	4.0	DPRE	81	75	85	73	6830	7430
LSD (0.05)[x] : Water timings			16		17		1720	
: Treatments			17		18		2070	

[z] DAE: Days after emergence.
[y] Timing: PPI= preplant incoroporated; PRE = preemergence; DPRE= delayed preemergence.
[x] LSD: To make comparisons between treatments across water timings.
To make comparisons of treatments within or across water timings.

Table 2. Herbicide programs involving clomazone for broad-spectrum weed control 56 DAE[z] at Stuttgart, 1999.

Herbicide Treatments	Rate	Application Timing[z]	Barnyardgrass Suscept.	Barnyardgrass Resistant	Morningglories Palmleaf	Morningglories Pitted	Northern Jointvetch	Hemp Sesbania	Rice Yield
	(lb ai/acre)		(% Control)						(lb/acre)
Untreated Check			0	0	0	0	0	0	5900
Clomazone + quinclorac	0.5 0.375	PRE	100	100	100	100	100	100	7120
Clomazone + quinclorac	0.2 0.19	PRE	100	100	100	100	60	70	6900
Clomazone + quinclorac	0.5 0.375	DPRE	100	100	100	100	98	90	6570
Clomazone + thiobencarb	0.5 4.0	DPRE	100	100	51	60	63	5	7010
Clomazone + thiobencarb	0.2 2.0	DPRE	100	100	70	15	15	5	7030
Clomazone + pendimethalin	0.2 1.0	DPRE	100	100	23	15	10	5	6170
Clomazone + quinclorac	0.2 0.19	DPRE	100	100	91	64	38	64	7320
Clomazone *fb* carfentrazone + AG-98 (0.25%)	0.5 0.02	PRE PREFLD	100	100	99	70	85	100	7970
Clomazone *fb* propanil	0.5 3.0	PRE PREFLD	100	100	66	35	99	100	7980

continued

Table 2. Continued.

Herbicide Treatments	Rate	Application Timing[2]	Barnyardgrass		Morningglories		Northern Jointvetch	Hemp Sesbania	Rice Yield
			Suscept.	Resistant	Palmleaf	Pitted			
	(lb ai/acre)		(% Control)						(lb/acre)
Clomazone *fb* propanil	0.2 3.0	PRE PREFLD	98	95	71	30	95	100	7540
Clomazone *fb* bensulfuron + Agri-Dex (1.0%)	0.2 0.06	PRE PREFLD	97	96	80	100	35	68	7570
Clomazone *fb* (propanil + molinate) + bensulfuron	0.2 4.5 0.06	PRE PREFLD	100	100	100	100	95	100	6850
Clomazone *fb* carfentrazone + AG-98 (0.25%)	0.5 0.02	DPRE PREFLD	100	100	100	98	98	99	6090
Clomazone *fb* propanil	0.5 3.0	DPRE PREFLD	100	100	76	45	99	100	6160
Quinclorac *fb* propanil	0.38 3.0	DPRE PREFLD	100	100	100	100	100	100	7500
LSD $_{(0.05)}$			2	3	27	24	25	21	1510

[1]DAE: Days after emergence
[2]Timing: PRE =preemergence; DPRE = delayed preemergence; and PREFLD = preflood

Table 3. Levee programs with clomazone for effective grass control 56 DAE[z], Stuttgart, 1999.

Herbicide Treatment[y]	Rate	Application Timing[x]	Barnyardgrass Control		Rice Yield
			Susceptible	Resistant	
	(lb ai/acre)		(% control)		(lb/acre)
Clomazone	0.4	PRE-A	0	0	2390
Clomazone *fb* clomazone	0.4 *fb* 0.2	PRE-A *fb* PRE-B	95	95	3650
Clomazone *fb* propanil	0.4 *fb* 4.0	PRE-A *fb* EPOST	76	25	1640
Clomazone *fb* propanil	0.4 *fb* 4.0	PRE *fb* PREFLD	84	45	2200
Clomazone *fb* propanil	0.4 *fb* 4.0	PRE-A *fb* EPOST	96	56	2490
Clomazone *fb* clomazone *fb* propanil	0.4 *fb* 0.2 *fb* 4.0	PRE-A *fb* PRE-B *fb* EPOST	95	96	4070
Clomazone *fb* (fenoxaprop + safener)	0.4 *fb* 0.098	PRE-A *fb* EPOST	95	92	4440
Clomazone *fb* clomazone + propanil	0.4 *fb* 0.4 + 4.0	PRE A *fb* EPOST	93	90	3570
Clomazone *fb* quinclorac + AG-98 (0.25%)	0.4 *fb* 0.25	PRE A *fb* EPOST	98	94	4710
Clomazone *fb* quinclorac + propanil	0.4 *fb* 0.25 + 4.0	PRE A *fb* EPOST	99	96	3710
Clomazone *fb* bispyribac-sodium + KIN	0.4 *fb* 0.02	PRE A *fb* PREFLD	99	96	3800
Clomazone *fb* propanil + bispyribac + KIN	0.4 *fb* 4.0 + 0.02	PRE A *fb* PREFLD	89	88	2990
$LSD_{(0.05)}$			13	22	2300

[z] DAE: Days after emergence.

[y] Timing: PRE-A = preemergence prior to levee formation; PRE-B = preemergence after levee formtion; EPOST = early postemergence; and PREFLD preflood.

[x] KIN: Kinetic at 0.125% V/V.

Table 4. Aquatic weed control late-season with clomazone and imazethapyr, Stuttgart, 1999.

Herbicide Treatment	Rate	Application Timing[z]	Ducksalad Control			
			56 DAE[1]	72 DAE	84 DAE	90 DAE
	(lb ai/acre)		(% control)			
Untreated check			0	0	0	0
Clomazone	0.3	PRE	10	0	0	0
Clomazone	0.5	PRE	8	0	0	0
Clomazone *fb* bensulfuron + Agri-Dex (1.0%)	0.5 0.06	PRE PRFLD PRFLD	94	36	23	0
Imazethapyr	0.094	PPI	18	58	45	40
Imazethapyr *fb* imazethapyr + AG-98 (0.25%)	0.063 0.063	PPI EPOST EPOST	41	93	73	50
Imazethapyr *fb* imazethapyr + AG-98 (0.25%)	0.063 0.063	PPI PREFLD PREFLD	15	86	74	53
Imazethapyr *fb* imazethapyr + AG-98 (0.25%)	0.063 0.063	EPOST PREFLD PREFLD	20	86	68	43
Quinclorac *fb* bensulfuron + Agri-Dex (1.0%)	0.375 0.06	PRE PREFLD PREFLD	90	31	15	0
$LSD_{(0.05)}$			19	20	16	9

[z] DAE: Days after emergence.

[y] Timing: PPI= preplant incoroporated; PRE = preemergence; EPOST= early postemergence; and PREFLD = preflood.

Table 5. Cultivar tolerance to clomazone PRE[z] at Stuttgart, 1999.

Cultivar & Treatment	Clomazone	Percent Chlorosis 7 DAE	14 DAE	21 DAE	28 DAE	Time to 50% Heading	Rice Yield
	(lb ai/acre)	(% chlorosis)				(DAE[y])	(lb/acre)
Drew							
Untreated check		0	0	0	0	77	7110
Clomazone	0.3	3	3	1	0	78	6690
Clomazone	0.6	23	21	9	2	77	6450
Lemont							
Untreated check		0	0	0	0	78	5750
Clomazone	0.3	1	1	0	0	79	7050
Clomazone	0.6	2	8	3	1	78	6060
Priscilla							
Untreated check		0	0	0	0	75	7300
Clomazone	0.3	1	5	1	0	75	7500
Clomazone	0.6	8	12	5	3	75	6220
Exp. Cultivar #2							
Untreated check		0	3	0	0	79	7240
Clomazone	0.3	0	5	0	0	79	7670
Clomazone	0.6	3	5	2	1	80	5930
Madison							
Untreated check		0	0	0	0	78	6060
Clomazone	0.3	4	3	0	0	79	5850
Clomazone	0.6	38	20	11	3	79	5340

continued

Table 5. Continued.

Cultivar & Treatment	Clomazone	Percent Chlorosis 7 DAE	14 DAE	21 DAE	28 DAE	Time to 50% Heading	Rice Yield
	(lb ai/acre)	(% chlorosis)				(DAE[y])	(lb/acre)
Cypress							
Untreated check		0	0	0	0	76	5560
Clomazone	0.3	2	3	0	0	76	5610
Clomazone	0.6	5	24	5	2	76	6600
Bengal							
Untreated check		0	0	0	0	75	7710
Clomazone	0.3	1	5	0	0	75	6740
Clomazone	0.6	2	19	4	3	75	6680
Exp. Cultivar #4							
Untreated check		0	0	0	0	77	5990
Clomazone	0.3	2	2	0	0	76	6670
Clomazone	0.6	4	9	3	1	77	6140
Kaybonnet							
Untreated check		0	0	0	0	76	5870
Clomazone	0.3	2	3	1	0	76	6860
Clomazone	0.6	10	10	3	0	75	6940
LaGrue							
Untreated check		0	0	0	0	75	7280
Clomazone	0.3	1	1	1	0	75	8180
Clomazone	0.6	3	8	1	0	75	7440

continued

Table 5. Continued.

Cultivar & Treatment	Clomazone	Percent Chlorosis				Time to 50% Heading	Rice Yield
		7 DAE	14 DAE	21 DAE	28 DAE		
	(lb ai/acre)	----------------- (% chlorosis) -----------------				(DAE[y])	(lb/acre)
Wells							
Untreated check		0	0	0	0	75	6450
Clomazone	0.3	4	3	0	0	75	7170
Clomazone	0.6	34	24	4	1	75	7090
Mars							
Untreated check		0	0	0	0	77	5950
Clomazone	0.3	0	0	0	0	76	6580
Clomazone	0.6	2	5	0	0	77	6140
Cocodrie							
Untreated check		0	0	0	0	69	6640
Clomazone	0.3	2	4	1	0	69	6510
Clomazone	0.6	10	30	6	4	69	6840
Exp. Cultivar #3							
Untreated check		0	0	0	0	69	5590
Clomazone	0.3	0	4	0	0	69	5440
Clomazone	0.6	2	16	2	0	69	5670
Koshihikari							
Untreated check		0	0	0	0	69	7840
Clomazone	0.3	0	2	0	0	69	8430
Clomazone	0.6	3	20	9	4	69	6300

continued

Table 5. Continued.

Cultivar & Treatment	Clomazone	Percent Chlorosis				Time to 50% Heading	Rice Yield
		7 DAE	14 DAE	21 DAE	28 DAE		
	(lb ai/acre)	---------------- (% chlorosis) ----------------				(DAE[y])	(lb/acre)
Exp. Cultivar #1							
Untreated check		0	0	0	0	69	5990
Clomazone	0.3	2	13	3	0	68	6760
Clomazone	0.6	10	30	11	6	68	6880
Jefferson							
Untreated check		0	0	0	0	69	7160
Clomazone	0.3	0	6	1	0	69	6910
Clomazone	0.6	4	16	3	2	68	6870
Exp. Cultivar #5							
Untreated check		0	0	0	0	69	7110
Clomazone	0.3	0	1	0	0	70	7960
Clomazone	0.6	6	7	6	1	69	8380
$LSD_{(0.05)}$ Different rates within a cultivar:		8	9	4	3	1	1540
$LSD_{(0.05)}$ Different rates over cultivars:		9	9	4	3	1	1500

[z] PRE = preemergence.
[y] DAE = days after rice emergence.

NEW STRATEGIES FOR LATE-SEASON WEED CONTROL IN RICE

R.E. Talbert, L.A. Schmidt, E.F. Scherder, and F.L. Baldwin

ABSTRACT

Various herbicides were evaluated for the control of weeds just prior to and following rice flooding. The sprayable dry-flowable (DF) formulation of quincloroc was significantly better for control of late-season barnyardgrass compared to the granular formulation at either flood depth (0 to 5 cm or 10 to 15 cm). The granular formulation performed better in the deeper flood depth (10 to 15 cm) than the shallow flood depth (0 to 5 cm). The DF formulation of quinclorac used in a spray was more effective on smaller barnyardgrass (8- to 13-cm tall) than larger barnyardgrass (15- to 25-cm tall) under shallow flood conditions (0- to 5-cm flood depth). Carfentrazone provided excellent control of tall hemp sesbania (1- to 1.5-cm height); however, rice yields were still severely reduced when the herbicide treatment was delayed until this late growth stage. Sequential treatments of bispyribac gave good to excellent control of hemp sesbania and northern jointvetch with mid-post and postflood applications.

INTRODUCTION

Dry-seeded rice production relies on effective herbicide programs and flooding to keep weed infestations under the economic threshold. Growers rely heavily on these two approaches to maintain a weed-free environment, therefore maximizing yield. When grasses or broadleaf weeds escape the flood, farmers may be reluctant to spray because of added input costs (herbicide cost and application fees) or low infestations of escaped weeds. These late-emerging weeds may cause a late-season yield loss and contaminate the harvested grains if not controlled. New strategies for late-season control of weeds using existing technologies and newer herbicides were evaluated.

PROCEDURES

Experiments were conducted in 1998 and 1999 at the Rice Research and Extension Center, Stuttgart, on DeWitt silt loam soil using standard drill-seeded rice production practices. One study was conducted in 1998 and 1999 to evaluate efficacy of quinclorac at 0.42 kg ai/ha at a postflood timing. This study had a factorial arrangement of treatments with factors of flood depth (0 to 5 and 10 to 15 cm), barnyardgrass (*Echinochloa crus-galli*) height (8 to 13 and 15 to 25 cm), and formulation of quinclorac [(DF) and granular (GR)]. Two studies were conducted in 1999 evaluating carfentrazone at 0.02 and 0.03 kg ai/ha for mid-season control of hemp sesbania (*Sesbania exaltata*), and bispyribac-sodium at 0.02 kg ai/ha in a program approach for grass and broadleaf weed control.

RESULTS

Quinclorac did not completely control barnyardgrass at a postflood timing with either formulation (Table 1). There was an interaction between flood depth and grass height 40 days after treatment (DAT) and between formulation and grass height 40 DAT. The DF formulation was more effective on barnyardgrass (80% for 0- to 5-cm flood and 77% for 10- to 15-cm flood) than the GR (45% for 0- to 5-cm flood and 56% for 10- to 15-cm flood). At a 0- to 5-cm flood depth, 8- to 13-cm grass was controlled significantly better (70%) with quinclorac than 15- to 25-cm grass (55%). The opposite was true with 15- to 25-cm barnyardgrass; a 10- to 15-cm flood gave better control (66%) than a 0- to 5-cm flood (55%). Yields were significantly higher with the DF formulation regardless of flood depth or grass height as compared to the GR formulation.

Carfentrazone applied mid-season to hemp sesbania (1- to 1.5-m tall) provided more than 97% control 35 DAT at both 0.02 and 0.03 kg/ha rates (Fig. 1). This level of control was equivalent to acifluorfen at 0.14 kg ai/ha (100%) and significantly better than triclopyr at 0.28 kg ae/ha (74%). Yield differences were not detected among the four herbicides; however, severe yield loss had already occurred because of earlier competition (Fig. 2). From this research, we conclude that an earlier application timing is needed to maximize yield.

In trials in 1998, bispyribac-sodium was shown to be a versatile herbicide because of its activity on grasses and broadleaf weeds common to rice (Table 2). This trial evaluated pendimethalin at 1.12 kg ai/ha delayed preflood (DREFL) followed by (*fb*) bispyribac-sodium at 0.02 kg/ha at a middle postflood (MPOST) and a postflood (POFL) timing and clomazone at 0.34 kg ai/ha DREFL *fb* bispyribac-sodium 0.02 kg/ha preflood (PREFL) and POFL. The standard comparisons were pendimethalin 1.12 kg/ha and clomazone 0.34 kg/ha *fb* propanil at 2.5 kg ai/ha + molinate at 2.5 kg ai/ha MPOST and PREFL respectively. Bispyribac-sodium was also evaluated as a standalone herbicide with applications of 0.02 kg/ha MPOST *fb* 0.03 kg/ha POFL. All treatments gave control of barnyardgrass. Bispyribac-sodium alone failed to control broadleaf signalgrass

(*Brachairia platyphylla*). Hemp sesbania control was achieved by 28 days after the POFL application with all treatments (>84%) except pendimethalin *fb* bispyribac-sodium MP (73%). Bispyribac-sodium was significantly better in a program approach with pendimethalin at the POFL timing than at MPOST. Northern jointvetch (*Aeschynomene virginica*) control followed the same trends as hemp sesbania control.

Table 1. Influence of quinclorac on barnyardgrass control and rice yield as affected by formulation, flood depth, and barnyardgrass height at Stuttgart, 1998 and 1999.

Barnyardgrass Height	Quinclorac Formulation[z]	Flood Depth	Barnyardgrass 40 DAT[y]	Rice Yield
(cm)		(cm)	(% control)	(kg/acre)
8-13	DF	0-5	87	7390
8-13	DF	10-15	74	6490
8-13	GR	0-5	60	4760
8-13	GR	10-15	53	5990
Untreated Check		0-5	0	3860
15-25	DF	0-5	78	6430
15-25	DF	10-15	76	5660
15-25	GR	0-5	36	3650
15-25	GR	10-15	53	4330
Untreated Check		10-15	0	2820
LSD 0.05			19	420

[z] Quinclorac: DF= dry flowable formulation, and GR= granular formulation.
[y] DAT: days after treatment.

Table 2. Influence of bispyribac-sodium in sequential applications with clomazone and pendimethalin on grass and broadleaf control and rice yield at Stuttgart, 1999.

Treatment	Rate	Timing[z]	Barnyardgrass	Broadleaf signalgrass	Hemp sesbania	Northern jointvetch	Rice yield
	(kg/ha)		(% control)				(kg/ha)
Untreated check			0	0	0	0	4940
Bispyribac-sodium *fb*[y]	0.022 *fb*	MPT	96	56	94	87	7340
bispyribac-sodium[x]	0.022	POFL					
Pendimethalin *fb*	1.12 *fb*	DPRE	93	81	73	72	7670
bispyribac-sodium	0.022	MPT					
Pendimethalin *fb*	1.12 *fb*	DPRE	95	83	86	90	7980
bispyribac-sodium	0.022	POFL					
Clomazone *fb*	0.34 *fb*	PRE	94	96	84	87	7160
bispyribac-sodium	0.022	PREFL					
Clomazone *fb*	0.34 *fb*	PRE	96	96	86	87	8320
bispyribac-sodium	0.022	POFL					
Pendimethalin *fb*	0.34 *fb*	DPRE	89	94	85	90	7250
Arrosolo[w]	5.0	MPT					
LSD (0.05)			6	14	9	9	730

[z] Timing: PRE = preemergence; DPRE = delayed preemergence; MPT = middle post; PREFL = preflood; and POFL = post flood.
[y] *fb* = followed by corresponding herbicide.
[x] Bispyribac-sodium: All treatments had Kinetic added at 0.125% v/v.
[w] Arrosolo = propanil at 2.5 kg/ha + molinate at 2.5 kg/ha.

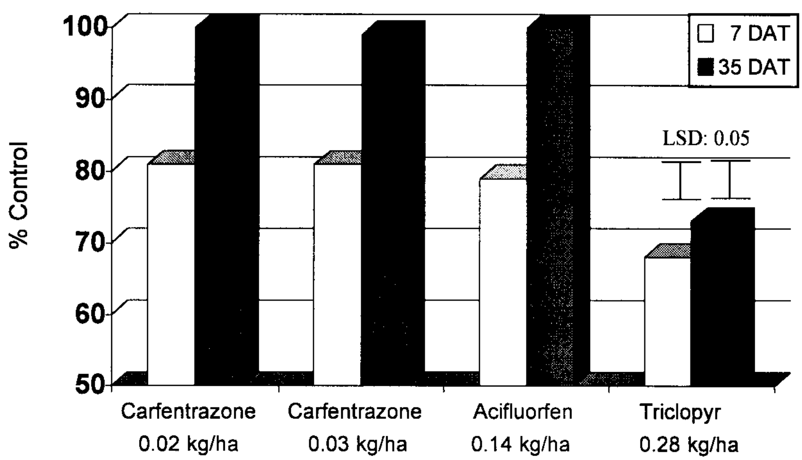


Fig. 1. Mid-season control of hemp sesbania at Stuttgart, 1999.

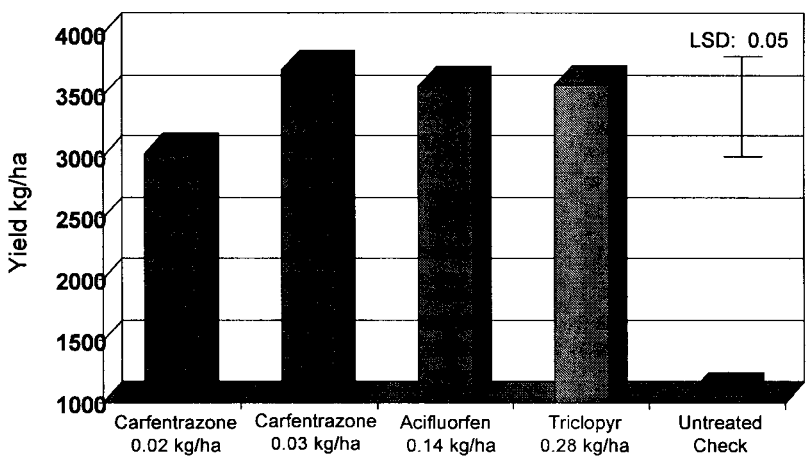


Fig. 2. Rough rice yield with mid-season herbicides at Stuttgart, 1999.

SCREENING RICE LINES FOR SUSCEPTIBILITY TO DISCOLORED KERNELS: RESULTS FROM THE ARKANSAS RICE PERFORMANCE TESTS

J.L. Bernhardt and K.A.K. Moldenhauer

ABSTRACT

Rice lines were evaluated for susceptibility to kernel discoloration. Advanced rice lines in the Arkansas Rice Performance Trials (ARPT) were compared to check varieties for susceptibility to feeding by rice stink bugs, to kernel smut infection, to other causes of bran and kernel discolorations, and to linear damage. Results of the ARPT evaluations in 1999 could be summarized as excellent for evaluating rice stink bugs because levels were very high, poor for evaluating kernel smut infections because weather did not favor high infection conditions, and excellent for evaluating linear discoloration because of high day and night temperatures. Information on two possible rice varieties was made available by the yearly evaluation of lines in the Uniform Regional Rice Nursery (URRN). The rice line RU9602074 is being considered for release by Louisiana with the variety name ‘Earl’. Based on evaluations of the URRN from 1996 to 1998, the medium-grain line should be considered resistant to kernel smut, moderately susceptible to bran discolorations, not susceptible to linear damage, but highly susceptible to damage from rice stink bugs. The rice line RU9603178 is being considered for release by Texas. Based on evaluations of the 1997 and 1998 URRN, the long-grain line should be considered to have no susceptibility to linear discolorations, low susceptibility to rice stink bug damage, and only moderate susceptibility to kernel smut. These data from yearly evaluations of rice lines and varieties are given to rice breeders and can be used to help in the selection of lines to continue in the breeding program. Rice growers can use the information to select varieties and use management practices that will reduce quality reductions due to discolored kernels.

INTRODUCTION

Rice lines have varying levels of susceptibility to organisms that discolor kernels (Bernhardt, 1992). In the field, kernel discolorations are caused by fungi alone, such as kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] or by fungi introduced by the rice stink bug, *Oebalus pugnax* (F.), and by physiological responses to adverse environmental conditions during grain fill, such as linear damage. Agents that discolor rice kernels are commonly found in all Arkansas rice fields. Rice stink bug adults and nymphs feed on rice kernels at all stages of development except at hard dough and maturity stages. The stage of kernel development when rice stink bugs feed determines the amount and type of damage. Feeding during the later stages of development often results in only a portion of the contents being removed. But very often after the hull is pierced by rice stink bugs, fungi gain entry, and the infection results in a discoloration of the kernel. The amount of damage by rice stink bugs and all other causes of discolored kernels often influences the acceptability and value of rough rice.

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

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

PROCEDURES

Rice samples from the following sources and years were evaluated: (1) rice lines from the rice-breeding program of the University of Arkansas placed in the ARPT (1988-1999); (2) rice lines from breeding programs of other universities and private seed companies in the ARPT (1988-1999); and (3) advanced rice lines placed in the URRN (1993-1999). Locations of the ARPT were the Rice Research and Extension Center, Stuttgart (RREC, Arkansas Co.); Jackson County near Newport; the Pine Tree Branch Experiment Station, Colt (PTBES, St. Francis Co.); the Northeast Research and Extension Center, Keiser (NEREC, Mississippi Co.); and the Southeast Branch Experiment Station, Rohwer (SEBES, Desha Co.). Locations of the URRN were the RREC in Arkansas (1993-1999); Rice Research Station, Crowley, Louisiana (1994-1996, 1998); Texas Agricultural Experiment Station, Beaumont, Texas (1994-1999);

and Delta Research and Extension Center, Stoneville, Mississippi (1995-1999). Among the entries in the ARPT and URRN, check varieties are used for comparisons. Data from check varieties and selected advanced rice lines in the ARPT from 1992 through 1999 are included in this report. Data from the possible variety releases in 2000 are also included. Data from the 1999 URRN are unavailable for this report.

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

RESULTS AND DISCUSSION

The 1999 ARPT was expanded by the addition of a new maturity group, the early season, which had 26 lines and check varieties. A total of 1248 samples were evaluated for discolored kernels from all locations except the NEREC.

Rice Stink Bug

Large field-plot tests such as the ARPT rely on natural infestations of the rice stink bug. In 1999, infestations of varied from light levels at the Jackson County location to very high levels at the RREC, SEBES, and PTBES locations. General trends that were noted in other years and other studies (Bernhardt, 1992) remained the same (Table 1). For example, the amount of discolored kernels in all medium- and short-grain varieties averaged more than in long-grain varieties. Also, long-grain varieties that routinely have less damage from rice stink bug, such as ‘Katy’, ‘Kaybonnet’, and ‘LaGrue’, had lower amounts of damage than in other long-grains, but because of high rice stink bug levels, discolored kernels in those varieties were at record high levels in 1999.

The early-season maturity group had the 17 advanced lines distributed as 12, 29, and 59% in short-, medium-, and long-grains, respectively. The two short-grain advanced lines RU9601096 and RU9601099 from a ‘Koshihikari/Mars’ cross were 47 and 31%, respectively, less susceptible to rice stink bugs than the parent Koshihikari. Kernels discolored by rice stink bugs in all medium-grain lines were numerically higher but statistically different from the check ‘M202’. Among the long-grain lines, 50% were numerically lower but not statistically different from the checks ‘Jefferson’, Maybelle’, and ‘L204’.

Of the 22 advanced rice lines in the very-short-season maturity group, 23% were medium-grains and 77% were long-grains. Although not statistically different from the check 'Bengal', all advanced lines had higher amounts (25 to 63%) of discolored kernels. No statistical differences were found between the advanced long-grain lines and the check varieties 'Cocodrie', 'Millie', and 'Jackson'. Of the advanced lines, 7 had amounts numerically (6 to 67%) greater than Cocodrie, 10 greater than Millie, and 16 greater than Jackson. One line, RU9901084, was 15% less than the amount in Jackson.

The 21 advanced lines in the short-season maturity group were long-grains. Of the 21 lines, 11 had higher amounts of discolored kernels than 'Cypress' and 'Wells'; 18 were higher than 'Priscilla'; 19 were higher than LaGrue and Kaybonnet. The lines STG96F5-01-131 and STG96F5-11-057 were 3 and 19%, respectively, lower than Kaybonnet.

Of the 21 advanced lines in the mid-season maturity group, only one, RU9801179, was a medium-grain and all others were long-grains. Discolored kernels in RU9801179 averaged a very high 4.25%. Of the 20 long-grain lines, 6 had higher amounts of discolored kernels than 'Newbonnet', 10 were higher than Katy and 'Lemont', 12 were higher than 'Drew', 15 were higher than 'Madison', and 5 were lower than Madison. Four of the five lines had amounts that were 1 to 8% lower, and line RU9901142 was 21% lower than Madison.

Kernel Smut

Kernel smut infects the open flower at anthesis and then grows in the developing kernel (Cartwright *et al.*, 1994). Often when the whole kernel is consumed, only black spores remain within the hulls. Our methods of sample preparation remove that type of infected kernels, but often detect kernels that have been only partially consumed by a kernel smut infection. Environmental conditions in 1999 were not conducive to kernel smut, and the incidence of partially consumed kernels in samples from the ARPT was much lower than that in 1998 (Table 2). Susceptible varieties such as Cypress, Cocodrie, LaGrue, M202, 'L205', Millie, and Newbonnet had low levels of kernel smut. In the early-season maturity group, three medium-grain lines (RU9901130, RU9801081, and STG96F5-06-058) had amounts equivalent to that of L204 and M202. The short-grains RU9601096 and RU9601099 appeared as resistant to kernel smut as Koshihikari. Three long-grain lines in the short-season group (RU9801121, RU9901099,and STG96P-46-083) had levels of kernel smut that were as high as M202 and higher than Cocodrie. Two long-grain lines in the short-season group (RU9901105 and RU9701050) had levels equivalent to LaGrue, Cypress, and Priscilla, and two (STG96F5-28-069 and RU9701179) had amounts substantially higher than that of LaGrue. Four long-grain lines in the mid-season maturity group (RU9801145, RU9901124, RU9901164, and RU9901102) had levels the were two to three times higher than Newbonnet.

Other Discolored Kernels

Our method of evaluation of rice also detects kernels that are not discolored by rice stink bugs, kernel smut, or linear damage. These kernels are placed in a "catch-all" category called "other damage." Many causes appear to contribute discolored kernels to this category. Some discolorations appear to be common to a variety and to be increased by specific weather conditions. The discolorations are most often confined only to the bran layer of immature, chalky kernels. Some discolorations are closely associated with infections of *Helminthosporium,* which causes brown spots on the hull and discolor the bran and occasionally discolors the kernel. Other causes for the bran discolorations in this category have not been identified. Also, the amount of kernels in this category varies from year to year even within a variety (Table 3). However, certain varieties appear to be more susceptible than others. For example, the short- and medium-grain lines Koshihikari, 'Akitakomachi', M202, and Bengal and the long-grain lines Cypress and 'Alan' often have moderate-to-high levels of bran discolorations. The short-grain lines RU9601096 and RU9601099 and the long-grain varieties Cocodrie and Lemont had moderate levels of bran discolorations. All advanced lines had amounts numerically lower than the highly susceptible varieties.

Linear Discolorations

This type of discoloration was described by Douglas and Tullis in 1950. The damage is characterized as a linear "cut" across the kernel that exposes the white kernel, and the area around the cut is either very dark brown or black. Kernels are weaken at the cut and frequently break during milling procedures. The discoloration is not limited to the bran, and milling does not eliminate the discoloration. Although all varieties have some damage, medium- and short-grain varieties with Asian varieties as one parent are more susceptible to linear damage. It is suspected that high temperatures during grain fill or maturation cause more linear damage in the susceptible varieties. Results of 1999 ARPT evaluations showed that conditions were very favorable for linear damage in all varieties and lines (Table 3), and some had the highest amounts ever recorded. Akitakomachi and the advanced line RU9901130 had nearly 2% or more linear damage. Other lines with high amounts were RU9901127 (medium-grain, early-season), and RU9801173 and RU9901136 (long- and-medium grain, very-short-season).

New Varieties

Louisiana is considering the release of the rice line RU9602074 named Earl, a blast-tolerant medium-grain with a grain size similar to Bengal. The line also has susceptibility to all causes of discolored kernels similar to Bengal (Table 4). Texas is considering the release of RU9603178, an early-maturing, semi-dwarf long-grain with resistance to blast and tolerance to sheath blight. The line has susceptibility to other and linear discolorations, and low susceptibility to rice stink bugs similar to that of LaGrue (Table 4), but unlike LaGrue it has only moderate susceptibility to kernel smut.

SIGNIFICANCE OF FINDINGS

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

The Louisiana medium-grain rice line RU9602074 should be considered resistant to kernel smut, moderately susceptible to bran discolorations, not susceptible to linear damage, but highly susceptible to damage from rice stink bugs. If growers have been discounted in the past for high levels of “pecky rice” (a term that refers to all discolored kernels regardless of cause) in Bengal, Earl may require applications of insecticides to reduce excessive discounts due to discolored kernels. The Texas long-grain rice line RU9603178, if released, should be considered resistant to linear discoloration, moderately susceptible to kernel smut and other discolorations, and slightly susceptible to rice stink bug damage.

REFERENCES

Bernhardt, J.L. 1992. Screening for rice stink resistance. *In:* B.R. Wells (ed.). Arkansas Rice Research Studies 1992. University of Arkansas Agricultural Experiment Station Research Series 431:96-103.

Cartwright, R.D., F.N. Lee, D.L. Crippen, and G.E. Templeton. 1994. Kernel smut research in Arkansas. *In:* B.R. Wells (ed.). Arkansas Rice Research Studies 1993. University of Arkansas Agricultural Experiment Station Research Series 439:71-77.

Douglas, W.A. and E.C. Tullis. 1950. Insects and fungi as causes of pecky rice. U.S. Dept. of Agric. Tech. Bull. 1015. U.S.D.A., Beltsville, MD. pp. 20.

Table 1. Average percent, by weight, of kernels discolored by rice stink bugs in brown rice samples of rice varieties in the Arkansas Rice Performance Trials (ARPT).

Maturity Group and Variety	Grain Type	Year 1992	1993	1994	1995	1996	1997	1998	1999
		(%)							
Mid-Season									
Newbonnet	L	0.44	1.50	0.64	1.02	1.40	0.67	1.34	2.56
Lemont	L	0.30	1.14	0.43	0.74	1.40	0.70	1.56	2.18
Katy	L	0.21	0.98	0.41	0.51	0.85	0.36	0.88	2.25
Drew	L	-	0.82	0.48	0.67	1.26	0.55	1.17	2.08
Madison	L	-	-	-	-	-	-	1.05	1.69
Short Season									
Kaybonnet	L	0.31	0.92	0.28	0.48	0.93	0.39	0.89	1.45
Cypress	L	0.44	1.30	0.59	0.99	1.62	0.53	1.67	2.02
LaGrue	L	0.30	0.78	0.31	0.51	0.71	0.42	0.94	1.59
Wells	L	-	-	-	-	0.60	0.88	1.83	1.97
Priscilla	L	-	-	-	-	-	-	1.41	1.75
Very Short Season									
Millie	L	0.36	1.15	0.54	0.35	1.26	0.64	1.50	1.64
Bengal	M	1.24	2.36	1.42	1.69	2.18	1.09	2.80	2.30
Cocodrie	L	-	-	-	-	-	0.76	1.99	1.90
Jackson	L	0.37	0.99	0.69	0.34	-	-	1.49	1.39
Early Season									
Maybelle	L	0.32	0.92	0.78	0.94	-	-	-	0.89
Jefferson	L	-	-	-	-	0.87	0.47	1.21	0.87
L204	L	-	-	-	-	1.41	0.63	1.21	1.10
M202	M	-	-	-	-	2.41	1.44	2.63	2.17
Koshihikari	S	-	-	-	-	2.06	-	3.41	2.86
Akitakomachi	S	-	-	-	-	-	-	-	2.11

Table 2. Average percent, by weight, of kernels discolored by kernel smut in brown rice samples of rice varieties in the Arkansas Rice Performance Trials (ARPT).

Maturity Group and Variety	Grain Type	1992	1993	1994	1995	1996	1997	1998	1999
		(%)							
Mid-Season									
Newbonnet	L	0.002	0.123	0	0.008	0.132	0.037	0.084	0.011
Lemont	L	0.008	0.035	0.006	0.003	0.053	0.073	0.080	0.034
Katy	L	0.003	0.007	0.030	0.002	0.038	0.004	0.046	0.004
Drew	L	-	0.025	0.042	0.005	0.058	0.015	0.097	0.017
Madison	L	-	-	-	-	-	-	0.062	0.008
Short Season									
Kaybonnet	L	0.006	0.021	0	0.001	0.056	0.008	0.066	0.017
Cypress	L	0.023	0.075	0	0.006	0.202	0.066	0.269	0.047
LaGrue	L	0.035	0.090	0	0.011	0.471	0.063	0.321	0.049
Wells	L	-	-	-	-	0.072	0.021	0.068	0.018
Priscilla	L	-	-	-	-	-	-	0.341	0.072
Very Short Season									
Millie	L	0.013	0.081	0.136	0.005	0.351	0.016	0.384	0.024
Bengal	M	0.006	0.016	0	0.002	0.033	0.010	0.093	0.030
Cocodrie	L	-	-	-	-	-	0.014	0.165	0.067
Jackson	L	0.020	0.120	0.244	0.010	-	-	0.453	0.037
Early Season									
Maybelle	L	0.010	0.099	0.264	0.005	-	-	-	0.053
Jefferson	L	-	-	-	-	0.254	0.016	0.261	0.063
L204	L	-	-	-	-	0.123	0.015	0.283	0.022
M202	M	-	-	-	-	0.397	0.068	0.277	0.154
Koshihikari	S	-	-	-	-	0.023	-	0.047	0.006
Akitakomachi	S	-	-	-	-	-	-	-	0.013

Table 3. Average percent, by weight, of linear discoloration and kernels discolored by other causes in brown rice samples of rice varieties in the Arkansas rice Performance Trials (ARPT).

Maturity Group and	Grain	All Other Discolored Kernels					Linear Damage			
Variety	Type	1995	1996	1997	1998	1999	1996	1997	1998	1999
		(%)								
Mid-Season										
Newbonnet	L	0.80	1.36	0.26	0.25	0.52	0.085	0.011	0.037	0.092
Lemont	L	0.68	1.66	0.43	0.66	0.92	0.008	0	0.029	0.043
Katy	L	0.41	1.07	0.16	0.20	0.60	0.019	0.002	0.013	0.033
Drew	L	0.27	0.69	0.17	0.28	0.51	0.014	0.005	0.014	0.027
Madison	L	-	-	-	0.45	0.74	-	-	0.017	0.028
Short Season										
Kaybonnet	L	0.29	0.64	0.16	0.24	0.50	0.018	0.013	0.023	0.066
Cypress	L	0.83	2.00	0.44	0.59	0.72	0.007	0.002	0.217	0.027
LaGrue	L	0.41	0.83	0.44	0.30	0.40	0.016	0.012	0.014	0.041
Wells	L	-	0.60	0.25	0.36	0.44	0.016	0.010	0.024	0.027
Priscilla	L	-	-	-	0.44	0.67	-	-	0.012	0.072
Very Short Season										
Millie	L	0.47	1.11	0.35	0.44	0.49	0.075	0.011	0.028	0.046
Bengal	M	1.43	2.49	0.48	0.68	0.41	0.119	0.076	0.097	0.112
Cocodrie	L	-	-	0.42	0.79	0.89	-	0.014	0.036	0.119
Jackson	L	0.55	-	-	-	0.54	-	-	-	0.041
Early Season										
Maybelle	L	0.68	-	-	-	0.44	-	-	-	0.132
Jefferson	L	-	1.42	0.43	0.45	0.53	0.061	0.007	0.020	0.077
L204	L	-	3.86	0.85	0.75	1.03	0.167	0.420	0.042	0.072
M202	M	-	6.69	1.56	1.81	1.62	0.261	0.141	0.099	0.415
Koshihikari	S	-	3.13	-	0.85	1.00	1.099	-	0.822	0.714
Akitakomachi	S	-	-	-	-	1.05	-	-	-	1.870

Table 4. Average percent, by weight, of discolored kernels in brown rice samples of possible new rice varieties in the Uniform Regional Rice Nursery (URRN).

Variety (state released)	Grain Type	State Grown	Cause of Kernel Discoloration					
			Rice Stink Bug			Kernel Smut		
			1996	1997	1998	1996	1997	1998
			(%)					
RU9602074 (LA)	M	AR	1.97	1.34	2.75	0.078	0.146	0.039
		LA	1.51	-	2.18	0	-	0
		MS	1.28	0.77	2.86	0.017	0.060	0.418
		TX	0.83	0.94	1.89	0.004	0.005	0.002
Bengal	M	AR	2.54	1.61	2.28	0.034	0.174	0.039
		LA	1.88	-	1.69	0	-	0
		MS	1.34	2.04	2.38	0.002	0.028	0.067
		TX	1.13	0.72	2.30	0.005	0	0.006
RU9603178 (TX)	L	AR	-	0.70	0.70	-	0.605	0.109
		LA	-	-	0.65	-	-	0
		MS	-	0.45	0.92	-	0.012	0.190
		TX	-	0.21	0.70	-	0.001	0.008
LaGrue	L	AR	-	0.57	1.17	-	1.819	0.139
		LA	-	-	0.61	-	-	0
		MS	-	0.91	0.92	-	0.003	0.511
		TX	-	0.26	0.63	-	0	0.017

continued

Table 4. Continued.

Variety (state released)	Grain Type	State Grown	Cause of Kernel Discoloration					
			Other			Linear		
			1996	1997	1998	1996	1997	1998
			(%)					
RU9602074 (LA)	M	AR	0.62	0.28	0.95	0.004	0.007	0.069
		LA	1.39	-	1.73	0.019	-	0.007
		MS	0.75	0.58	1.10	0.020	0.005	0.053
		TX	1.58	1.09	1.97	0.035	0.048	0.005
Bengal	M	AR	1.09	2.06	0.84	0.051	0.007	0.149
		LA	1.82	-	1.09	0.224	-	0.066
		MS	1.22	0.92	1.29	0.070	0.075	0.269
		TX	2.55	2.62	2.76	0.085	0.022	0.039
RU9603178 (TX)	L	AR	-	1.07	0.46	-	0	0.016
		LA	-	-	0.66	-	-	0.002
		MS	-	0.70	0.78	-	0.003	0.006
		TX	-	0.65	1.75	-	0.003	0.005
LaGrue	L	AR	-	0.54	0.49	-	0	0.021
		LA	-	-	0.47	-	-	0.002
		MS	-	0.13	0.52	-	0.006	0.013
		TX	-	0.43	1.30	-	0.004	0.003

TRAPPING ADULT RICE WATER WEEVILS WITH AQUATIC BARRIER TRAPS AND FLOATING CONE TRAPS, WITH NOTES ON CHEMICAL ECOLOGY

R.L. Hix, D.T. Johnson, J.L. Bernhardt, J.D. Mattice, and B.A. Lewis

ABSTRACT

Trapping rice water weevil adults immediately after permanent flooding of drill-seeded fields can aid decision-making for the application of λ-cyhalothrin or diflubenzuron against weevils in rice. The aquatic barrier traps caught 2.5 to 18 times more rice water weevil adults than did the yellow or gray floating cone traps, regardless of lure or no lure. Larval rice water weevil infestations ranged from moderate (at or below threshold of 10 larvae/core) to a high of 62.75 larvae/core. A regression analysis found a significant correlation ($r^2 = 0.63$) between adults captured in traps and subsequent larval density. For example, for every 1.0 rice water weevil adults captured in barrier traps, we could predict a density of 1.41 larvae per plant/soil core sample. Rice volatiles elicited an electroantennogram response with saline-electrodes. However, rice water weevil antennae are hydrophobic, so the future electroantennogram protocol will involve use of tungsten electrodes inserted into antennae.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, (Coleoptera: Curculionidae) is a pest of rice in Arkansas. Weevil larvae have been adequately controlled with carbofuran since the early 1970s. However, carbofuran is no longer legal for use in rice and has been replaced with λ-cyhalothrin (Karate) and diflubenzuron (Dimilin). Lambda-cyhalothrin targets the adults, and diflubenzuron targets the eggs. These new insecticides worked best when applied within 10 days after permanent flood (Bernhardt 1997, 1998). The scouting methods for carbofuran are either inadequate (adult leaf feeding scar method) or too late (larval soil core sampling) (Morgan *et al.*, 1989). Therefore, a reliable scouting method for adults is urgently needed.

Odor may be one way the rice water weevil detects and orients to rice, but little information has been reported. Only hexanal has been shown to elicit an electroantennogram (EAG) response in rice water weevil (Hix *et al.*, 1998). Hernandez *et al.* (1989) listed several volatiles from two rice varieties.

This study determined the response of rice water weevil antennae to several rice volatiles, evaluated floating cone traps with a blend of five rice volatiles, and compared captures of adult weevils with floating cone traps and aquatic barrier traps to subsequent larval counts from plant/soil core samples in various drill-seeded rice fields in eastern Arkansas. The aquatic barrier trap was designed based on rice water weevil swimming behavior (Hix *et al.*, 2000).

PROCEDURES

Experiment 1

Rice water weevil antennal response to eight rice volatiles were recorded using an EAG. Hexanal was used as a reference compound. One microliter of each compound was applied to filter paper (Whatman No. 1) that had been placed in Pasteur pipets. The EAG responses were recorded using IDAC-2 hardware and software (Syntech, Hilversum, The Netherlands). A saline-filled glass electrode was inserted into the back of an excised rice water weevil head, and one was placed over the tip of the antennae using the "surface-contact" method. The antennae were continuously flushed with charcoal-filtered humidified air. Stimuli were added to the air stream by forcing the air from the Pasteur pipets with the volatile treated filter paper. Hexanal served as the reference (control) compound in the EAG. A replication consisted of an EAG recording of a blank pipet, test compound, and reference compound.

Experiment 2

A randomized complete block design was used with four bays 100 m by 25 m drill-seeded with 'Cypress' rice in a commercial field near Cherry Valley (Cross County). On 5 June, 10 gray floating cone traps or 10 yellow floating cone traps per bay were placed in the borrow pits. No attractants were placed in the traps. The traps were checked daily for 7 days after permanent flood. Larvae were monitored in four plant/soil core samples taken from edges and four from the centers of each of the bays at 21 and 25 days postflood. Soil was washed from the plant roots into a 40-mesh sieve screen. The screen was immersed in a brine, and rice water weevil larvae removed and counted. The floating cone traps were described and depicted in Hix *et al.* (1998, 1999). This was a repeat of an experiment conducted in 1998 (Hix *et al.*, 1999), except no cone traps were placed in vegetation in 1999.

Experiment 3

Immediately following permanent flood on 9 June 1999, two aquatic barrier traps, two yellow floating cone traps baited with grandisoic acid, two floating cone traps, and two yellow floating cone traps baited with a blend of rice volatiles eliciting an EAG responce were placed in each of eight bays (10 m by 142 m) of 'Bengal' rice in Stuttgart. A 1-dram shell vial packed with glass wool had these compounds injected into it: heptanal (30 µl); 2-penten-1-ol (30 µl); 2,4-hexadienal (20 µl); 3-methyl-4-heptanone (10 µl); and (Z,Z)-2,4-nonadienal (10 µl) for each trap baited with rice volatiles. One trap was placed at each end of the bays, and three were placed on the sides of the bays about 45 m apart. The traps were checked daily for 9 days. Larval core samples were taken at 21 days and 26 days postflood, and the larvae were removed as previously described. Each aquatic barrier trap was made as described by Hix *et al.* (2000). Traps used in 1998 did not have flotation devices and were clipped to the stake of two metal flags (Hix *et al.*,1999).

Experiment 4

In June 1999, 16 barrier traps (8 at the field edge and 8 in the field interior) were placed immediately following permanent flooding and checked daily for 6 days in three commercial fields in three counties: (1) 38 acres of 'Bengal' in St. Francis County (1 June 1999); (2) 70 acres of 'Drew' in Cross County (2 June 1999); and (3) 19 acres of 'Drew' in Arkansas County (Foundation Seed fields at the Rice Research and Extension Center, Stuttgart, 9 June 1999). The edge traps were placed in water adjacent to rice plants near levees at 100-m intervals. The field edges between the rice and likely over wintering sites were chosen. The interior traps were placed at 100-m intervals as well, with the nearest trap at least 100 m from the nearest field edge. Sixteen traps were placed in a 20-acre field of Bengal in Cross County that had been treated with Karate 1 day before flood as a control. One 10 by 10-cm larval core sample was taken within 2 m of each trap at 21 days postflood and checked for larvae as described previously.

Experiment 5

Immediately following permanent flood (9 June 1999), eight barrier traps were placed in each of four bays (10 m by 142 m) of Bengal rice; one trap was placed at each end of the bays, and three were placed on the sides of the bays about 45 m apart. The traps were checked daily for 9 days. Larval core samples were taken at 21 and 26 days postflood, and the larvae were removed as previously described. This experiment was repeated as described above in Bengal planted 17 June 1999. Permanent flooding was applied 28 July 1999, with barrier traps placed the same day following flooding. The traps were checked daily for 9 days postflood. Larval core samples were taken at 21 days postflood, with larval removal as previously described.

RESULTS AND DISCUSSION

Experiment 1

The EAG responses are depicted in Fig. 1. Only responses of the reference compound (hexanal), 2-penten-2-ol, and (Z,Z)-2,4-nonadienal were replicated. Short antennal preparation life, hydrophobic antennal structures, and chemosensory structures being located on the distal third of the antennal club all made electrophysiological contact difficult to maintain with the saline electrodes. An alternative technique will be attempted using tungsten electrodes.

Experiment 2

There was no difference in adult trap means between gray or yellow floating cone traps (Fig. 2A). The mean totals for adults in the 7-day trap were 16.73 adults/trap (± 2.15 SE) for the yellow and 14.45 adults/trap (± 1.69 SE) for the gray traps. The traps caught about the same number of weevils as in the experiment in 1998. In 1998, larval numbers were significantly below the current Arkansas economic threshold of 10 larvae/core. The larval densities were above the threshold in 1999 (Fig. 2B). The low trap means in 1998 could have been due to low weevil pressure, but that does not explain the low cone trap means for 1999. For the trap design to work, rice plant volatile lures and/or rice water weevil pheromones will have to identified.

Experiment 3

The aquatic barrier traps caught 11 times more adult weevils than any of the floating cone traps with and without lures. There were no significant differences in trap catches among the floating cone traps (Fig. 3). There were no significant differences among the eight bays in larval means from core samples. The overall mean for the bays was 20.81 larvae/core (± 4.36 SE), which was above the accepted level that causes economic damage in rice in Arkansas.

Experiment 4

The Cross County field had the largest mean barrier trap catch, followed by St. Francis County, and Arkansas County had the lowest (Table 1). The data from the untreated commercial fields is summarized in Table 1. The Cross County site and St. Francis County were above the previous Arkansas threshold of 10 larvae/core (Morgan *et al.*, 1989), while the Arkansas County site was slightly at or below the previous threshold. Less than one adult weevil/trap was caught by the barrier traps in the control field in Cross County, and the larvae/core was below one/core. A significant regression ($r^2 = 0.63$) was calculated using all edge and center trap data. Thus 1.0 adult count per day per trap equaled 1.41 larvae per plant/soil core sample (Fig. 4).

Experiment 5

For each sample period, early June and late July 1999, the mean adult barrier trap captures and larvae/core among four bays were similar, indicating good trap precision (Fig. 5). The 1998 preliminary barrier trap evaluation is depicted to show the linear relationship of these extremely high mean densities of adults and larvae to lower trap and core means recorded in 1999. For early June, the means of bay adult per trap ranged from 9 to 14. Concurrently, bay larval means per core ranged from 12 to 21, and all means were above the previous threshold. A similar trend was observed in late July, during which bay adult means were higher as were bay larval means. The mean counts of larvae/core were about the same within the early June plots and within the late July plots. Over 10,000 weevils were caught in 32 traps over a 9-day period in the late small-plot evaluation.

SIGNIFICANCE OF FINDINGS

Data from these studies indicate that aquatic barrier traps could be used to determine the need for insecticidal treatment against adult rice water weevils within 10 days after permanent flooding of drill-seeded rice. The aquatic barrier trap intercepted swimming adult weevils requiring no lure or bait. There was a linear relationship between the number of adult rice water weevils caught in the barrier traps and the subsequent number of larvae in plant/soil core samples at 21 days postflood. Data indicated that 1.0 adult weevils per trap equaled about 1.41 larvae per core. These data could be a good starting point for establishing an economic threshold for the barrier traps.

ACKNOWLEDGMENTS

We thank Dan Baxter, Tahir Rashid, Bond Farms, Shelby Wright Farms, and Crossed-I Farms. We also thank the Arkansas Rice Research and Promotion board for funding this project.

LITERATURE CITED

Bernhardt, J.L. 1997. Control of rice water weevil with Karate 1996. Arthropod Management Tests. 22:289.

Bernhardt, J.L. 1998. Control of rice water weevil with Dimilin,1997. Arthropod Management Tests. 23:258.

Hernandez, H.P., T.C.Y. Hsieh, C.M. Smith, and N.H. Fischer. 1989. Foliage volatiles of two rice cultivars. Phytochemistry 28:2959-2962.

Hix, R.L., D.T. Johnson, and J.L. Bernhardt. 2000. An aquatic barrier trap for monitoring adult rice water weevils. Florida Entomol. 83 (in press).

Hix, R L., D.T. Johnson, J.L. Bernhardt, T.L. Lavy, J.D. Mattice, and B.L. Lewis. 1998. Development of an IPM Monitoring Program for Rice Water Weevil Adults. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1997. University of Arkansas Agricultural Experiment Station Research Series 460:95-102.

Hix, R. L., D.T. Johnson, J.L. Bernhardt, J.D. Mattice, and B.L. Lewis. 1999. Trapping adult rice water weevils with floating cone and barrier traps. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:135-141.

Morgan, D.R., N.P. Tugwell, and J.L. Bernhardt. 1989. Early rice field drainage for control of rice water weevil (Coleoptera: Curculionidae) and evaluation of an action threshold based upon leaf-feeding scars of adults. J. Econ. Entomol. 82:1757-1759.

Table 1. Mean (± SE) adult weevils per barrier trap (n = 8) for the three commercial fields for 1 to 6 days post flood and sample mean counts of larvae per plant/soil core at 21 days post flood (n = 8) in 1999.

	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	Trap Totals	Larvae/Core
Cross County	21.4	19.0	28.4	20.3	28.0	15.0	132.0	62.8
Edge	(4.16)	(2.34)	(6.87)	(6.23)	(7.11)	(3.43)	(19.28)	(6.69)
Cross County	86.6	25.8	21.3	4.5	1.0	1.81	140.9	23.1
Interior	(12.73)	(7.86)	(6.29)	(1.69)	(0.33)	(0.42)	(21.31)	(2.68)
St. Francis County	2.4	3.0	6.9	17.9	13.6	14.5	60.6	15.3
Edge	(0.57)	(0.71)	(1.43)	(2.64)	1.59	2.77	(6.23)	(2.17)
St. Francis County	23.9	13.6	24.0	16.8	8.1	7.5	80.8	17.3
Interior	4.88	(2.99)	(2.40)	(4.28)	2.07	(1.3)	16.37	(2.74)
Arkansas County	10.1	6.6	5.3	4.4	4.9	6.4	37.6	10.0
Edge	(1.69)	(1.4)	(1.57)	(1.94)	(2.01)	(2.75)	(10.57)	(1.67)
Arkansas County	6.1	2.1	1.5	0.8	3.0	12.4	25.9	6.4
Interior	(0.91)	(0.4)	(0.42)	(0.49)	(1.25)	(4.14)	(5.14)	(1.41)

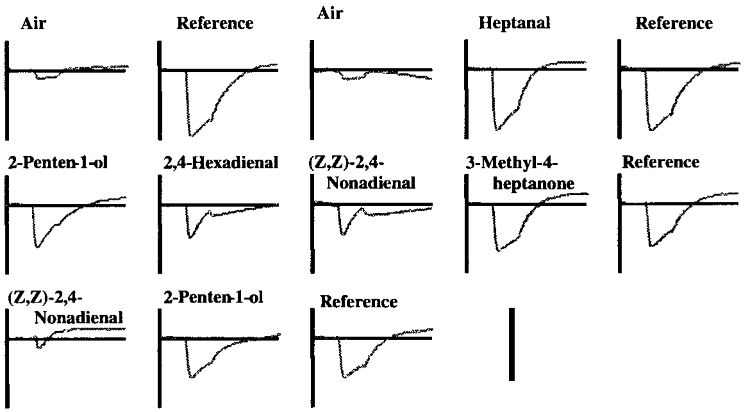


Fig. 1. Electroantennogram responses to volatile standards. The reference compound was hexanal. The bar = 1 millivolt.

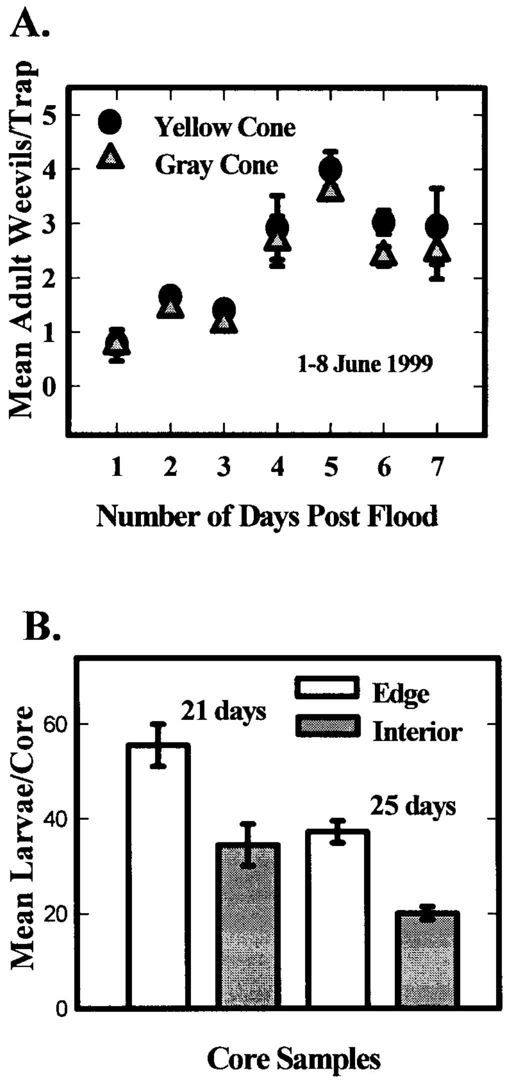


Fig. 2. A. Daily adult rice water weevil means for gray and yellow floating cone traps in Cross County. Bars denote SE (N=4). B. Larval rice water weevil core samples at 21 and 25 days postflood. Previous Arkansas economic threshold = 10 larvae/core. Bars denote SE (n = 32).

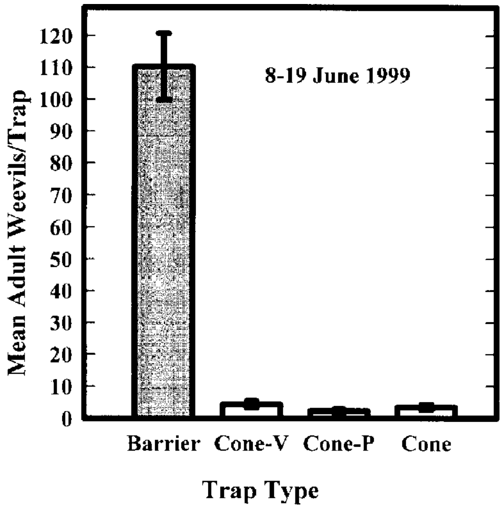


Fig. 3. Mean weevil captures by aquatic barrier trap (barrier), floating cone trap with volatiles (Cone-V), floating cone trap with grandisoic acid (Cone-P), and floating cone trap without lure (Cone) at the Rice Research and Extension Center, Stuttgart. The bars represent SE (n = 16).

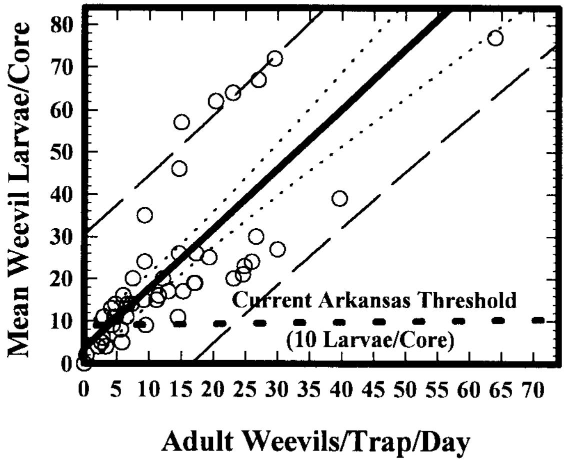


Fig. 4. Scatter plot and regression of the three commercial fields and control field. Small dots indicate 95% confidence intervals, and large dashes indicate prediction intervals ($r^2 = 0.63$; n = 64).

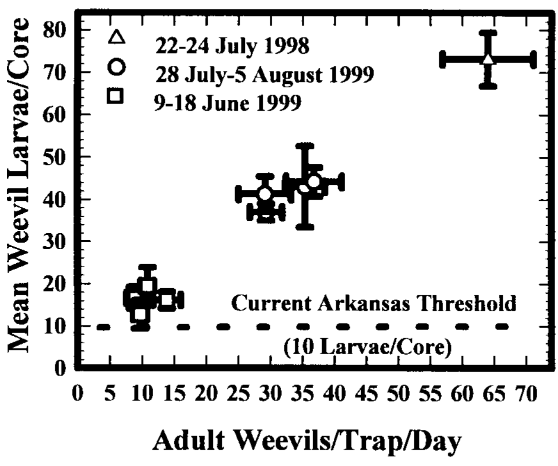


Fig. 5. Small-plot evaluations of aquatic barrier trap in 1998 (n = 16) and 1999 (n = 8). The horizontal bars represent SE for the adult means, and the vertical bars represent the SE for the larval means.

REACTION OF RICE CULTIVARS/LINES TO FALSE SMUT, STEM ROT, AND BLACK SHEATH ROT DISEASE

R.D. Cartwright, F.N. Lee, T. Beaty, E.A. Sutton, and C.E. Parsons

ABSTRACT

A total of 161 rice lines were evaluated in three separate disease nurseries at the Pine Tree Experiment Station. The false smut nursery relied on natural inoculum, while the stem rot and black sheath rot nurseries were inoculated to produce uniform disease. There were 108 lines infected by false smut, with 28 lines having greater than 10 smut balls on any panicle. The highest number of smut balls observed on any panicle was 28, for line RU9901121. All 160 lines evaluated for stem rot and black sheath rot were infected by the respective pathogens (one line was left out in these nurseries). For stem rot, the lines STG96L--23-048 and STG96L--01-058 were the most susceptible. There were 79 lines rated 3.0 or higher in the stem rot nursery, a level indicating susceptibility. Only seven lines were rated below 2.0 and considered possibly resistant to stem rot. The most susceptible lines to black sheath rot were RU9801111 and RU9901133, although 35 other lines were also considered susceptible in this nursery. Only 17 lines were rated consistently resistant, scoring a 1.0 out of the 0 to 9 scale.

INTRODUCTION

Numerous "minor" rice diseases continue to cause problems for Arkansas growers in certain fields or years when conditions favor their development. Developing rice varieties resistant to these sporadic and difficult to research diseases has not been a priority in any United States rice-breeding effort, for various reasons. Nevertheless, resistance is the most practical and economical means of minimizing the impact of kernel smut, false smut, stem rot, and black sheath rot. While priority for disease resistance development will remain focused on the major diseases, sheath blight and blast, efforts to evaluate germplasm in Arkansas to the sporadic diseases continues.

False smut is caused by the fungus *Ustilaginoidea virens* and was first reported in Arkansas during 1997 (Cartwright *et al.*, 1998), where it was found in four northeast counties. Since then, the disease has spread to all major rice-producing counties in the state. While it has caused only minor yield loss so far, its impact on the quality of Arkansas rice is a major concern, given the unattractive appearance of the smut balls harvested with rice grain and their reported toxic properties.

Stem rot remains a sporadic problem in Arkansas, mainly on the thin, potassium-deficient soils where most rice is produced. The similar stem disease, black sheath rot, causes concern mainly in fields new to rice production or fields that have been rotated out of rice for many years. Both have been the target of expensive and usually unnecessary fungicide applications over the years, an economic problem that resistant varieties could eliminate.

Evaluation of advanced rice lines and other germplasm for reaction to the minor diseases was continued in this study as a component of the resistant cultivar development program at the Rice Research and Extension Center, Stuttgart, directed by F.N. Lee.

PROCEDURES

Small plots of 161 cultivars/lines were planted in three nurseries using a tray planter (three rows, 3 ft long with 1-ft spacings) with four replications per line. One nursery was located in an area that had false smut the previous season. The other two nurseries were located next to each other but divided by levees and had separate irrigation systems. The false smut nursery relied on natural inoculum, while the stem disease nurseries were inoculated. False smut ball levels were estimated in each plot, and the maximum value for any panicle within a line was reported. False smut data were too erratic to analyze.

Stem rot inoculum was prepared according to the method of Krause and Webster (1972) with the following modification. Instead of separating sclerotia from the grain/hull mixture, the mixture was air dried and stored in plastic boxes at room temperature until needed. Just prior to inoculation, the mixture was pulverized to uniformity and screened using hardware cloth (0.25 in. diameter), then applied with a hand-held seeder (Cyclone) throughout the plots at panicle initiation and again 7 days after panicle differentiation (based on cv 'Jefferson'). Approximately 1 L of grain/hull/ sclerotia mixture was applied at approximately 1 L/100 ft^2 of plot each time.

Black sheath rot inoculum was prepared by growing the fungus in V-8 juice broth on a lab shaker for 5 to 7 days at 200 rpm at room temperature. Flask contents were blended with 1% sodium alginate/1% corn meal/12% mineral oil (in water) mixture [1:3 proportion] for 1 min, then dripped into 0.25 M $CaCl_2$ solution to gelatinize as floating pellets. Pellets were air dried 24 hours, then stored at 5°C until needed. Pellets were applied with a hand seeder to the black sheath rot plots at approximately 200 ml of pellets/100 ft^2 at panicle initiation of Jefferson.

For stem rot, tillers from each plot were inspected just prior to grain maturity and evaluated according to the 1 to 5 rating scale of Krause and Webster (1972). Black sheath rot was evaluated on the basis of a 0 to 9 scale as follows: 0 = no disease; 1 = relative lesion height (RLH) of 1-9; 2 = RLH of 10-19; 3 = RLH of 20-29; 4 = RLH of 30-39 and/or mild culm/node rot; 5 = RLH of 40-49 and/or moderate culm/node rot; 6 = RLH of 50-59 and/or moderately severe culm/node rot; 7 = RLH of 60-69 and/or severe culm/node rot; 8 = RLH of 70+ and/or very severe culm/node rot; and 9 = tillers killed prior to grain fill. RLH was determined by dividing symptom height by tiller height and multiplying by 100.

Other problems in the nurseries were noted, but not assessed quantitatively. Data were analyzed using analysis of variance (PRM software, Gylling Corp.) and a least significant difference value reported if there was a significant F test value ($P = 0.05$).

RESULTS AND DISCUSSION

The false smut nursery relied on natural inoculum, and the result was very erratic infection throughout the plots. To evaluate the lines, the maximum number of smut balls on any panicle within each line was reported (Table 1). Of the 161 entries (some varieties were repeated once from different seed sources), 108 had false smut. There were 28 entries with more than 10 smut balls on a panicle, 40 entries with 5 to 9 smut balls, and 40 entries with 1 to 4 balls (Table 1). The highest number of smut balls observed on any panicle was 28 for line RU9901121.

Inoculation of the stem disease nurseries resulted in uniform disease; however, data were not collected on line RU9602074. In the stem rot nursery, all 160 remaining entries were infected (Table 1). There were four entries with a disease index of 5.0, the most severe damage possible. These entries were SKG96L--23-048, SKG96L--01-058, RU9901136, and 'Lemont', and all were prematurely killed by the fungus (Table 1). The two SKG lines were killed very quickly and suffered greater than 50% grain blanking, by visual estimate, and should be considered extremely susceptible. Another eight entries had disease indices between 4.0 and 4.9 (Table 1). This level of damage means the culm was penetrated but may not have been completely colonized or killed prematurely. Nevertheless, these entries should be considered very susceptible to stem rot. There were 67 entries with disease indices between 3.0 and 3.9, meaning at least the outside of the culm was attacked (Table 1). These should be considered susceptible. An additional 74 entires were rated between 2.0 and 2.9, meaning the sheaths were damaged and should be rated as moderately susceptible (Table 1). Only 7 entries scored between 1.1 and 1.9 which would be considered moderately resistant to resistant if consistent under repeated testing (Table 1).

In the black sheath rot nursery, all 160 lines were infected (Table 1). There were two lines rated 6 out of a possible 9 for damage: RU9801111 and RU9901133 (Table 1).

Another 19 lines were rated 5.0, and 16 lines were rated 4.0, both categories being considered moderately susceptible to susceptible (Table 1). An additional 58 lines were rated 3.0, while 48 lines were rated 2.0 (Table 1). These groups would likely fit in a moderately resistant category if consistent under repeated testing. Only 17 lines rated 1.0, considered resistant (Table 1).

Other disease observations were made in the stem disease nurseries. Moderate false smut was observed on the following lines: RU9701050, RU9801136, RU9901111, RU9801170, STG96P--46-062, STG96L-04-067, and STG96L-04-003. Neck blast was observed on RU9901164, STG96L-05-077, 'Newbonnet', and RU9601093. An unusual interveinal bronzing was prominent on RU9701179, STG94M50-067, STG93M27-039, STG93M27-037, and STG95L--28-050. The cause of the bronzing was not known.

Many factors influence disease evaluation nurseries, so year-to-year data may vary for the same line. Ratings of susceptible to very susceptible are more reliable than those rated resistant, which may have escaped infection. To accurately define disease reaction, consistent long-term nurseries should be established and maintained.

SIGNIFICANCE OF RESULTS

The data reported are novel for certain U.S. rice-breeding lines, as little effort is being made elsewhere to accurately evaluate germplasm for reaction to these minor diseases. It is hoped that these results will help rice-breeding programs select and develop improved varieties without releasing a potential "time bomb" for any grower.

ACKNOWLEDGMENTS

Funding for this research was provided by rice grower checkoff funds through the Arkansas Rice Research and Promotion Board. We gratefully acknowledge the help of Mr. Roger Eason, Director of Pine Tree Experiment Station, and his staff for making this work possible. We appreciate the cooperation and support of Dr. Karen Moldenhauer in providing seed and technical advice.

LITERATURE CITED

Cartwright, R.D., F.N. Lee, R.M. Chlapecka, and S.R. Vann. 1998. First report of false smut of rice in Arkansas. Proc. 30th Annu. RTWG Meeting, March 1-5, 1998, Reno, Nevada (Abst.).

Krause, R.A., and R.K. Webster. 1972. Sclerotial production, viability determination and quantitative recovery of Sclerotium oryzae from soil. Mycologia 64:1333-1337.

Table 1. Evaluation of rice germplasm to false smut, stem rot, and black sheath rot disease, 1999.

		Diseases and ratings[z]		
Cultivar/Line	Pedigree	False Smut	Stem Rot	Black Sheath Rot
RU9801081[y]	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	3	1.8	1
RU9601096	291643/MARS	0	2.8	1
RU9601099	291643/MARS	0	1.7	1
RU9701090	LBNT/9902//NWBT/3/MILL	0	2.7	1
RU9801099	514661/MARS	0	3.0	1
RU9901014	GCHW/GFMT	0	1.8	2
RU9502008	CCDR	8	2.8	2
RU9801090	880427	0	3.2	2
RU9801148	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	0	2.7	2
RU9801111	LGRU/LSCN	6	3.3	6
RU9901030	880427	0	2.0	3
RU9601053	WELLS	1	1.8	2
PI 568891	LGRU	3	1.8	3
RU9801105	LMNT/RA73//L202/TBNT	0	2.0	5
RU9701030	M201/KATY//MARS/TBNT	2	2.8	2
RU9701050	M201/KATY//NWBT	0	2.0	5
PI 561734	CPRS	11	3.0	3
RU9201176	DREW	3	2.8	3
RU9801121	LBNT/9902//NWBT/3/KATY/NWBT	2	1.8	1
RU9801136	NWBT/3/DAWN/9695//STBN/4/KATY/STBN	14	1.8	1
RU9801142	LBNT/9902//NWBT/3/LMNT/RA73	3	3.3	5
RU9801145	LGRU-12	2	3.0	5
RU9801173	KATY/NWBT//MARS/TBNT	4	3.0	2
PI 583278	KBNT	3	3.0	2

continued

Table 1. Continued.

Cultivar/Line	Pedigree	Diseases and ratings[z]		
		False Smut	Stem Rot	Black Sheath Rot
RU9901081	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	5	3.0	2
RU9901087	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	5	3.3	3
RU9901090	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	12	2.7	5
RU9901093	L201/9NRZ//KATY/3/MILL	0	3.0	5
RU9901096	LGRU//KATY/STBN	5	4.3	3
RU9901099	LGRU//KATY/STBN	9	3.0	3
RU9901102	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	22	3.0	4
RU9901105	86179/LGRU	8	3.0	2
RU9901108	LMNT/KATY/4/LBNT/9902/3/DAWN/9695//STBN	8	3.0	3
RU9901111	DREW/3/LMNT/RA73//KATY	4	3.0	2
RU9901121	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	28	3.0	2
RU9901124	KATY-45	2	4.0	3
RU9901127	M401/BNGL	0	2.0	2
RU9901130	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	6	2.8	2
RU9901133	ADAR/JDON	8	3.0	6
RU9901136	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	0	5.0	3
RU9901139	BNGL/3/SMARS/MARS//MARS	1	3.0	3
RU9901142	NWBT//LBNT/STBN/3/CPRS	20	3.0	4
RU9901145	RSMT//NWBT/KATY	0	3.0	1
RU9901148	KBNT/L202	0	3.0	1
RU9801151	NWBT//LBNT/STBN/3/LCSN	11	3.0	3
RU9901161	KATY/STBN//RSMT	0	3.0	1
RU9901164	KBNT/LCSN	0	2.3	1
RU9801167	KATY/STBN//CPRS	1	3.0	2

continued

Table 1. Continued.

		Diseases and ratings[z]		
Cultivar/Line	Pedigree	False Smut	Stem Rot	Black Sheath Rot
RU9801170	DLMT//KATY/NWBT	6	3.0	3
RU9801176	LBNT/9902//NWBT/3/KATY/NWBT	2	2.8	2
RU9801179	330464/MARS	3	3.0	2
RU9701179	LGRU/LCSN	3	2.0	4
RU9801185	KATY/NWBT//LMNT/RA73	0	2.7	3
RU9901188	L202/TBNT//NWBT/KATY	8	2.0	3
FarmBuster		0	3.3	3
L204		0	2.7	2
L205		18	2.3	2
Jefferson		3	2.0	5
Koshi-Hikari		0	2.0	1
M202		0	2.0	5
STG93M27-039	291643/MARS	0	2.0	3
STG93M27-037	291643/MARS	0	2.0	3
STG95L--28-050	KATY/STBN//9101001	0	2.0	3
STG96L--21-121	9101001/KATY	0	3.0	4
STG96L--01-050	KATY/NWBT/4/BN73/9837//PI265116/3/V6DW/STTD//L202	0	2.0	2
STG96L--23-048	9101001/KATY	0	5.0	2
STG96L--01-058	KATY/NWBT/4/BN73/9837//PI265116/3/V6DW/STTD//L201	0	5.0	3
Maybelle		0	3.0	3
STG96F5-38-001	M401/BNGL	3	2.0	2
STG96F5-10-054	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	0	2.0	1
STG95F5-27-084	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	9	3.0	4
STG94L40-137	LBNT/9902//NWBT/3/MILL	0	2.7	3

continued

Table 1. Continued.

		Diseases and ratings[z]		
Cultivar/Line	Pedigree	False Smut	Stem Rot	Black Sheath Rot
AkitaKomachi		0	4.0	3
STG94M58-085	514661/MARS	0	2.7	1
STG96F5-06-058	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	8	2.7	5
STG96F5-09-090	BNGL/M202	0	2.0	3
STG92L03-052	88427	19	2.3	3
STG96F5-10-029	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	0	3.0	4
STG96L--04-019	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	12	3.0	3
STG96L--06-091	LGRU//KATY/STBN	9	3.0	3
Millie		0	3.3	2
Jackson		4	3.0	3
Cocodrie		5	2.7	3
STG92L03-042	88427	11	2.0	1
STG96L--05-077	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	4	2.2	2
Bengal		0	3.0	3
RU9602074	RU9602074	0		
STG95F5-27-044	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	2	2.0	3
STG95L20-008	NWBT/3/DAWN/9695//STBN/4/KATY/STBN	4	2.3	2
STG95L15-045	KATY/NWBT//MARS/TBNT	2	2.7	2
STG96F5-09-027	BRAZ/TBNT/3/164986-4/NV66//NTAI/4/BNGL	0	4.0	3
STG96F5-20-011	BNGL/3/SMARS/MARS//MARS	2	3.0	2
STG96P--46-084	L202/TBNT//NWBT/KATY	8	2.0	3
STG95L04-050	LBNT/9902//NWBT/3/KATY/NWBT	6	2.0	2
STG96L--05-088	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	2	3.0	3
STG96L--06-089	LGRU//KATY/STBN	1	3.7	3

continued

Table 1. Continued.

Cultivar/Line	Pedigree	Diseases and ratings[z]		
		False Smut	Stem Rot	Black Sheath Rot
STG96F5-37-092	BNGL/3/SMARS/MARS//MARS	0	2.0	2
STG96P--46-102	CPRS/LGRU	10	3.0	4
STG96L--05-084	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	9	2.0	4
STG96L--05-078	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	5	3.0	3
STG96P--46-056	L202/TBNT//NWBT/KATY	6	3.0	4
STG96P--46-083	L202/TBNT//NWBT/KATY	2	3.0	3
STG96L--09-135	86179/LGRU	0	2.0	1
STG96L--05-092	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	3	3.0	2
STG95L08-108	DLMT//KATY/NWBT	22	3.0	5
STG96P--46-062	CPRS/RU9201176	17	2.0	4
Kaybonnet		2	2.0	2
LaGrue		0	2.3	3
Wells		6	2.0	2
Priscilla		6	2.0	2
Cypress		2	3.3	3
STG96L--13-127	IRGA409/RXMT	12	2.0	2
STG96L--13-129	IRGA409/RXMT	6	2.0	3
STG95F5-06-131	LGRU/LSCN	6	2.7	2
LGRU-2	LGRU-2	8	2.3	3
STG96L--25-043	KATY/STBN//KATY/STBN	6	2.0	4
STG94L25-138	M201/KATY//NWBT	8	3.7	5
STG95L04-111	LBNT/9902//NWBT/3/LMNT/RA73	4	3.0	3
STG96L-10-012	L201/9NRZ//KATY/3/MILL	0	3.0	5
STG96L-10-114	86179/LGRU	8	2.0	4

continued

Table 1. Continued.

		Diseases and ratings[z]		
Cultivar/Line	Pedigree	False Smut	Stem Rot	Black Sheath Rot
STG96L-11-047	LMNT/KATY/4/LBNT/9902/3/DAWN/9695//STBN	12	2.0	2
STG96P-19-059	RU9201176/3/LMNT/RA73//KATY	4	3.0	2
STG94L40-025	LBNT/9902//NWBT/3/KATY/NWBT	0	4.0	2
STG96F5-25-045	TBNT/KATY//CPRS	0	4.3	5
STG96F5-36-073	KBNT/CPRS	5	4.0	4
STG96F5-25-016	TBNT/KATY//L202/TBNT	7	3.0	5
STG96F5-28-005	CPRS//NWBT/KATY	0	4.7	3
STG96F5-28-069	CPRS//NWBT/KATY	7	2.7	3
STG94L18-010	LGRU/LCSN	0	3.0	3
STG96F5-01-131	KATY/L202	3	3.0	2
STG96F5-32-049	LCSN//LMNT/RA73	14	2.7	4
STG96F5-11-057	KBNT/RSMT	11	2.0	3
Drew		0	2.0	3
Katy		0	2.0	3
Newbonnet		18	3.0	2
Lemont		0	5.0	5
Madison		0	2.0	5
STG94P44-048	LMNT//82CAY21/CICA8/3/MARS/TBNT	9	2.0	3
STG95F5-21-018	LMNT/RA73//L202/TBNT	4	3.0	4
STG94L44-114	M201/KATY//MARS/TBNT	2	3.0	3
RU9801145	LGRU-12	2	2.0	3
STG96L--04-067	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	15	3.0	2
STG96L--04-003	LBNT/9902/3/DAWN/9695//STBN/4/LGRU	16	3.0	3
RU9901124	KATY-45	6	3.0	5

continued

Table 1. Continued.

		Diseases and ratings[z]		
Cultivar/Line	Pedigree	False Smut	Stem Rot	Black Sheath Rot
STG96F5-16-128	ADAR/JDON	8	3.7	3
STG96F5-08-127	NWBT//LBNT/STBN/3/CPRS	5	2.7	2
STG96F5-30-012	RSMT//NWBT/KATY	18	3.0	3
STG96F5-12-049	KBNT/L202	3	2.3	2
STG95F5-25-088	NWBT//LBNT/STBN/3/LCSN	15	3.0	3
STG96F5-13-007	KATY/STBN//RSMT	5	2.7	3
STG96F5-36-034	KBNT/LCSN	7	3.0	4
STG95F5-34-067	KATY/STBN//CPRS	11	2.0	3
STG96F5-29-008	RSMT//NWBT/KATY	5	2.3	2
STG94M50-067	330464/MARS	3	2.0	2
STG96P--46-061	CPRS/RU9201176	17	3.3	4
STG94L35-085	KATY/NWBT//LMNT/RA73	9	3.0	3
STG96P--46-087	L202/TBNT//NWBT/KATY	13	2.0	3
STG96L--24-049	LMNT/RA73//KATY	10	2.0	5
RU9601093	STIFF STRAW	0	2.0	1
Early LaGrue		2	2.3	2
LaGrue-13		18	2.0	2
LSD (0.05)			1.2	1.8

[z] False smut data are maximum number of false smut balls on any infected panicle; Stem rot data are disease index values where 1= no disease and 5 = culm infected and tiller prematurely killed; Black sheath rot data are ratings from 0-9 where 0 = no disease and 9 = tillers killed.

[y] Entries preceeded with RU, PI, or STG are experimental rice varieties that are not for sale.

DISEASE MONITORING AND ON-FARM EVALUATION OF RICE VARIETIES IN ARKANSAS

R.D. Cartwright, F.N. Lee, C.E. Parsons, W.J. Ross, and E.A. Sutton

ABSTRACT

The rice disease monitoring program continued in 1999, with 17 cultivar/lines planted on farms in seven counties and 13 cultivar/lines in five other counties. Statewide, diseases were less severe in 1999 than the past few years because of the extremely hot and dry July and August. Cultivar/line yields varied, with the Arkansas and Lawrence county sites being the highest overall. The highest-yielding varieties across all locations were 'Wells', 'Drew', 'Cocodrie', 'LaGrue', and 'Priscilla'. Yields varied least across locations for Drew, Priscilla, 'Cypress', Wells, and 'Bengal'. Cultivars with the highest yield at any location were Wells, LaGrue, Drew, and Cocodrie. Diseases were sporadic at each location, with false smut present at the Lawrence, Randolph, and Lonoke sites and straighthead dominating the Faulkner site. Blast was nonexistent except for the Randolph location. Sheath blight was evident at several locations but was not as severe as in previous years.

INTRODUCTION

Numerous diseases of rice occur worldwide and vary in type and intensity owing to geographic location and production practices (Ou, 1985). Over time, new diseases emerge or minor diseases may change in importance (Webster and Gunnell, 1992).

In the United States, there are at least five major diseases (sheath blight, blast, stem rot, kernel smut, and seed/seedling disease) caused by fungi and one major physiological disorder (straighthead) (Webster and Gunnell, 1992). In addition, brown spot of rice can be of major importance on potassium-deficient rice, as observed in Arkansas in 1994 (Cartwright *et al.*, 1995). There are also numerous minor diseases principally caused by fungi, although a bacterial and nematode disease has also been reported (Webster and Gunnell, 1992). In addition, there remain several diseases of yet unknown cause that have been recently noted.

In Arkansas, many fungal diseases and straighthead are common, and this project continues to define them and their relative severity (Cartwright *et al.*, 1994; Cartwright *et al.*, 1995).

Monitoring rice diseases is important in a changing agroecosystem. New problems must be identified early, before causing widespread damage. An example of change occurred in 1997 and 1998, as false smut became more widespread and important for unknown reasons. For maximum value, monitoring must be consistent and ongoing. Results from monitoring programs can guide research through early detection and suggest potential control options. A second aspect of this monitoring program is the use of replicated-variety plots on different farms, which allows ongoing evaluation of variety performance across widely varying growing conditions. This on-farm evaluation effort can provide data for diseases that cannot be produced artificially and offer training on rice diseases to growers, county agents, consultants, and others.

PROCEDURES

A set of 17 rice cultivars/lines with different susceptibility to rice diseases were planted in grower fields in Chicot, Clay, Faulkner, Lawrence, Lonoke, Prairie, and Randolph counties. A set of 13 cultivars/lines were planted in Arkansas, Craighead, Cross, Poinsett, and Woodruff counties. Grower fields were selected by cooperating extension agents on the basis of disease history, cultural practices, and previous observations. Cultivars were planted in plots eight rows wide and 25 ft long with 7-in. spacing and replicated four times in a randomized complete-block design. Fertilization and other management practices were conducted by the grower with the rest of the field. No fungicides were applied to any of the test plots. Plots were examined periodically for diseases beginning at internode elongation, and final disease incidence and severity data were taken just prior to grain maturity for each location. Plots were harvested with a plot combine and yields adjusted to 12% moisture.

RESULTS AND DISCUSSION

Rice diseases were generally less severe in 1999 than previous years, probably because of the extremely hot, dry weather after the first week of July. Many minor foliar diseases commonly observed in most years were not noted in 1999. Overall, sheath blight and leaf blast were aggressive in June, but moderated or disappeared in July and August. Kernel smut was much less important statewide than any of the previous six seasons. However, severe kernel smut was observed in a few northeast Arkansas fields planted with LaGrue. False smut continued to spread to other counties and now is likely in every major rice county in the state. Severity of false smut was lower, however, than in 1998. Other diseases were minor to nonexistent.

The Craighead location was lost to herbicide injury, while the Poinsett location was not harvested because of red rice. Of the remaining sites, yields varied widely as in previous years (Table 1). Yields were highest at the Arkansas and Lawrence county sites, characterized by few problems, and lowest at the Chicot location (lodging) and the Faulkner county site (straighthead) (Table 1). The highest-yielding varieties across locations were Wells, Drew, Cocodrie, LaGrue, and Priscilla. The most stable varieties as measured by variation in yield across locations (CV) were Drew, Priscilla, Cypress, Wells, and Bengal. Varieties with the highest yield at any location were Wells, LaGrue, Drew, and Cocodrie. Yield performance for selected rice varieties in the disease monitoring program since 1994 is detailed in Table 2. From 1994 to 1999, Bengal and LaGrue had the highest average yield across all sites, although Bengal's performance since 1996 has dropped (Table 2). Drew and Wells had the next highest yields over this time period (Table 2).

Disease reactions of the varieties for 1999 are listed in Table 3. Only sheath blight, blast, kernel smut, false smut, and straighthead were included. The false smut reactions were from an inoculated site in Lonoke County next to the disease monitoring plots, but natural levels around the state were much lower. Most disease levels were lower in 1999 than previous years. Straighthead reactions were taken from the Faulkner County site. Based on these and other data, letter reactions for the varieties were updated and are provided in Table 4. These reactions may differ slightly from previous reports because of new data. Reaction letters represent a "worst case" scenario where disease conditions are extremely favorable, which does not usually occur over large areas in any given year. Nevertheless, growers should understand when selecting a variety that risk potential is equally important to yield potential under Arkansas conditions. This is especially true under current economic conditions, in which no grower can afford a single field failure.

SIGNIFICANCE OF RESULTS

Results demonstrate the impact of diseases on various rice varieties in the state. Data can be used by growers to evaluate not only the on-farm yield potential of different varieties, but also their risk potential under disease favorable conditions. By considering both, Arkansas rice growers can help ensure the maximum performance and profitability of each rice field on their farm. Results also continue to define variety reaction to the new disease false smut, which may become more important to growers because of the growing quality concerns of rice buyers.

ACKNOWLEDGMENTS

This research was funded by rice grower checkoff funds through the Arkansas Rice Research and Promotion Board. Special thanks to Drs. K.A.K. Moldenhauer and Nathan Slaton. Sincere appreciation to the following Cooperative Extension Service agents for their outstanding cooperation in this research: W. Dodgen, R. Gipson, C. Hayden, Q. Hornsby, J. McGee, M. Phillips, S. Runsick, P. Sims, B. Thiesse, R. Thompson, and R. Wimberley. Finally, deeply sincere appreciation to all participating rice growers, without whose land, equipment, patience, and excellent advice this program would not have been possible.

LITERATURE CITED

Cartwright, R.D., F.N. Lee, D.L. Crippen, and G.E. Templeton. 1994. Monitoring of rice diseases under different locations and cultural practices in Arkansas. *In:* B.R. Wells (ed.). Arkansas Rice Research Studies 1993. University of Arkansas Agricultural Experiment Station Research Series 439:86-100.

Cartwright, R.D., F.N. Lee, G.L. Cloud, D.L. Crippen, and G.E. Templeton. 1995. Monitoring of rice diseases under different locations and cultural practices in Arkansas. *In:* B.R. Wells (ed.). Arkansas Rice Research Studies 1994. University of Arkansas Agricultural Experiment Station Research Series 446:125-136.

Ou, S.H. 1985. Rice Diseases, 2nd ed. Kew: Commonwealth Mycological Institute, CAB. 380 pp.

Webster, R.K., and P.S. Gunnell, eds. 1992. Compendium of Rice Diseases. Minneapolis: American Phytopathological Society. 62 pp.

Table 1. Rice disease monitoring plot yields for 1999.

Variety	Arkansas	Chicot	Clay	Cross	Faulkner	Lawrence	Lonoke
				(bu/acre)			
AB647		61	179		93	169	131
AB1542		94	109		76	168	142
AB2975		58	136		74	165	125
AB3004			165		110	173	109
Bengal	149	102	112	154	104	145	115
Cocodrie	184	156	132	176	77	178	133
Cypress	159	122	125	145	97	155	108
Drew	183	164	139	160	121	158	121
Jefferson	118	167	124	161	73	153	109
LaGrue	190	42	150	186	140	187	127
Lemont	166	128	129	159	86	160	95
Madison	163	139	122	158	91	165	85
M202	112		159	135	70	182	121
Priscilla	164	159	138	164	124	178	113
Wells	195	166	141	170	107	180	119
RU9602074		34	148		153	148	138
RU9801148	165	114	129	153	94	147	111
LSD (0.05)	20	21	11	24	22	14	16

continued

Table 1. Continued.

Variety	Prairie	Randolph	Woodruff	Average yield across sites	CV[z]	Maximum yield across sites
	(bu/acre)					
AB647	141	143		131	32	179
AB1542	136	182		130	30	182
AB2975	17	171		119	36	171
AB3004	114	114		131	23	173
Bengal	111	161	167	132	19	167
Cocodrie	145	168	153	150	21	184
Cypress	135	162	141	135	16	162
Drew	137	162	159	150	13	183
Jefferson	118	145	162	133	22	167
LaGrue	143	137	176	148	30	190
Lemont	126	145	136	133	20	166
Madison	128	156	147	135	21	165
M202	132	105	67	120	31	182
Priscilla	129	136	167	147	15	178
Wells	148	160	171	156	18	195
RU9602074		163		131	37	163
RU9801148	122	133	180	135	20	180
LSD (0.05)	18	21	18			

[z] CV = coefficient of variation for yield across all sites.

Table 2. Summary yield data of selected varieties from rice disease monitoring plots (1994 to 1999).

Variety	1994	1995	1996	1997	1998	1999	Mean 1994-1999
	(bu/acre)						
Bengal	181	164	171	162	135	131	157
Lagrue	167	146	181	158	142	148	157
Drew	165	144	172	152	130	150	152
Wells	—	—	—	151	135	156	147
Kaybonnet	165	138	165	143	124	—	147
Cocodrie	—	—	—	—	130	150	140
Priscilla	—	—	—	145	124	147	139
AB647	—	—	—	148	132	131	137
Newbonnet	141	118	162	135	125	—	136
Lemont	147	126	149	138	115	133	135
Cypress	140	127	155	136	116	135	135
Katy	149	128	150	132	111	—	134
Jefferson	—	—	142	129	117	133	130
Madison	—	—	—	—	115	135	125
Koshi-hikari	—	—	—	133	110	—	122
M202	—	—	149	114	91	119	118

Table 3. Summary disease data for various rice cultivars/lines at the most severe monitoring locations (within year) in Arkansas, 1994 to 1999[z].

VARIETY	SHB 1994	SHB 1995	SHB 1996	SHB 1997	SHB 1998	SHB 1998	NB 1994	NB 1995	NB 1996	NB 1997	NB 1998	NB 1999
AB647				2.5	3.5	2				0	0	0
Bengal	5	5	4	4	4.5	3.5	1	44	18	4	0	1
Cocodrie					8	6.5					0	0
Cypress	6	7	6	6	8	6.5	6	10	2	0	0	0
Drew	3	5	4	4.5	6	4		0	0	0	0	0
Jefferson			5	6	7	4			12	6	0	1
Katy	4	6	4	5	7			0	0	0	0	
Kaybonnet	5	6	5	4.5	6		1	1?	0	0	0	
Koshihikari				4	4					0	0	
Lafitte			4	4.5	5				0	0	0	
Lagrue	4	6	4	5	6	4.5	4	35	36	18	10	15
Lemont	6	7	6	6	8	7	1	70	16	2	0	2
Litton				4	5					0	0	
Madison					8	6					0	0
M202			4	4.5	6.5	7			100	52	50	35
Newbonnet	3	5.5	3	4	5		10	100	40	22	10	
Priscilla				4.5	6	4				4	0	5
Wells				4	5.5	4.5				1	0	13

continued

Table 3. Continued.

VARIETY	KS 1994	KS 1995	KS 1996	KS 1997	KS 1998	KS 1999	FS 1998	FS 1999	SH 1999
AB647				4	5	1	3.8	28.3	50
Bengal	3	6	3	9	5	1	0.4	3.3	40
Cocodrie					8	3	3.1	15.0	90
Cypress	8	13	7	15	13	5	1.4	5.7	5
Drew	4	7	5	8	9	1	2.7	18.0	0
Jefferson			6	8	11	1	0.4	1.7	1
Katy	1	3	1	4	6		0.9		
Kaybonnet	5	4	3	8	7		1.8		
Koshihikari				2	1		1.2		
Lafitte			8	14	6		0.5		
Lagrue	11	18	13	20	19	6	1.6	16.0	10
Lemont	2	3	1	3	5	0	0.9	5.0	35
Litton				20	15		0.1		
Madison					5	0	0.0	4.7	30
M202			5	12	6	5	0.1	0.7	50
Newbonnet	9	12	6	14	12		2.4		
Priscilla				12	11	8	1.1	10.3	15
Wells				6	8	1	1.9	3.3	20

z Diseases were evaluated as follows: Sheath blight (SHB) = 0-9 ratings where 0 = no disease and 9 = severe disease; neck blast (NB) = % infected tillers; kernel smut (KS) = % smutted kernels; false smut (FS) = 1998 = no. of false smut balls/panicle and 1999 = no. of false smut balls/lb rice; straighthead (SH) = % of panicles with an distortion.

Table 4. Disease reactions for United States rice cultivars/lines that have been included in the monitoring/on-farm evaluation program (1994 to 1999).

Variety	Sheath Blight	Blast	Stem Rot	Kernel Smut	False Smut[z]	Brown Spot	Straighthead
AB647	MS[y]	R	MS	S	S	R	VS
Bengal	MS	MS	VS	MS	MR	VS	VS
Cocodrie	VS	MS[x]	S	VS	S	R	VS+
Cypress	VS	MR	MS	VS	S	R	MS
Drew	MS	R	MS	MS	S	S	MS
Jefferson	MS	S	MS	S	MR	R	MR
Katy	MS	R	MS	R	MR	R	S
Kaybonnet	MS	R	MS	MS	MS	S	S
Koshihikari	MS	MR	S	R	MR	MR	-
Lafitte	MS	MR	MS	S	S	MS	VS
Lagrue	MS	S	MS	VS	S	R	MS
Lemont	VS	MR	MS	R	MS	R	MS
Litton	S	MS	MS	S	R	-	MS
Madison	VS	R	MS	R	MS	R	MS
M-202	S	VS[w]	MS	VS	MR	S	S
Newbonnet	MS	VS	S	VS	S	R	MR
Priscilla	MS	S	MS	S	S	R	MR
Wells	MS	S	MS	MR	MS	R	MS

[z] Abbreviations: R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; and VS = very susceptible.
[y] Ratings are tentative.
[x] Rating based on LSU observations. Tentative for Arkansas conditions.
[w] Not recommended for Arkansas because of extreme susceptibility to rice blast.

EFFECT OF NITROGEN FERTILIZER RATE AND APPLICATION METHOD ON SHEATH BLIGHT AND YIELD OF 'CYPRESS' RICE

R.D. Cartwright, R.J. Norman, and N.A. Slaton

ABSTRACT

Field experiments to determine the effect of nitrogen (N) fertilizer timing and rate on sheath blight and grain yield of 'Cypress' rice were conducted in 1998 and 1999 at the Rice Research and Extension Center, Stuttgart. Application methods compared were the Optimum (formerly Single) Preflood Method (OPM), 2-Way Split (2WS), and the traditional 3-Way Split Method (3WS), all with 0, 60, 90, 120, 150, and 180 lb total N/acre applied. Yield and final sheath blight levels were similar across all application methods at recommended N rates of 120 lb (OPM) or 150 lb (2WS, 3WS). However, higher N rates of 150 or 180 lb/acre applied using the OPM did result in earlier sheath blight damage than when using the 2WS or 3WS methods. While the OPM offers a more efficient and less expensive way of applying N fertilizer on the newer short-season rice, growers using this method should clearly avoid N rates higher than recommended (>120 lb/acre)—especially on sheath blight-susceptible semi-dwarf cultivars.

INTRODUCTION

Sheath blight has become the most important rice disease in the southern United States, largely because of semi-dwarf varieties, excessive nitrogen fertilizer use, excessive seeding rates, and intense crop rotations. Sheath blight causes direct yield and head rice loss through damage to rice foliage prior to the completion of grain fill. Yield losses of 50% have been measured in very severe instances but are typically 8 to 15% on severely affected semi-dwarf rices in Arkansas. Head rice losses of 1 to 3 lb/cwt have been noted in severely diseased fields.

The use of N fertilizer on modern rice is one of the most critical practices to assure high yield and quality. However, rates of N fertilizer higher than that required for optimum yield can result in increased sheath blight damage. While the effect of total N rate on sheath blight severity is well recognized, the effect of N timing on sheath blight has not been adequately studied.

There are currently three common timing methods for applying N fertilizer to rice in Arkansas. The OPM, formerly known as the Single Preflood Method, is newer and involves applying all the N fertilizer to the soil just prior to permanent flooding. The total N applied with the OPM method is 30 lb N/acre less than that used with the 2WS and 3WS methods. The 2WS divides the total N into two applications, the first and larger amount placed on the soil just prior to permanent flood and the final amount applied into the flood when rice reaches panicle initiation (PI) to panicle differentiation (PD) stage. The 3WS is the traditional way of applying N fertilizer to rice in Arkansas and divides the fertilizer into three applications—the first and largest applied to the soil just prior to permanent flood, the second between PI and PD, and the balance about a week later.

Since many newer rice cultivars do not respond with increased yields to midseason N applications and farmers are interested in cutting costs, the OPM and 2WS are becoming more popular. The objective of this study was to determine what effect these newer methods have on sheath blight and yield of a popular semi-dwarf cultivar, Cypress, before the practices become widely adopted.

PROCEDURES

Cypress rice seed was drill-seeded in DeWitt (formerly Crowley) silt loam soil at the Rice Research and Extension Center on 20 April 1998 and 3 May 1999. Seeding depth was approximately 0.5 in. and rate was 110 lb/acre. Plots were nine rows wide (7- in. spacing) x 15 ft long.

The experimental design was a split-plot (four replications), with application method (OPM, 2WS, or 3WS) being the main plot and N rate (0, 60, 90, 120, 150, or 180 lb N/acre) being the subplots. Preflood N was applied to dry soil immediately before flooding at the four- to five-leaf stage. The total N rate was applied preflood for the OPM. The preflood-midseason split N rates for the 2WS were 0-0, 30-30, 45-45, 60-60, 90-60, and 120-60 (lb N/acre). Likewise, the 3WS preflood-first midseason split-second midseason split rates were 0-0-0, 30-15-15, 50-20-20, 60-30-30, 90-30-30, and 120-30-30 (lb N/acre). Urea (45-0-0) was the fertilizer used. The first midseason N application was made between PI and PD and applied to the 2WS and 3WS treatments on the same day. The second midseason N application for the 3WS was made 7 days later.

Soybean was grown before rice in the rotation each year. Phosphorus and potassium fertilizers were broadcast preplanting at a rate equal to 0-40-60/acre and incorporated each year. Weeds were controlled using conventional rice herbicides recommended by the Cooperative Extension Service, University of Arkansas.

All plots were inoculated at PI with 200 ml floating calcium alginate pellets containing mycelium of the sheath blight fungus, *Rhizoctonia solani* AG1-1A, to ensure uniform disease pressure. Plots were rated for sheath blight on 13 July, 24 July, and 7 August in 1998 and 7 July, 20 July, 28 July, and 15 August in 1999. Ratings were taken by inspecting the center of each plot for disease symptoms and the following variables recorded: percent infected tillers, height of symptoms above the soil, and height of plant canopy. A disease index was calculated by multiplying percent infected tillers times height of symptoms and dividing by canopy height. The index represents the amount of the plot damaged by sheath blight, expressed as a number between 0 to 100 and is equivalent to percentage. At maturity, 12 ft of the center four rows of each plot were harvested using a small combine, with grain weight adjusted to 12% moisture and reported as bu/acre. A bushel is equivalent to 45 lb of rice. All data were analyzed using analysis of variance (PRM5 software, Gylling Corporation).

RESULTS AND DISCUSSION

A significant interaction between application method and N rate was noted in both years, and results are reported in Tables 1 and 2. Native N fertility levels of the sites differed, since 1999 grain yields at the 0 lb N/acre rate were about twice that observed in 1998 (Tables 1 and 2).

Maximum rice grain yields were achieved with at least 30 lb N/acre less total N when the OPM method was used compared to the 2WS and 3WS methods (Tables 1 and 2). Grain yields of rice in 1998 did not significantly increase when more than 60, 120, and 90 lb N/acre were applied with the OPM, 2WS, and 3WS methods, respectively, and the corresponding sheath blight ratings for these methods when these respective N rates were applied were not significantly different. Results in 1999 were very similar to those in 1998; grain yields of rice in 1999 did not significantly increase when more than 60, 90, and 90 lb N/acre were applied with the OPM, 2WS, and 3WS methods, respectively, and the corresponding sheath blight ratings for these methods when these respective N rates were applied were not significantly different.

Highest numerical yield for the OPM was at 90 and 120 lb N/acre in 1998, but final sheath blight ratings were also high at these rates, with index values of 70 and 69, respectively (Table 1). Results were similar in 1999, but rates of 60, 90, and 120 lb N/acre gave higher yields while final sheath blight ratings were more modest than in 1998, with values of 44, 62, and 64, respectively (Table 2). The current recommended N rates for Cypress using the three methods are 120 lb N/acre with the OPM and 150 lb N/acre with the 2WS and 3WS methods. Grain yield and final sheath blight levels were similar for all methods at the respective recommended N rates. However, yields in the OPM plots decreased in both years at the 150 and 180 lb N/acre rates as sheath blight ratings increased to 71 to 79 levels (top of canopy, Tables 1 and 2). Sheath blight reached damaging levels earlier in the OPM plots compared to the other two application methods, especially at the 150 and 180 lb N/acre rates (Figs. 1 through 4). This explains the greater yield decrease at higher N rates for the OPM plots than that observed in the 2WS and 3WS plots, where the divided applications of N apparently delayed disease progress somewhat (Figs. 1 through 4).

Highest grain yields for the 2WS method were observed at N rates of 120 to 180 lb N/acre in 1998 and 90 to 180 lb N/acre in 1999 (Tables 1 and 2). Sheath blight was most severe at the 180-lb N/acre rate in 1998 and equally severe at the 150 and 180 lb N/acre rates in 1999 (Tables 1 and 2). Highest yield for the 3WS method was observed at the 90- to 180-lb N/acre rates in 1998 and 1999 (Tables 1 and 2). Highest sheath blight ratings were observed for the 120- to 180-lb N/acre rates in both years (Tables 1 and 2). Sheath blight tended to be lower overall in 1999, probably because of the extraordinarily hot and dry conditions during July and August (Tables 1 and 2).

CONCLUSIONS

Based on results from this 2-year study, we conclude that sheath blight is affected more by total rate of N than by method of application; however, rates of N higher than recommended resulted in more and earlier sheath blight damage using the OPM than using either the 2WS or 3WS methods. For this reason, growers applying all N fertilizer at preflood should carefully use the recommended rate of N to avoid heavy sheath blight damage and optimize grain and milling yields.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board and Arkansas rice growers for checkoff monies to support this research.

Table 1. Effect of N fertilizer rate and application method on grain yield and sheath blight of Cypress rice, 1998.

Nitrogen Fertilizer Rate	Application Method: Optimal Preflood		2-Way Split		3-Way Split	
	Grain Yield	Sheath Blight	Grain Yield	Sheath Blight	Grain Yield	Sheath Blight
(lb N/acre)	(bu/acre)	(0 to 100 index)	(bu/acre)	(0 to 100 index)	(bu/acre)	(0 to 100 index)
0	53	0	64	0	61	2
60	135	21	105	33	108	23
90	140	70	119	54	133	30
120	146	69	146	42	134	51
150	137	79	143	59	138	61
180	124	77	140	72	141	67
$LSD_{(0.05)}$	17	24	17	24	17	24

[z] 0 to 100 index represents the amount of damage by sheath blight expressed as an index between 0 and 100, and is equivalent to percentage.

Table 2. Effect of N fertilizer rate and application method on grain yield and sheath blight of Cypress rice, 1999.

Nitrogen Fertilizer Rate	Application Method					
	Optimal Preflood		2-Way Split		3-Way Split	
	Grain Yield	Sheath Blight	Grain Yield	Sheath Blight	Grain Yield	Sheath Blight
(lb N/acre)	(bu/acre)	(0 to 100 index)	(bu/acre)	(0 to 100 index)	(bu/acre)	(0 to 100 index)
0	100	4	112	9	112	10
60	148	44	134	27	131	46
90	157	62	148	49	146	49
120	147	64	146	51	135	62
150	127	71	151	70	157	61
180	131	71	152	70	156	61
$LSD_{(0.05)}$	13	8	13	8	13	8

[z] 0 to 100 index represents the amount of damage by sheath blight expressed as an index between 0 and 100, and is equivalent to percentage.

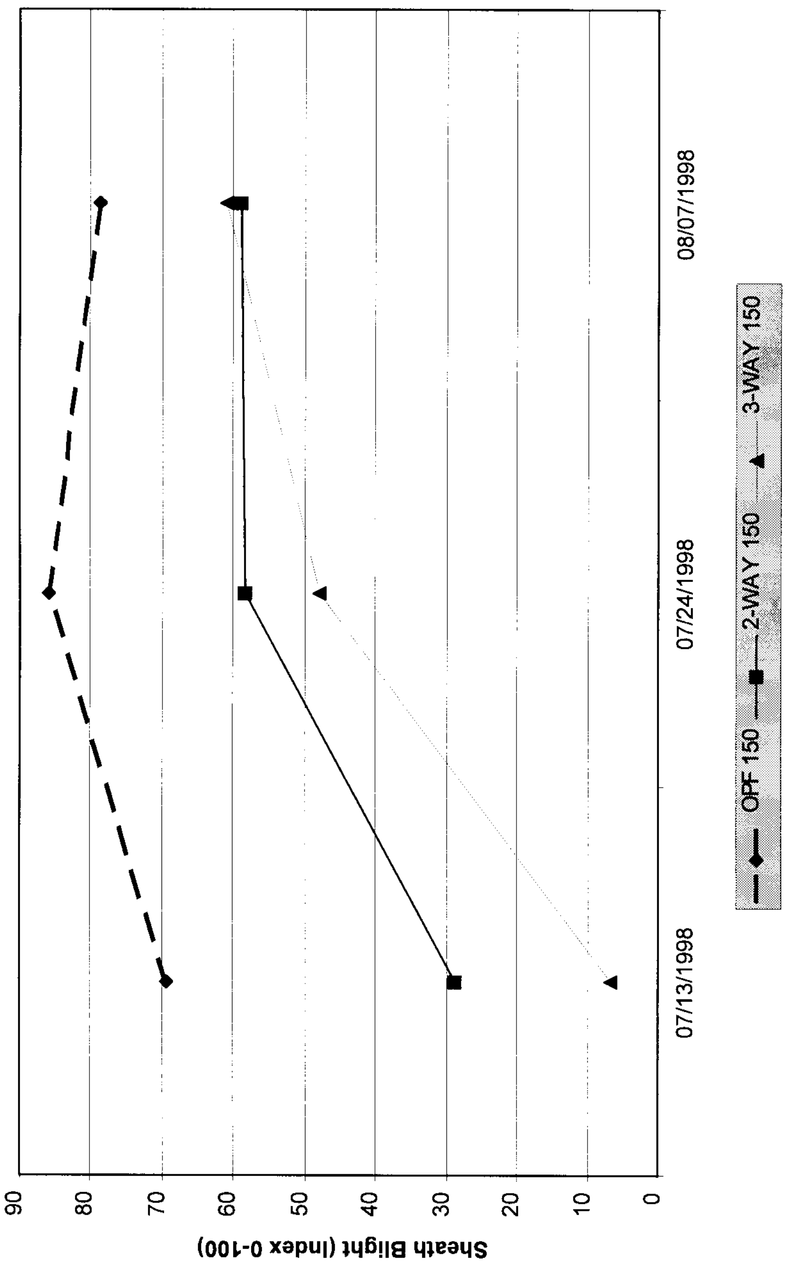


Fig. 1. Effect of N application method on sheath blight of Cypress rice in 1998 when 150 lb N/acre was applied.

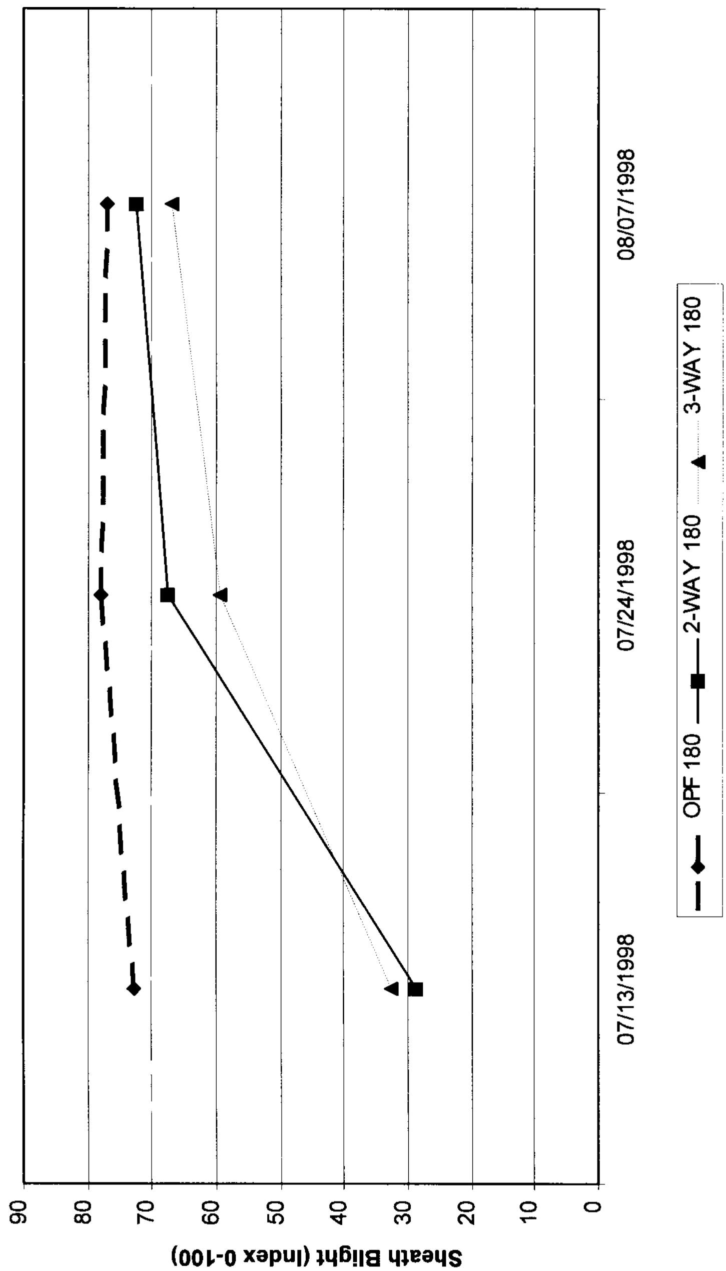


Fig. 2. Effect of N application method on sheath blight of Cypress rice in 1998 when 180 lb N/acre was applied.

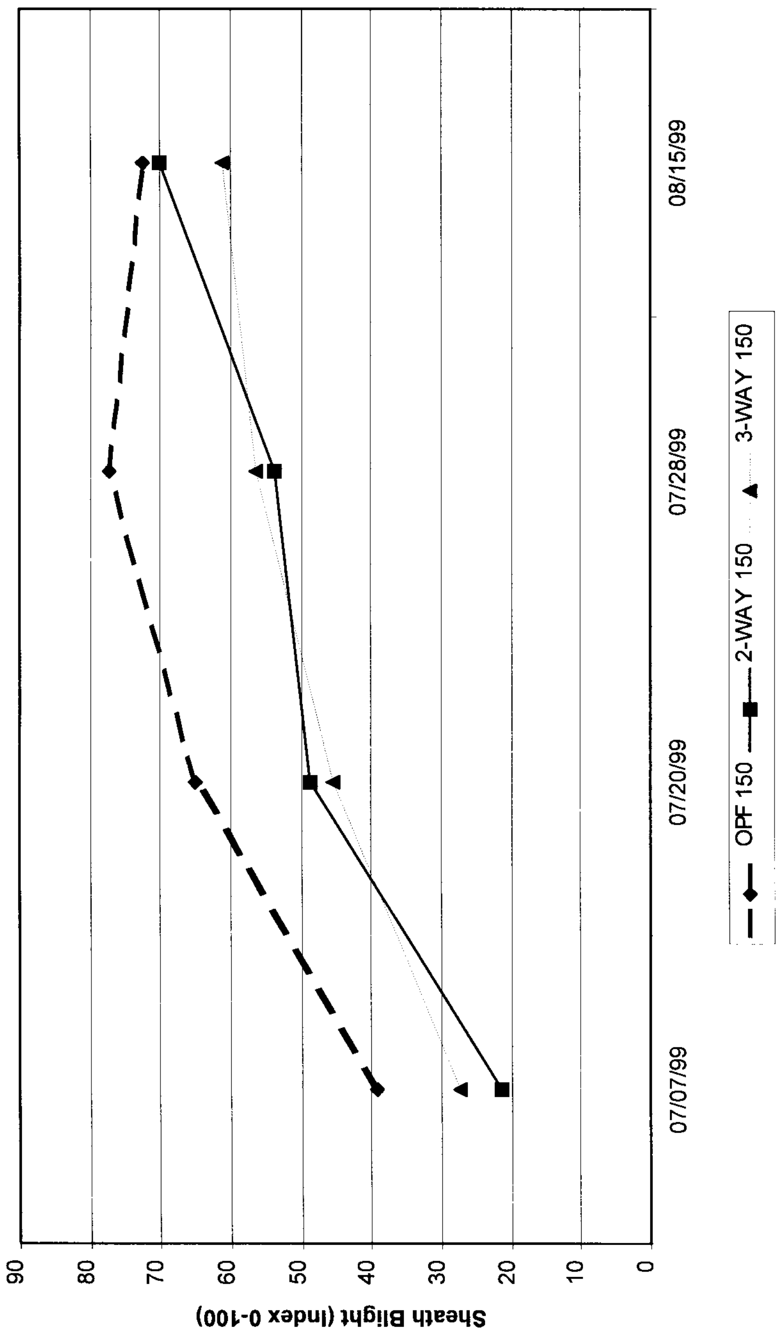


Fig. 3. Effect of N application method on sheath blight of Cypress rice in 1999 when 150 lb N/acre was applied.

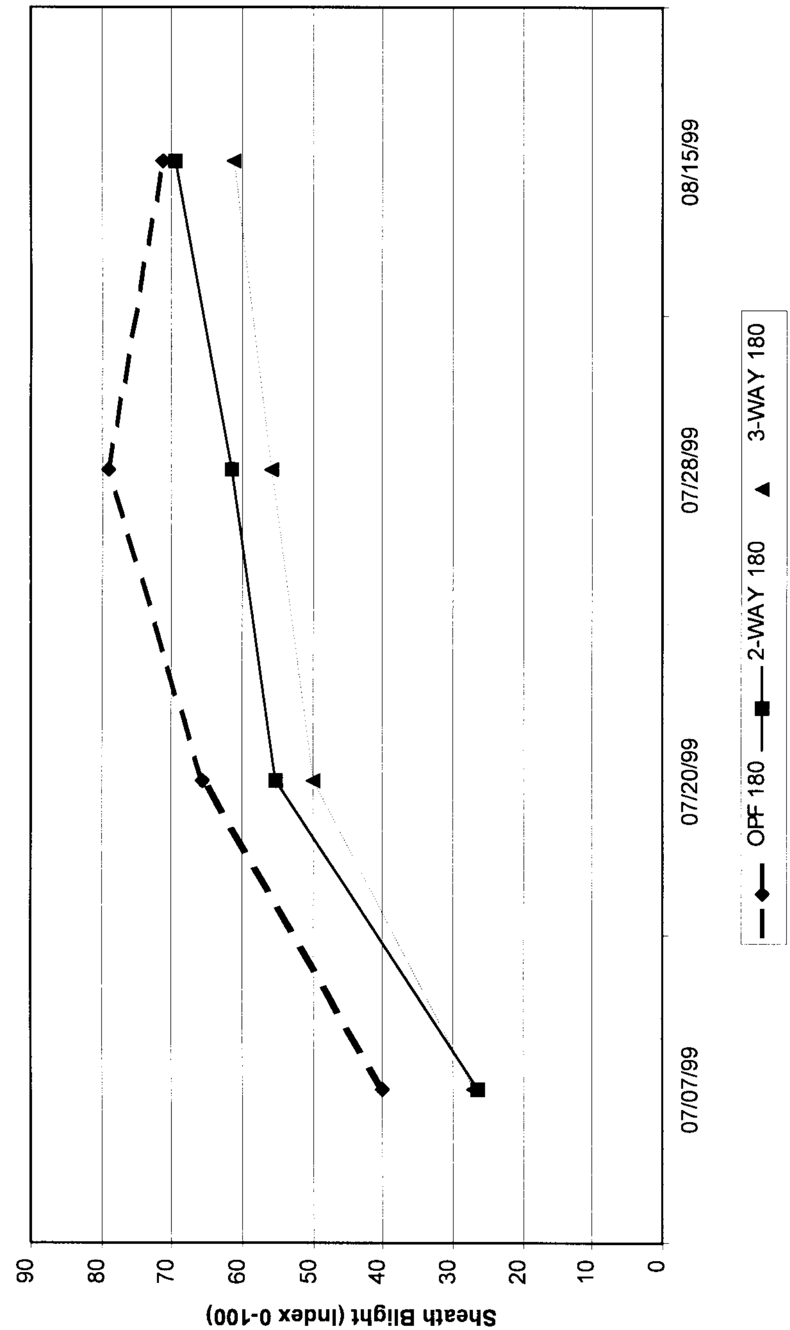


Fig. 4. Effect of N application method on sheath blight of Cypress rice in 1999 when 180 lb N/acre was applied.

RELATIONSHIP OF RACES, DNA FINGERPRINT GROUPS, VEGETATIVE COMPATIBILITY GROUPS, AND MATING TYPE AMONG ISOLATES OF RICE BLAST PATHOGEN *Pyricularia grisea* IN ARKANSAS

J.C. Correll and F.N. Lee

ABSTRACT

Efforts to breed for disease resistance to rice blast disease must take into account the genetic diversity of the pathogen. To examine the genetic diversity of the rice blast fungus (*Pyricularia grisea*), a total of 540 isolates were recovered from rice in the United States. The isolates were examined for diversity using genetic and molecular tests (DNA fingerprinting, vegetative compatibility, and mating type). The collection represented contemporary field isolates collected from throughout Arkansas since 1991 and archived isolates collected in the 1970s and 1980s. The collection also included isolates recovered from Texas, California, Mississippi, Louisiana, and Missouri and represented 10 of the races known to commonly occur in the United States. Four DNA fingerprint groups, designated A, B, C, and D, were identified among the isolates recovered since 1991. Fingerprint groups E, F, G, and H were identified among the older isolates collected in the 1970s and 1980s. Isolates recovered from California in 1997 were most similar to DNA fingerprint group H, recovered from Arkansas and Texas in 1982 and 1974, respectively. A genetic test was developed to assess a more cost-effective method of genetically characterizing the rice blast pathogen. The genetic test examined the ability of isolates to fuse with one another. Isolates that fused belong to the same genetic subgroup, or vegetative compatibility group (VCG). The genetic test proved to be very reliable in identifying the fingerprint groups; all contemporary isolates examined in groups A, B, C, and D belonged to VCGs US-01, 02, 03, and 04, respectively. Also both mating types of the rice blast pathogen were well distributed in Arkansas, with all VCG US-01 and US-04 isolates belonging to one mating type (mat1-1) and all VCG US-02 and US-04 isolates belonging to the other (mat1-2). Thus, although

both mating types are common in Arkansas, the nonrandom association of the independent genetic and molecular markers provide strong evidence that the rice blast pathogen is reproducing asexually and no evidence of sexual recombination was apparent. Multiple races were identified within each of the VCGs, indicating that virulence diversity likely was resulting from mutations within each of the genetic subgroups. Vegetative compatibility can be a useful means of characterizing genetic structure in contemporary populations of the rice blast fungus. Continued breeding efforts should focus on the mutational potential (i.e., race shifts) within each of the four contemporary genetic families to increase the durability of resistance.

INTRODUCTION

Rice is an important agricultural crop worldwide, supplying approximately 23% of the per capita energy for the world's 6 billion people (Maclean, 1997). Although sporadic from year to year, *Pyricularia grisea* (teleomorph: *Magnaporthe grisea*), the cause of rice blast disease, has the potential to cause severe epidemics in Arkansas on susceptible cultivars. Populations of the rice blast pathogen throughout the world have been studied for their phenotypic and genotypic variation (Correll and Gordon, 1999; Ou, 1980; Zeigler *et al.*, 1994; Zeigler, 1998). These studies have allowed plant breeders to incorporate major and minor resistance genes into commercial rice cultivars. Examination of the population dynamics of the rice blast pathogen will provide a more thorough understanding of the potential for the pathogen to adapt to resistant cultivars (Zeigler, 1998). Information on independent genetic and molecular markers often reveal the reproductive strategies used by the pathogen and therefore its adaptive potential. Thus, the objective of this study was to determine the relationship between race, DNA fingerprint group, vegetative compatibility group, and sexual mating type among a collection of isolates of *P. grisea.*

PROCEDURES

A total of 540 isolates of *P. grisea* were examined for vegetative compatibility, MGR586 DNA fingerprint diversity, and mating type. The various genetic and molecular markers were compared to their race identity for isolates recovered throughout the United States.

Isolates of the rice blast fungus were examined for their ability to fuse with one another using nitrate non-utilizing (nit) and sulfate (sul) non-utilizing mutants as previously described (Correll *et al.*, 2000b; Harp and Correll, 1998). Isolates that were able to fuse, or anastomose, were considered vegetatively compatible and therefore in the same VCG.

Reference Collection

The reference collection consisted of 23 contemporary and archival isolates of *P. grisea,* which were assembled to be representative of the eight MGR586 lineages (previously designated MGR586 A through H) known to occur in the United States (Levy *et al.*, 1991; Xia *et al.*, 1993; Xia *et al.*, 2000). The isolates were collected from Arkansas, Louisiana, Mississippi, Texas, and California between 1975 and 1997 (Table 1). The virulence phenotype of many of the isolates had previously been characterized (Correll *et al.*, 2000b; Xia *et al.*, 1993; Xia *et al.*, 2000).

Race Collection

The race collection consisted of 70 contemporary isolates of *P. grisea,* which were assembled to be representative of the race diversity that has been identified in the United States (Marchetti *et al.*, 1976). Isolates ZN1-ZN50 were collected from Louisiana, Mississippi, Texas, or Florida between 1992 and 1996 and represented a minimum of seven races (Table 2). Isolates ZN51-ZN70 and A431 were collected in Arkansas and represented three different races (Xia *et al.*, 2000).

Contemporary Collection

The contemporary collection consisted of 447 field isolates recovered from symptomatic rice tissue from most major rice growing areas in Arkansas (Xia *et al.*, 2000) (Table 3). The isolates were recovered from 18 commercial rice fields in nine counties in Arkansas.

RESULTS AND DISCUSSION

Four DNA fingerprint groups (A, B, C, and D) were identified among all of the contemporary isolates from Arkansas collected in the 1990s. Prior to 1991, several archived isolates belonged to groups E, F, G, and H. Isolates collected from California in 1997 and 1998 also belonged to group H.

There was a complete correspondence between fingerprint groups, A, B, C, and D, and the VCGs—VCG US-01, US-02, US-03, and US-04, respectively (Figs. 1, 2, and 3; Tables 1, 2 and 3). In addition, isolates representing different races were found within each of the VCGs. The data indicate that virulence changes can likely occur among asexually reproducing individuals within a given group and the changes likely originate from mutation (Correll *et al.*, 2000a).

SIGNIFICANCE OF FINDINGS

In the Philippines and Colombia, 6 and 10 DNA fingerprint groups have been identified in the rice blast pathogen population, respectively (Zeigler, 1998). In various rice-growing regions of the Indian Himalayas, over 20 DNA fingerprint groups can occur and may be indicative of the pathogen sexually reproducing. The data presented in the current study indicate that the genetic diversity in the rice blast pathogen population in Arkansas, and likely the United States, is very low relative to other rice-growing regions of the world. However, virulence diversity appears to result from mutational changes that affect virulence among individuals within each of the four predominate genetic groups. Consequently, advanced breeding lines should be screened for disease resistance by inoculation with multiple isolates of each of the genetic groups. Fungal variants that show a mutation to be able to attack previously resistant cultivars can then be used to screen additional host material for resistance.

ACKNOWLEDGMENT

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

LITERATURE CITED

Correll, J.C., and T.R. Gordon. 1999. Population structure in ascomycete/deuteromycete fungi: what we have learned from case studies. pp. 225-250. *In:* J.J. Worrall (ed.). Structure and Dynamics of Fungal Populations. Kluwer Academic Press, Dordrecht, The Netherlands.

Correll, J.C., T.L. Harp, J.C. Guerber, and F.N. Lee. 2000a. Differential changes in host specificity among MGR586 DNA fingerprint groups of *Pyricularia grisea.* D. Tharreau (ed.). 2nd International Symposium on Rice Blast Disease, Kluwer Academic Press, Dordrecht, The Netherlands (in press).

Correll, J.C., T.L. Harp, J.C. Guerber, R.S. Zeigler, and F.N. Lee. 2000b. Assessment of population structure of the rice blast pathogen (*Pyricularia grisea*) in the United States by vegetative compatibility. Phytopathology (submitted).

Harp, T.L., and J.C. Correll. 1998. Recovery and characterization of spontaneous, selenate-resistant mutants of *Magnaporthe grisea*, the rice blast pathogen. Mycologia 90:954-963.

Kang, S., J.A. Sweigard, and B. Valent. 1995. The PWL host specificity gene family in the blast fungus, *Magnaporthe grisea.* Mol. Plant-Microbe Inter. 8:939-948.

Levy, M., J. Romao, M.A. Marchetti, and J.E. Hamer. 1991. DNA fingerprint with a dispersed repeated sequence resolves pathotype diversity in the rice blast fungus. The Plant Cell 3:95-112.

Maclean, J. 1997. Rice Almanac. International Rice Research Institute, Los Banos, Philippines.

Marchetti, M. A., M.C. Rush, and W.E. Hunter. 1976. Current status of rice blast in the southern United States. Plant Dis. Rep. 60:721-725.

Ou, S.H. 1980. Pathogen variability and host resistance in rice blast disease. Annu. Rev. Phytopathol. 18:167-187.

Xia, J.Q., J.C. Correll, F.N. Lee, and D.D. Rhoads. 1993. DNA fingerprinting to examine microgeographic variation in the *Magnaporthe grisea* (*Pyricularia grisea*) population in two rice fields in Arkansas. Phytopathology 83:1029-1035.

Xia, J.Q., J.C. Correll, F.N. Lee, W.J. Ross, and D.D. Rhoads. 2000. Regional population diversity of the rice blast pathogen, *Pyricularia grisea* (*Magnaporthe grisea*), in Arkansas and the influence of host selection. Plant Disease 8 (in press).

Zeigler, R.S. 1998. Recombination in *Magnaporthe grisea*. Annu. Rev. of Phytopathol. 36:249-275.

Zeigler, R.S., J. Thome, R. Nelson, M. Levy, and F. Correa. 1994. Lineage exclusion: a proposal for linking blast population analysis to resistance breeding: proposed strategy for durable resistance. pp. 267-292. *In:* R.S. Zeigler, S. Leong, and P.S. Teng (eds.). Rice Blast Disease. Commonwealth Agricultural Bureaux International, Willingford, UK.

Table 1. Contemporary and archived reference isolates of *Pyricularia grisea* recovered from rice in the United States.

Isolate	VCG[z]	MGR586 lineage[y]	Mating type[x]	Race[w]	Origin Year	Origin Location
A598	US-001	A	1	IB49	1993	AR
LO1-4	US-001	A	1	IB1	1991	AR
85M2	US-002	B	2	IG1	1985	MS
75A49	US-002	B	2	IG1	1975	AR
LO3-8	US-002	B	2	IG1	1991	AR
A264	US-002	B	2	IC17	1993	AR
S1	US-002	B	2	IC17k	1994	AR
BM1-24	US-003	C	2	IB49	1991	AR
A119	US-003	C	2	IB49	1993	AR
49D	US-003	E	1	IB49	1985	AR
793	US-003	E	1	IB49	1987	LA
75A11	US-?[v]	F	2	IB45	1975	AR
85L2	US-004	A	1	IB1	1985	LA
D1	US-004	D	1	IC17	1993	AR
85A7	US-004	D	1	IC17	1985	AR
75A1	US-004	D	1	IC17	1975	AR
BM5-11	US-004	D	1	IC17	1991	AR
A347	US-004	D	1	IC17	1993	AR
75A10	US-?[v]	G	1	IB45	1975	AR
82A1	US-004	H	1	IG1	1982	AR
74T3	US-004	H	1	IG1	1974	TX
CA205	US-004	H	1	IG1	1997	CA
CA305	US-004	H	1	IG1	1997	CA

[z] VCG = vegetative compatibility group.
[y] MGR586 lineages were previously described (Xia *et al.*, 1993).
[x] Mating type was determined by probing southern blots of EcoR1 digested DNA with each of the mating type alleles *mat*1-1 and *mat*1-2 (Kang *et al.*, 1995).
[w] Race identification was previously determined (Xia *et al.*, 1993; Xia *et al.*, 2000).
[v] No inter- or intra-strain complementation was observed.

Table 2. Contemporary isolates of *Pyricularia grisea* representative of the race diversity in the United States.

Isolate	VCG[z]	MGR586 lineage[y]	Mating type[x]	Race	Origin	
					Year	Location
ZN08	US-001	A	1	IB49	1995	TX
ZN10	-	A	1	IB49	1995	TX
ZN14	US-001	A	1	IB49	1996	TX
ZN15	US-001	A	1	IB1	1996	TX
ZN24	-	A	1	IC17	1995	MS
ZN28	US-001	A	1	-	1996	MS
ZN29	US-001	A	1	-	1994	LA
ZN30	US-001	A	1	-	1994	LA
ZN31	US-001	A	1	-	1994	LA
ZN32	US-001	A	1	-	1994	LA
ZN33	US-001	A	1	-	1994	LA
ZN34	US-001	A	1	-	1994	LA
ZN35	-	A	1	IB17	1996	LA
ZN36	US-001	A	1	IE1	1996	LA
ZN38	US-001	A	1	IB1/IE1	1996	LA
ZN40	US-001	A	1	IB49	1996	LA
ZN41	US-001	A	1	IE1	1995	FL
ZN42	US-001	A	1	ID1	1995	FL
ZN43	US-001	A	1	IC17	1995	FL
ZN44	US-001	A	1	IC1	1995	FL
ZN46	US-001	A	1	IC1	1996	FL
ZN48	US-001	A	1	IC17	1995	FL
ZN49	US-001	A	1	IE1	1995	FL
ZN51	US-001	A	1	IB49	1992	AR
ZN52	US-001	A	1	IB49	1992	AR
ZN53	US-001	A	1	IB49	1992	AR
ZN54	US-001	A	1	IB49	1992	AR
ZN55	US-001	A	1	IB49	1992	AR
ZN1	US-002	B	2	IC17	1995	TX
ZN2	US-002	B	2	IC17	1995	TX
ZN3	-	B	2	IC17	1995	TX
ZN5	US-002	B	2	IE1	1995	TX
ZN6	US-002	B	2	IE1	1995	TX
ZN7	US-002	B	2	IE1	1995	TX
ZN11	US-002	B	-	IE1	1996	TX
ZN12	US-002	B	2	IE1	1996	TX
ZN13	-	B	-	IE1	1996	TX
ZN16	US-002	B	2	IC17	1996	TX
ZN19	US-002	B	2	IE1k	1993	MS
ZN50	US-002	B	2	IC17	1995	FL

continued

Table 2. Continued.

Isolate	VCG[z]	MGR586 lineage[y]	Mating type[x]	Race[w]	Origin Year	Origin Location
ZN56	US-002	B	2	IC17	1992	AR
ZN57	US-002	B	2	IC17	1992	AR
ZN58	US-002	B	2	IC17	1992	AR
ZN59	US-002	B	2	IC17	1992	AR
ZN60	US-002	B	2	IC17	1992	AR
A431(#24)	US-002	B	2	IG1	1992	AR
ZN4	US-003	C	2	IE1	1995	TX
ZN9	US-003	C	2	IE1	1995	TX
ZN17	US-003	C	2	IB49	1992	MO
ZN20	US-003	C	2	-	1994	MS
ZN21	US-003	C	2	-	1994	MS
ZN22	US-003	C	2	-	1994	MS
ZN23		C	2	-	1994	MS
ZN25	US-003	C	2	-	1995	MS
ZN26	US-003	C	2	-	1996	MS
ZN27	-	C	2	-	1996	MS
ZN61	US-003	C	1	IB49	1992	AR
ZN62	US-003	C	1	IB49	1992	AR
ZN63	US-003	C	1	IB49	1992	AR
ZN64	US-003	C	1	IB49	1992	AR
ZN65	US-003	C	1	IB49	1992	AR
ZN18	US-004	D	1	IC17	1992	MO
ZN37	US-004	A	1	IB49	1996	LA
ZN39	US-004	D	1	IG1	1996	LA
ZN45	US-004	D	1	IC17	1995	FL
ZN66	US-004	D	1	IC17	1992	AR
ZN67	US-004	D	1	IC17	1992	AR
ZN68	US-004	D	1	IC17	1992	AR
ZN69	US-004	D	1	IC17	1992	AR
ZN70	US-004	D	1	IC17	1992	AR

[z] VCG = vegetative compatibility group.

[y] MGR586 lineages were previously described (Xia *et al.*, 1993).

[x] Mating type was determined by probing southern blots of EcoR1 digested DNA with each of the mating type alleles *mat*1-1 and *mat*1-2 (Kang *et al.*, 1995).

[w] Race identification was previously determined (Xia *et al.*, 1993; Xia *et al.*, 2000).

Table 3. Collection of contemporary field isolates of *Pyricularia grisea* recovered from rice in Arkansas.

	Number of isolates in each MGR586 lineage				Mating type[y]			Origin	
VCG[z]	A	B	C	D	*Mat*1-1	*Mat*1-2	Race[x]	Year	Location
US-001	125	-	-	-	118	0	IB49	1992	AR
US-002	-	158	-	-	0	126	IC17/IG1	1992	AR
US-003	-	-	107	-	0	94	IB49	1992	AR
US-004	-	-	-	57	51	0	IC17	1992	AR

z VCG = vegetative compatibility group.

y Mating type was determined by probing southern blots of EcoR1 digested DNA with each of the mating type alleles *mat*1-1 and *mat*1-2 (Kang *et al.*, 1995).

x A subset of isolates from each MGR lineage was previously characterized for race (Xia *et al.*, 2000).

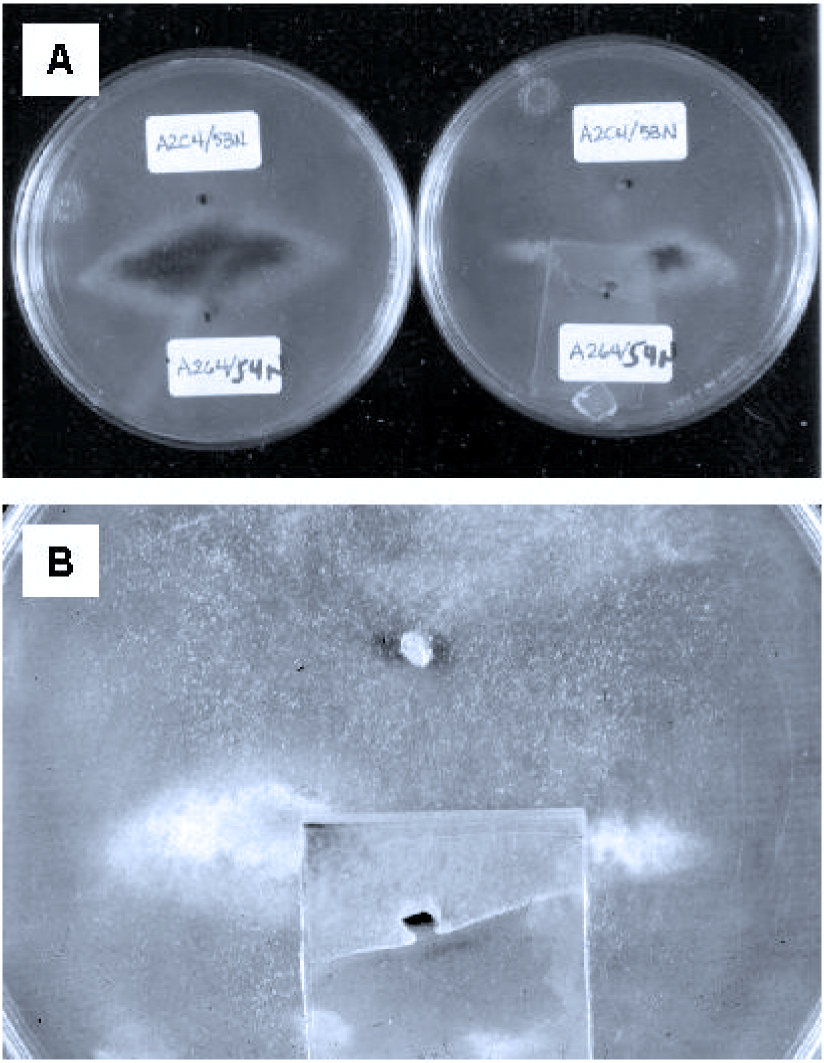


Fig. 1. Genetic tests were developed to demonstrate vegetative compatibility. Heterokaryon formation between two complementary nit mutants (A264/53N and A264/54N) of *P. grisea*. Note robust heterokaryon formation in *A*. *B*: Pairing between the same nit mutants with a piece of cellulose dialysis membrane preventing direct contact between the mycelium of the two different mutants. Note heterokaryon formation only occurs where mycelium come in direct contact with one another beyond the edges of the membrane.

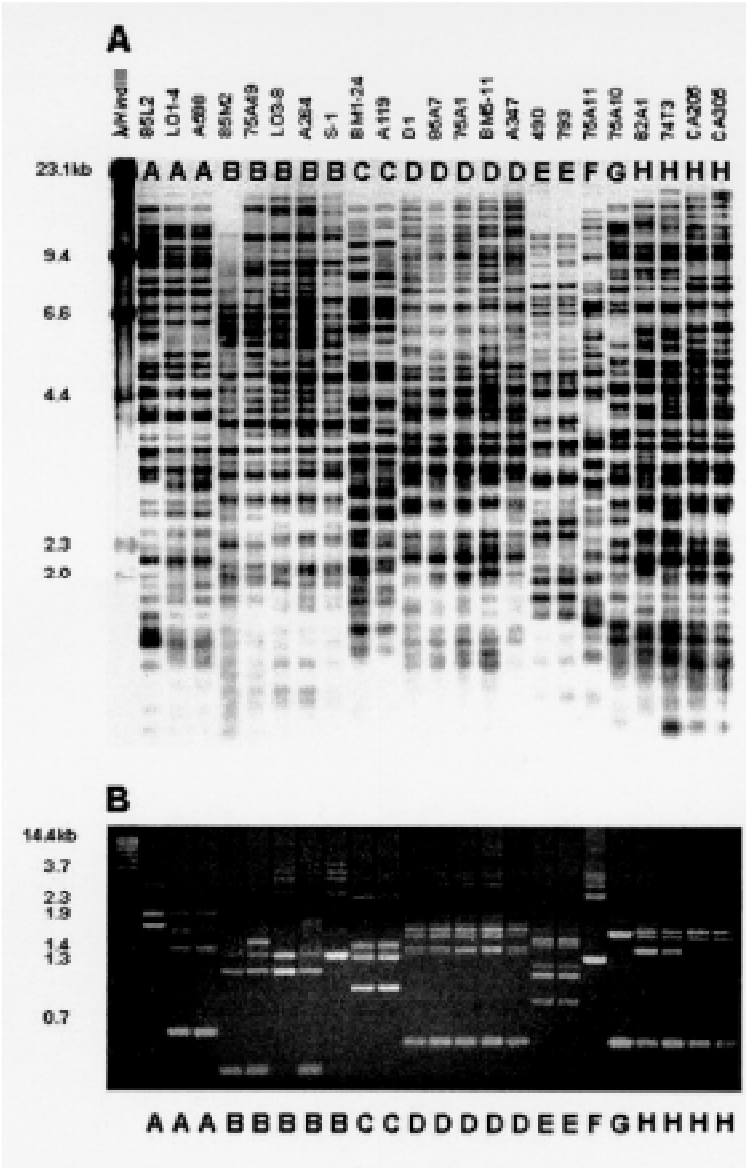


Fig. 2. ***A.*** **DNA of 23 reference isolates was restricted with EcoR1, separated by electrophoresis, and then transferred to nitrocellulose. The nitrocellulose blot was then probed with a chemiluminescent-labeled MGR586 probe.**
B. **DNA of the same 23 isolates was amplified with the Pot2 primers and then separated by electrophoresis followed by staining with ethidium bromide.**

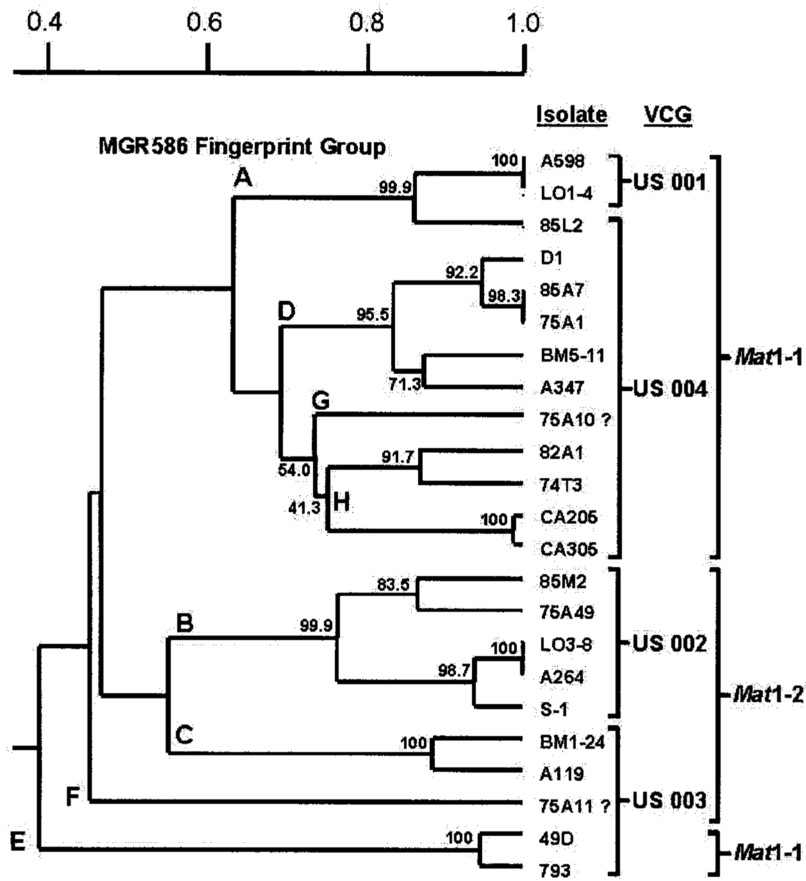


Fig. 3. Statistical comparison (using UPGMA dendrogram) of the similarity in DNA fingerprints among selected isolates (1.0 on scale = 100% band similarity). Bootstrap values are indicated on the corresponding node for each cluster. Note that no intra- or inter-strain complementation occurred with two isolates (75A10 and 75A11), and these could not be assigned to a vegetative compatibility group.

STRAIGHTHEAD OF RICE AS INFLUENCED BY ARSENIC AND NITROGEN

R.H. Dilday, N.A. Slaton, J.W. Gibbons, K.A. Moldenhauer, and W.G. Yan

ABSTRACT

Straighthead is a physiological disorder of rice (*Oryza sativa* L.) that results in blank florets and distorted lemma and palea, and in extreme cases, the panicles or heads do not form. Consequently, severe straighthead can result in almost a total loss of yield. Cultivars that show tolerance to arsenic (As) [i.e., monosodium methanearsonate (MSMA), which has an arsenic base] also appear to be tolerant to straighthead. Twelve cultivars—including 10 of the most popular cultivars grown in the southern United States, a Chinese line, and a Japanese germplasm accession—were evaluated for their response to As and nitrogen (N). On a scale of 1 (low susceptibility) to 9 (high susceptibility), 'Cocodrie', 'Kaybonnet', 'Bengal', and 'Mars' were the most susceptible to straighthead. The straighthead rating of these four cultivars ranged between 7.0 and 8.0 at all rates of N and the 6 lb/acre level of MSMA. 'Zhe 733' (2.0), a germplasm accession from China, and 'Priscilla' (4.5) were the most tolerant to straighthead. 'Cypress', 'LaGrue', and Priscilla had less straighthead at 120 and 240 lb/acre of N than at 60 lb/acre of N. Straighthead reduced the yield of Mars, Kaybonnet, Cocodrie, and Bengal by 96, 95, 92, and 75%, respectively, when averaged over all N rates. Conversely, straighthead reduced the yield of Priscilla only 5%. The yield of Zhe 733 increased by 7%. In the 1999 Straighthead Uniform Rice Nursery Test, the average straighthead ratings of the advanced breeding lines from Arkansas, Louisiana, Mississippi, and Texas were 7.3, 7.5, 7.0, and 6.5, respectively.

INTRODUCTION

Straighthead has been reported as a physiological disorder of rice that results in blank florets and distorted lemma and palea, and in extreme cases, the panicles or heads do not form. When the grains do not develop, the heads remain upright at maturity; hence, the name straighthead. Closer inspection of the diseased panicles shows that they can be partly or completely sterile and greatly reduced in size with poor or no emergence from the sheath of the boot, and they may have very few florets. The lemma and palea, or both, may be lacking, but if they are present they are distorted and crescent-shaped, particularly in long-grain varieties, forming a characteristic symptom of straighthead called "parrot beak" (Rasamivelona *et al.*, 1995). Additional symptoms of straighthead are the presence of unusually vigorous dark green leaves in mature rice plants and strikingly abnormal root systems. The affected plants usually have relatively large, shallow roots with few branches and root hairs (Atkins *et al.*, 1956; Atkins *et al.*, 1957).

Straighthead has been reported in Cuba, Guyana, Japan, Mexico, Panama, Southeast Asia, and the United States. In the United States, the first reported case of straighthead or blight is generally attributed to Collier (1912) and Hewitt (1912). However, Atkins (1974) reported that Metcalf described, "A disease of rice, so far nameless, was reported in Texas, in which the glumes simply remained empty, the heads in consequence standing erect; while aside from this the plant is normal, so far as has been detected." Hewitt (1912) reported that the disease was called to the attention of the Arkansas Experiment Station in 1907. Straighthead was reported from Louisiana as early as 1915.

The exact cause of straighthead is unknown, but independent studies have shown that irrigation practices, soil type, soil organic matter content, arsenic level in the soil, etc., can influence the occurrence of straighthead. It has been reported that straighthead is related to poor drainage (Cheaney, 1955; Collier, 1912; Padwick, 1950). Padwick found that straighthead occurs only on soil that is flooded and poorly aerated during the early development stages of the rice plant. Collier reported that straighthead is correlated to low oxygen levels in flooded soils. Straighthead usually occurs on sandy soil that is low in clay content (Collier, 1912; Hewitt, 1912; Tisdale and Jenkins, 1921; Todd and Beachell, 1954; Tullis, 1941). Also, low soil pH and low free iron have been found in some soil where severe straighthead occurs (Baba and Harada, 1954). Jones *et al.* (1938) first reported that straighthead is apparently caused by organic materials in the soil, and later Kataoka *et al.* (1983) and Tisdale and Jenkins (1921) reported that the type of organic matter in the soil appears to have an influence on the level of straighthead in rice. Tisdale and Jenkins found that rice following maize or cowpeas is particularly susceptible to straighthead. Kataoka *et al.* (1983) found that straighthead was more severe where barley straw had been applied to paddy fields in Japan. Joshi *et al.* (1975) suggested that the degradation of organic matter may produce toxic substances, such as hydrogen sulfide which may be the cause of straighthead. Straighthead in rice has been found on soils high in arsenic, especially when rice is grown on land where arsenic has accumulated from applications of herbicides with an arsenic base such as MSMA (Atkins *et al.*,1957; Olsen, 1956). Arsenic toxicity in rice has been known for a long time, and residual arsenicals in the soil have been shown to cause damage in rice that is similar to straighthead (Baker *et al.*, 1976; Epps and Sturgis, 1939; Reed and Sturgis, 1936; Schweizer, 1967, Wells and Gilmour, 1977). Wells and Gilmour found that cultivars showing tolerance to MSMA also appeared to be resistant to straighthead. Dilday *et al.* (1984) reported that there was an interaction between genotype, As, and N. Five varieties or advanced lines (RU8103165, RU8203085, RU8201133, S-201, and Stg808930), 5 levels of As (0.0, 0.5, 1.0, 2.0, and 3.0 lb/acre), and 3 levels of N (0, 60, and 120 lb/acre) were evaluated, and a significant positive correlation was found between As and N for S-201 and Stg808930 (i.e., as N increased, the degree of straighthead increased). However, a significant negative correlation was found between As and N for RU8103165 and RU8203085 (i.e., as N increased, the degree of straighthead decreased). The objectives of this study were to (1) determine the effect of As and N on current rice cultivars grown in Arkansas; (2) determine the level of tolerance of the advanced breeding lines in the Uniform Rice Nursery from Arkansas, Louisana, Mississippi, and Texas; and (3) determine the level of tolerance of Arkansas breeding lines.

PROCEDURES

Straighthead Response to As and N

The test was conducted on a DeWitt silt loam soil at the Rice Research and Extension Center (RREC) near Stuttgart in 1999. Twelve cultivars, including 10 of the most popular cultivars grown in the southern United States (Bengal, Cocodrie, Cypress, 'Drew', 'Jefferson', Kaybonnet, LaGrue, Mars, Priscilla, and 'Wells'), a Chinese line (Zhe 733), and a Japanese germplasm accession (Japan 92.09.31) were evaluated for their response to As and N. Three levels of N (60, 120, and 240 lb/acre) and three levels of As (0, 6, and 8 lb/acre of MSMA) were arranged in a split-plot design with four replications, where the level of As was the main plot. Data for the 0 and 6 lb/acre of MSMA have been analyzed and are reported. The plots were nine rows wide with 8-in. spacing between rows and 5 ft long. Soil samples were taken before seeding, and then MSMA was applied to the soil surface and incorporated. The five soil samples that were taken prior to applying MSMA ranged from 56 to 63 lb As/acre. Fertilizer was applied to each plot and a permanent flood was established at about the five-leaf stage. The flood was maintained throughout the growing season to ensure ideal straighthead conditions.

Data were collected at maturity by visually rating the center of each plot for floret fertility or sterility and panicle emergence from the boot. The rating scale ranged from 1 to 9 , where 1 = no apparent sterility and more than 80% of the grains were developed; 2 = 71 to 80% of the grains were developed and 96 to 100% of the panicles emerged from the boot; 3 = 61 to 70% of the grains were developed and 91 to 95% of the panicles were emerged from the boot; 4 = 41 to 60% of the grains were developed and 61 to 90% of the panicles were emerged from the boot; 5 = 21 to 40% of the grains were developed and 31 to 60% of the panicles were emerged from the boot and this is the stage where there is an initial appearance of distorted and parrot-beak grains; 6 = 11 to 20% of the grains were developed and 10 to 30% of the panicles were emerged from the boot; 7 = 0 to 10% of the grains were developed with the panicle emerged but totally upright; 8 = no grains were developed and 0 to 10% of the panicles were emerged from the boot, and 9 = short, stunted plants with no panicles emerged from the boot.

Heading dates of each plot were recorded when 50% of the panicles emerged from the boot. At maturity, plant height was measured in centimeters from the ground to the tip of the panicle. Grain yield was estimated by harvesting 0.91 m, or 3 ft, of the center three rows in each plot. The data were analyzed using an SAS program.

URN Straighthead Test

Advanced rice lines that are part of the Uniform Rice Nursery (URN) were evaluated on a DeWitt silt loam soil at the RREC in 1999. There were 201 entries in the test, including 50 from Arkansas, 51 from Louisiana, 25 from Mississippi, 50 from Texas, 24 check cultivars, and a standard straighthead check, Mars. The test was designed as a randomized complete block with four replications. Three grams of seed of each entry was planted in a single row 4.5 ft long and 8 in. apart. Soil samples were taken before planting the test, and then MSMA was applied at the rate of 6 lb/acre to the soil surface and incorporated. Three split applications of urea were applied [60 lb/acre of N at preplanting, 30 lb/acre of N at 0.5 inch internode elongation (IE), and 30 lb/acreof N 10 days after 0.5 inch IE]. A permanent flood was established at about the fifth true leaf stage and maintained throughout the growing season to ensure ideal straighthead conditions. The data were collected at maturity from the center of each row by visually rating the plots, as described in the As and N test, and analyzed by SAS.

Straighthead Evaluation - Arkansas Breeding Lines

One hundred five entries, including 82 elite breeding lines from the Arkansas breeding program and 23 check cultivars, were arranged in a randomized complete-block design with four replications. The test was seeded, managed, rated, and analyzed as described in the URN Straighthead Test.

RESULTS AND DISCUSSION

Straighthead Response to As and N

On a scale of 1 to 9, Cocodrie, Kaybonnet, Bengal, and Mars were the most susceptible to straighthead. These four cultivars ranged between 7.0 and 8.0 for straighthead at all N rates at 6 lb/acre of MSMA. Zhe 733 (2.0) and Priscilla (4.5) were the most tolerant to straighthead. Cypress, LaGrue, and Priscilla had lower straighthead rates at 120 and 240 lb/acre of N than at 60 lb/acre of N. As the level of N increased, the straighthead rating increased for Drew and Mars and decreased for Priscilla. Wells and

Zhe 733 did not seem to be affected by the level of N (Table 1). Averaged over all N rates, straighthead reduced the yield of Mars, Kaybonnet, Cocodrie, and Bengal by 96, 95, 92, and 75%, respectively. Conversely, straighthead reduced the yield of Priscilla by only 5%. The yield of Zhe 733 increased by 7% (Table 2). Plant height decreased in all of the cultivars except Zhe 733, which remained the same height, when MSMA (As) was applied to the soil (Table 3). Correlation analysis of As (MSMA), N, straighthead rating, grain yield, plant height, and heading showed a significant positive correlation between MSMA and straighthead rating, N and plant height, N and heading, straighthead rating and heading, yield and plant height, and plant height and heading. There was a significant negative correlation between MSMA and yield, MSMA and plant height, straighthead rating and yield, straighthead rating and plant height, yield and heading, and plant height and heading (Table 4).

URN Straighthead Test

There are seven maturity groups in the URN. The average straighthead rating of the advanced breeding lines from Arkansas was greater than 7.0 in six of the seven maturity groups, with an overall rating of 7.3 for all maturity groups. The advanced breeding lines from Louisiana were greater than 7.0 for all maturity groups, with an overall average of 7.5. The advanced breeding lines from Mississippi were greater than 7.0 in three of the seven maturity groups, with an overall average of 7.0, and the advanced breeding lines from Texas were greater than 7.0 in two of the seven maturity groups, with an overall average of 6.5 (Table 5). A straighthead breeding program was initiated at Beaumont and Eagle Lake, Texas, in 1953, and cultivars that are less susceptible to straighthead were developed early in the program (Adair *et al.*, 1973; Atkins, 1974). Consequently, cultivars that have been developed in the Texas program generally appear to be more tolerant to straighthead than cultivars developed in the other southern rice-breeding programs.

Sraighthead Evaluation—Arkansas Breeding Lines

The average rating of all the Arkansas elite breeding lines was 7.5; however, five lines had an average rating of 6.0 or less (Table 6). The three most tolerant check cultivars to straighthead were Jefferson (4.8), 'Maybelle' (5.0), and Priscilla (5.5), and the three most susceptible cultivars were Cocodrie (8.8), Bengal (8.3), and L204 (8.3)

SIGNIFICANCE OF FINDINGS

Producers can use these data when selecting rice cultivars to be grown on land with a history of straighthead. For example, Cocodrie, Kaybonnet, Bengal, and Mars were the most susceptible cultivars to straighthead, and rice producers may want to select a more tolerant cultivar to plant on land with a history of straighthead. Also, these data indicate that the level of tolerance of a cultivar to straighthead can be influenced by the level of N applied. The germplasm accession Zhe 733 was identified as a potential tolerant parent to straighthead and could be used in the Arkansas breeding program.

ACKNOWLEDGMENT

This research was partially funded by the rice producers' checkoff fund through the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Adair, C.R., C.N. Bollich, D.H. Bowman, N.E. Jodon, T.H. Johnston, B.D. Webb, and J.G. Atkins. 1973. Rice breeding and testing methods in the United States. *In:* Rice in the United States: Varieties and Production. USDA Agric. Handb. 289. p. 47.

Atkins, J.G. 1974. Rice diseases of the Americas. USDA Agric. Handb. 448. p. 58-63.

Atkins, J.G., Jr. H.M. Beachell, and L.E. Crane. 1956. Testing and breeding rice varieties for resistance to the straighthead disease. Rice J. 59:36-38.

Atkins, J.G., Jr. H.M. Beachell, and L.E. Crane. 1957. Testing and breeding rice varieties for resistance to straighthead. International Rice Commission Newsletter. 7:12-14.

Baba, I., and T. Harada. 1954. Akiochi, akagare and straighthead. *In:* Physiological diseases of rice plant in Japan. Ministry of Agriculture and Forestry, Japanese Government. Tokyo.

Baker, R.S., W.L. Barrentine, D.H. Bowman, W.L. Hawthorne, and J.V. Pettiet. 1976. Crop response and arsenic uptake following soil incorporation of MSMA. Weed Sci. 24:322-326.

Cheaney, R.L. 1955. Effect of time of draining of rice on the prevention of straighthead. Tex. Agric. Exp. Sta. Prog. Rep. 1774.

Collier, J.S. 1912. Rice blight. Illinois Agric. Exp. Sta. Circular 156. p. 19.

Dilday, R.H., B.R. Wells, R.A. Klerk, K.A. Kuenzel, and T.H. Johnson. 1984. Induced straighthead: Interaction of genotype, arsenic, and nitrogen fertility. Proc. 20th Rice Tech. Working Group. p. 34.

Epps, E.A. and M.B. Sturgis. 1939. Arsenic compounds toxic to rice. Soil Sci. Soc. Am. Proc. 4: 215-218.

Hewitt, J.L. 1912. Rice blight. Ark. Agric. Exp. Sta. Bul. 110: 447-459.

Jones, J.W., J.M. Jenkins, R.H. Wyche, and M. Nelson. 1938. Rice culture in the southern states. USDA. Farmers' Bul. 1808. p. 28.

Joshi, M.M., I.K.A. Ibrahim, and J.P. Hollis. 1975. Hydrogen sulfide: effect on the physiology of rice plants and relation to straighthead disease. Phytopath. 65:1165-1170.

Kataoka, T., K. Matsuo, T. Kon, and Y. Komatsu. 1983. Factors affecting the occurrence of straighthead of the rice plant. I. The occurrence of straighthead by the application of barley straws in paddy field. Japanese J. of Crop Sci. 52:349-354.

Olsen, K.L. 1956. Recent research on two rice production problems. Ark. Farm Res. 5:2.

Padwick, G.W. 1950. Manual of rice diseases. The Commonwealth Mycological Institute. Kew, Surrey, U.K. p. 198.

Rasamivelona, A., K.A. Gravois, and R.H. Dilday. 1995. Heritability and genotype x environment interactions for straighthead in rice. Crop Sci. 35:1365-1368.

Reed, J.F. and M.B. Sturgis. 1936. Toxicity from arsenic compounds to rice on flooded soils. J. Am. Soc. Agron. 28:432-436.

Schweizer, E.E. 1967. Toxicity of DSMA soil residues to cotton and rotational crops. Weeds 15:72-76.

Tisdale, W.H. and J.M. Jenkins. 1921. Rice straighthead and its control. USDA. Farmers' Bul. 1212. p. 16.

Todd, E.H. and H.M. Beachell. 1954. Straighthead of rice as influenced by varieties and irrigation practices. Rice J. 57:20-22.

Tullis, E.C. 1941. Straighthead. Tex. Agric. Exp. Sta. Ann. Rep. 53:163-164.

Wells, B.R. and J.T. Gilmour. 1977. Sterility in rice cultivars as influenced by MSMA rate and water management. Agron. J. 69:451-454.

Table 1. Straighthead ratings of 12 cultivars and their response to MSMA (arsenic) and nitrogen fertilization (lb N/acre)

	0 lb MSMA/acre			6 lb MSMA/acre		
Cultivar	60 N	120 N	240 N	60 N	120 N	240 N
Bengal	3.0	3.0	2.8	7.0	7.5	7.0
Cocodrie	3.8	3.3	2.8	7.2	7.8	7.8
Cypress	3.5	3.0	3.3	6.0	4.8	5.2
Drew	2.5	2.3	2.5	5.2	5.5	6.5
Jefferson	3.3	3.5	3.5	5.0	5.2	5.0
Japan92.09.31	2.5	2.3	2.3	5.8	5.8	4.2
Kaybonnet	2.8	2.5	2.5	7.5	7.5	8.0
LaGrue	3.0	2.8	2.8	6.8	6.0	6.2
Mars	2.8	2.5	2.8	7.2	7.5	7.8
Priscilla	3.8	3.0	3.0	5.0	4.2	4.2
Wells	3.8	3.3	3.0	6.5	6.5	6.5
Zhe 733	2.3	2.0	2.0	2.0	2.0	2.0
LSD (0.05)	0.7	0.9	0.6	1.1	0.7	0.9

Table 2. Grain yield (lb/acre) of 12 cultivars and yield reduction due to MSMA (arsenic) and their response to nitrogen fertilization (lb N/acre).

	0 lb MSMA/acre			6 lb MSMA/acre, 60 N		
Cultivar	60 N	120 N	240 N	(lb/acre)	Reduction	
	------- (lb/acre) -------			(lb/acre)	(lb/acre)	(%)
Bengal	6770.5	6615.2	5219.7	1410.4	5360.1	79
Cocodrie	6533.6	7102.9	6816.2	533.5	6000.1	92
Cypress	6005.8	5672.5	5609.4	3163.1	2842.7	47
Drew	6663.0	6520.2	5774.2	2772.0	3891.0	58
Jefferson	4991.9	5138.5	5765.6	3548.6	1443.3	29
Japan92.09.31	6609.5	6343.5	5807.6	2229.0	4380.5	66
Kaybonnet	5631.4	6158.7	6006.3	336.2	5295.2	94
LaGrue	7610.6	7182.6	5923.2	2089.0	5521.6	73
Mars	6542.6	6012.0	4558.7	298.0	6244.6	95
Priscilla	5851.6	5911.7	4645.6	4352.4	1499.2	26
Wells	5618.0	7113.9	4994.7	1829.7	3788.3	67
Zhe 733	5559.3	5561.7	4310.8	5335.3	224.0	4
LSD (0.05)	1551.0	1094.9	1451.8	1309.7		

contini

Table 2. Continued.

	6 lb MSMA/acre, 120 N			6 lb MSMA/acre, 240 N		
Cultivar	(lb/acre)	Reduction		(lb/acre)	Reduction	
	(lb/acre)	(lb/acre)	(%)	(lb/acre)	(lb/acre)	(%)
Bengal	1383.1	5232.1	79	1777.6	3442.1	66
Cocodrie	525.8	6577.1	93	583.6	6232.6	91
Cypress	4376.2	1296.3	23	4491.4	1118.0	20
Drew	3845.2	2675.0	41	3330.3	2443.9	42
Jefferson	3828.0	1310.5	26	4216.3	1549.3	27
Japan92.09.31	2284.8	4058.7	64	4054.8	1752.8	30
Kaybonnet	246.9	5911.8	96	298.0	5708.3	95
LaGrue	3303.6	3879.0	54	3521.3	2401.9	41
Mars	222.6	5789.4	96	184.8	4373.9	96
Priscilla	4951.3	960.4	16	5844.9	-1199.3	-26
Wells	2939.6	4174.3	59	3511.3	1483.4	30
Zhe 733	5974.8	-413.1	-7	5083.1	-772.3	-18
LSD (0.05)	1233.1			1476.2		

Table 3. Plant height (cm) of 12 cultivars and their response to arsenic and nitrogen fertilization (lb N/acre).

	0 lb MSMA/acre			6 lb MSMA/acre, 60 N		
Cultivar	60 N	120 N	240 N	cm	Reduction	
	---------- (cm) ----------			(cm)	(cm)	(%)
Bengal	84.0	90.5	96.0	70.5	13.5	16
Cocodrie	83.0	89.0	92.0	79.0	4.0	5
Cypress	84.0	85.5	84.0	75.0	9.0	11
Drew	103.5	107.5	111.5	91.0	12.5	12
Jefferson	82.0	82.0	80.5	66.5	15.5	19
Japan92.09.31	93.5	98.5	94.0	83.3	10.2	11
Kaybonnet	95.0	105.5	101.0	82.5	12.5	13
LaGrue	109.5	105.0	111.0	94.5	15.0	14
Mars	109.5	109.5	109.0	78.5	31.0	28
Priscilla	85.5	87.0	87.5	76.5	9.0	11
Wells	93.0	101.5	97.0	81.0	12.0	13
Zhe 733	81.0	82.5	87.0	81.5	-0.5	-1
LSD (0.05)	8.7	5.1	11.4	9.8		

continued

Table 3. Continued.

	6 lb MSMA/acre, 120 N			6 lb MSMA/acre, 240 N		
Cultivar	cm	Reduction		cm	Reduction	
	(cm)	(cm)	(%)	(cm)	(cm)	(%)
Bengal	70.5	20.0	22	83.0	13.0	14
Cocodrie	79.0	10.0	11	83.5	8.5	9
Cypress	74.5	11.0	13	80.5	3.5	4
Drew	94.0	13.5	13	98.5	13.0	12
Jefferson	68.0	14.0	17	71.0	9.5	12
Japan92.09.31	90.0	8.5	9	87.5	6.5	7
Kaybonnet	93.5	12.0	11	94.5	6.5	6
LaGrue	99.5	5.5	5	102.0	9.0	8
Mars	95.0	14.5	13	104.5	4.5	4
Priscilla	78.5	8.5	10	86.5	1.0	1
Wells	90.5	11.0	11	96.5	0.5	1
Zhe 733	84.0	-1.5	-2	84.5	2.5	3
LSD (0.05)	7.4			6.0		

Table 4. Correlation analysis of MSMA (arsenic), nitrogen (N), straighthead rating (Rate), grain yield (Yield), plant height (Height), and heading (Head).

	MSMA	N	Rate	Yield	Height	Head
	---------- (lb/acre) ----------			(lb/acre)	(cm)	(days)
MSMA	1.000	-0.00188	0.75345***	-0.69862***	-0.37624***	0.07021
		0.9748	<0.0001	<0.0001	<0.0001	0.2365
N		1.000	-0.03409	-0.01704	0.21053***	0.14259*
			0.5658	0.7749	<0.0003	0.0158
Rate			1.000	-0.84687***	-0.28586***	0.36597***
				<0.0001	<0.0001	<0.0001
Yield				1.000	0.31221***	-0.12897*
					<0.0001	<0.0298
Height					1.000	0.22513***
						<0.0001
Head						1.000

Table 5. Average straighthead rating of the advanced breeding lines in the Uniform Rice Nursery from Arkansas, Louisiana, Mississippi, and Texas in 1999 (7 maturity groups).

	Maturity Groups							
States	1	2	3	4	5	6	7	Mean
Arkansas	7.3	7.6	7.3	7.6	6.4	7.1	7.6	7.3
Louisiana	7.5	7.2	8.0	7.2	7.2	7.6	7.8	7.5
Texas	5.7	6.5	6.3	7.5	6.0	6.6	7.2	6.5
Mississippi	6.4	6.9	6.4	7.5	6.7	7.5	7.4	7.0
Mean	6.7	7.0	7.0	7.4	6.6	7.2	7.5	7.1
Check	6.8	7.1	5.9	7.5	6.9	7.2	9.0	7.2

Table 6. 1999 Arkansas breeding lines which rated 6.0 or below for straighthead.

Designation	Pedigree	Straighthead Rate
STG 95 L-28-050	Katy/STBN//9101001	6.0
STG 96 L-05-078	LBNT/9902/3/Dawn/9695//STBN/4/LGRU	6.0
STG 96 P-46-062	CPRS/RU9201176	6.0
STG 96 F_5-28-069	CPRS//NWBT/KATY	5.8
STG 96 F_5-11-057	KBNT/RSMT	5.5
Checks		
Katy		8.3
Cypress (CPRS)		6.0
Kaybonnet (KBNT)		7.5
Jefferson		4.8

THE IMPORTANCE AND CAUSES OF SEEDLING DISEASE PROBLEMS IN RICE, 1999

C.S. Rothrock , S.A. Winters, and R.L. Sealy

ABSTRACT

Stand problems consistently cause significant production and management losses in Arkansas rice fields. This research is designed to identify the role of environmental factors (soil salinity, pH, temperature, and moisture) and soil-borne plant pathogens in limiting rice stand establishment. The goal is to determine the conditions in which soil-borne pathogens play an important role in stand establishment and to develop control strategies for reducing seedling disease losses. Results support a role for soil-borne pathogens in stand establishment problems. The removal of pathogens by soil pasteurization increased plant stands, heights, and weights in soils from a number of fields. In the field, selected fungicides resulted in stand increases over two planting dates in 1999 at the Pine Tree Branch Experiment Station (PTBES), also indicating the importance of seedling pathogens. The fungicide Apron showed the greatest stand response for the early planting date. Ascend showed the greatest stand response for the second planting date. The best fungicide treatment resulted in a 15% stand increase for the first planting date and a 22% stand increase for the second planting date. Identification of the fungi isolated from seedlings support these results, with *Pythium* spp. being more frequently isolated from seedlings from the first planting date and *Fusarium* spp. isolated more frequently from seedlings from the second planting date. Virulence tests have indicated that a number of *Pythium* isolates were pathogenic on rice in artificially infested soils.

INTRODUCTION

Stand establishment continues to be a serious problem for Arkansas rice producers. An estimated 300,000 acres have some level of stand establishment problem, with resulting management difficulties on several cultivars the rest of the season. The causes of poor stands in Arkansas rice each year are unclear, and thus practices that would eliminate or reduce losses cannot be implemented. The most consistent stand problems have been associated with high soil salinity, saturated soils (too wet, too long), cool temperatures (early planting), and no tillage. However, the role of these environmental factors in seed rot and seedling death is unclear. Environmental factors may cause seedling death directly or indirectly by placing stresses on the plant or favoring seedling diseases. Defining the role of each of these factors is critical to developing profitable management practices that will assure a consistent, uniform stand establishment.

Seedling diseases have long been recognized as an important problem in drilled and water-seeded rice. It also has been recognized that damage is greatly influenced by environmental conditions. Seedling diseases cause thin, erratic stands with poor vigor as a result of rapid death of the seedling during or shortly after emergence. A number of seedling disease fungi have been associated with the seedling disease complex on rice including *Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp., and *Sclerotium rolfsii* (Rush, 1992). However, the identity and role of these pathogens is still poorly understood. These fungi are common in most crop soils, and there are also numerous fungi on the seed or in crop residue that may attack rice seed and seedlings.

This ongoing research project is designed to identify the role of abiotic environmental factors and plant pathogens in seedling losses in problem fields, with the overall objective of developing management practices to reduce stand losses. Initial results from controlled environmental studies indicate that soil-borne pathogens are important in stand establishment problems in soils from a number of fields, with the removal of soil pathogens by soil pasteurization generally increasing plant stands, heights, and weights compared to nonpasteurized soils (Rothrock and Sherrill, 1999).

PROCEDURES

Soils were collected from sites with a history of stand establishment problems in Poinsett and Arkansas counties and at PTBES. A system was designed to examine the relative importance of abiotic and biotic components on rice seedling establishment. Soil was stored at 39°F and divided into two lots—one lot was pasteurized at 140°F for 30 min to kill soil-borne plant pathogens and the other lot was not treated. Soils were placed in 6-in. pots and subjected to various environmental treatments. Soil temperature treatments included 60, 65, and 70°F. After incubating soils for 1 wk, the soils were planted with 15 seed per pot of the cultivar 'LaGrue'. Soil water treatments were watering as needed or continuous soil saturation. The experiment for each soil was a 3 x 2 x 2 factorial design with three replications. Stands were recorded weekly and plant development and weight assessed after 3 to 4 wk. Seedlings were evaluated for disease using a 1 to 5 scale. The root rating was 1 = no discoloration, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = >50% root discoloration. The coleoptile rating was 1 = healthy, 2 = discolored coleoptile, 3 = lesion on coleoptile, 4 = lesion expanding to leaf sheath, and 5 = death of leaf. Seedlings were washed in running water for 20 min, and roots were disinfected in 0.5% NaOCl for 1.5 min. Root systems were plated on water agar amended with the antibiotics rifampicin and ampicillin and the miticide Danitol to isolate fungal pathogens. After 3 to 4 days, developing colonies were transferred to potato dextrose agar amended with rifampicin, ampicillin, and Danitol for identification.

Field studies were established in 1999 at PTBES to examine the importance of specific soil-borne pathogens and their control through the application of fungicides having specific activity to the seed. The treatments were Apron (metalaxyl), active against Oomycetes, and the fungicides Baytan (triadimenol), a sterol-inhibiting fungicide, and Ascend (TCMTB), a fungicide with a broad range of activity, including against *Fusarium* spp. The cultivars 'Lemont'and 'Drew' were planted on 23 April and 3 May. Plant stands were assessed on three arbitrary 1-m rows on two dates, and 15 seedlings were dug from each plot to determine prevalence of genera containing plant pathogens, using the procedures described above.

Pathogenicity of selected *Pythium* isolates was evaluated in 1999 to determine the range of virulence of isolates. Isolates from seedlings were purified and cultured on corn meal agar. Inoculum was prepared by placing pieces of cultures in flasks containing sterilized sand and corn meal and cultured for 10 days prior to placing inoculum in vermiculite and planting rice. Data collected included stand, plant height and weight, and disease indices.

RESULTS AND DISCUSSION

The removal of pathogens by soil pasteurization generally increased plant stands, heights, and weights in soils from a number of sites. Plant weight in pasteurized and nonpasteurized soils has been one of the most sensitive indicators of damage from soil-borne pathogens. This response was consistent for both 1998 and 1999, as indicated by data from PTBES (Table 1). The response from soil treatment was greater at 70°F than 60°F, and there was no consistent response for watering regime on plant weight. *Pythium* spp. were frequently isolated from seedlings.

Field studies established in 1999 at the PTBES to examine the importance of specific soil-borne pathogens and their control using the fungicides Apron, Baytan, and Ascend showed stand increases by one or more fungicides for both planting dates (Table 2). The fungicide proving most effective differed with the date of planting. Apron showed the greatest stand response for the earlier planting date. Ascend and Baytan showed the greatest stand response for the second planting date. The best fungicide treatment resulted in a 15% stand increase for the first planting date and a 22% stand increase for the second planting date. Cultivars responded similarly by 4 weeks after planting. However for 2 weeks after planting for the earlier planting date, plant stand per foot of row for Lemont (6.9) was lower than for Drew (8.6). Significant rainfall occurred within 3 days of each planting. Identification of the fungi isolated on seedlings support these results. *Pythium* spp. were more frequently isolated from the first planting date—41% of seedlings—compared to the second planting date, 34%. In contrast, *Fusarium* spp. were isolated from 37% of seedlings from the first planting date and 45% of seedlings from the second date of planting.

Pathogenicity assays have been conducted on 26 isolates to date, with a range of reactions from no damage to complete stand loss (Table 3). Several *Pythium* isolates showed greater virulence than the standard isolate used in the assay, *Pythium ultimum*.

Current research is expanding the soils being characterized under controlled conditions and field sites for fungicide evaluations. The role of the soil environment on damage from *Pythium* spp. is being examined.

SIGNIFICANCE OF FINDINGS

Results from controlled environmental studies emphasize the role of soil-borne pathogens in stand establishment problems. The removal of soil pathogens by soil pasteurization increased plant stands, heights, and weights for soils from a number of fields. In the field, selected fungicides gave stand increases over two planting dates in 1999 at PTBES, also indicating the importance of seedling pathogens. Application of Apron to the seed gave a 15% increase in stand for the first planting date and the fungicide Ascend gave a 22% stand increase for the second planting date. Identification of the fungi isolated from seedlings support these results, with *Pythium* spp. being more frequently isolated for the first planting date and *Fusarium* spp. isolated more frequently for the second planting date. Pathogenicity tests have indicated a number of *Pythium* isolates recovered from rice that were pathogenic on rice in artificially infected soils.

ACKNOWLEDGMENTS

The authors would like to give special thanks to the Arkansas Rice Research and Production Board for their financial support of this project.

LITERATURE CITED

Rothrock, C.S., and J. Sherrill. 1999. The importance and causes of seedling disease problems in 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 468:220-224.

Rush, M.C. 1992. Seedling diseases. R.K. Webster and P.S. Gunnell (eds.). Compendium of Rice Diseases. APS Press, St. Paul, MN. pp 12-14.

Table 1. Influence of soil-borne pathogens and environment on plant weight[z].

	Pine Tree Branch Experiment Station		
	1998		1999`
Treatment	Rice[z]	Soybean[z]	
	----------------- (fresh plant weight per pot in g)		-----------------
Pasteurize			
+	0.14 a	0.08 a	0.26 a
–	0.09 b	0.07 b	0.13 b
Temperature (°F)			
60	0.08 b	0.05 b	0.06 c
65			0.16 b
70	0.16 a	0.10 a	0.35 a
Water			
Saturated	0.14 a	0.07 a	0.20 a
Nonsaturated	0.10 b	0.08 a	0.19 a
Temp * Past	*		
Temp * Water	*		
Past * Water			*
Temp * Water * Past			

[z] Previous history of crop production in field.

Table 2. Influence of selective seed treatment fungicides on rice stand establishment, Pine Tree Branch Experiment Station.

	Date of Planting	
Fungicide treatment	23 April	3 May
	---------------------------- (plants / ft of row)	----------------------------
None	9.0 b	8.2 b
Apron	10.4 a	8.7 ab
Ascend	10.1 ab	9.8 a
Baytan	10.1 ab	9.4 a
	$P = 0.08$	$P = 0.02$

Table 3. Pathogenicity of Pythium isolates from rice.

Isolate	Stand (no. seedlings / pot)
Noninfested	9.3
Nonpathogenic *Pythium* sp.	8.6
Pythium ultimum	6.6
Pythium 4N171/G1	8.0
Pythium 7N171/E1	0.0
Pythium 7N172/G1	0.0
Pythium R305/11	0.3
Pythium 7N271/D1	1.3

INTEGRATING BIOLOGICAL CONTROL OF NORTHERN JOINTVETCH WITH COLLEGO AND CHEMICAL CONTROL OF RICE DISEASES AND WEEDS

D.O. TeBeest and C. Guerber

ABSTRACT

Collego, a formulation of the fungus *Colletotrichum gloeosporioides* f. sp. *aeschynomene*, was registered with Environmental Protection Agency as a biological herbicide to control northern jointvetch (NJV) in rice and soybeans. Collego causes a disease on NJV to control the weed and can therefore be adversely affected by the use of fungicides, insecticides, and herbicides. In 1999, selected pesticides, including Benlate, Blazer, Moncut, Quadris, Rovral, and Tilt, were applied to replicated small plots 7 days before, 7 days after, and on the same day Collego was applied to control NJV. None of the treatments were tank mixes. Blazer and Tilt reduced control of NJV with Collego in all three applications. Benlate reduced effectiveness when applied before or on the same day as Collego, while Rovral reduced the effectiveness of Collego when applied on the same day or 7 days after application of Collego. Moncut and Quadris did not significantly reduce the effectiveness of Collego in any of the applications. Additional work is needed to confirm these data before recommendations can be made with confidence.

INTRODUCTION

Northern jointvetch, *Aeschynomene virginica* (L.) BSP., is a problem weed in Arkansas and other states of the Mississippi River delta. In sufficient numbers, the weed is competitive with rice and soybean and can reduce yields accordingly. However, NJV is more important in rice production because it produces black seeds that lower the quality of milled rice.

Collego was developed to control NJV through a joint project of the University of Arkansas Division of Agriculture, the USDA, and industry (Smith, 1986). This product was registered with EPA and used extensively in Arkansas from 1982 to 1992 as a result of this work (Bowers, 1986). From 1992 to 1997, Collego was not marketed because of loss of a manufacturer. Continued interest in the product by rice producers supported efforts to re-register the product, and in 1997, a new manufacturer for Collego was identified and a re-registration of Collego with EPA was obtained.

Return of Collego to the marketplace in Arkansas has resulted in a number of questions concerning its use. Among the more important of these were questions re-lates to the integration of Collego with chemical pesticides used to control diseases, insects, and weeds. Klerk *et al.*, (1985) had previously described the effect of several chemical pesticides on Collego in 1978. However, in 1998 there were new questions regarding interactions with the more recently registered fungicides, such as Quadris, labeled for use in rice.

The objectives of our research were to determine the effects of several chemical pesticides on the effectiveness of Collego in the field and to construct an application schedule that minimizes any problems with the effectiveness of Collego in rice by selected chemical pesticides.

PROCEDURES

The experiments were conducted at the Pine Tree Experiment Station, Colt, with four replications of each treatment. Rice was drill-planted in plots nine rows wide by 16 ft long in early May 1999. Plots were maintained, irrigated, and fertilized according to standard rice production practices.

Northern jointvetch seedlings were planted into 12-oz paper cups in the green-house on 14 May 1999 from pregerminated seeds grown and collected in the field at Fayetteville. Seedlings were watered daily and fertilized once weekly with Peter's Complete Fertilizer. Fifteen NJV plants were transplanted into the flooded rice plots at Pine Tree on 7 June 1999, when plants were approximately 10 to 14 in. tall. Five plants were placed in three small groups (A, B, and C) in the front, middle, and back of each plot, respectively.

Each pesticide and pesticide x Collego interaction was tested in a split-split plot design with four replications of each treatment and interaction. Main treatments con-sisted of selected chemical pesticides (Benlate, Blazer, Moncut, Quadris, Rovral, and Tilt) applied to the transplanted NJV plants in flooded rice in one of three secondary treatments. The secondary treatments consisted of an application of each pesticide one week before (Group A), on the same day as (Group B), and one week after (Group C) a single application of Collego, respectively. Four additional plots of NJV were treated with Collego alone. All applications were made with a backpack sprayer applying 10 gal/acre. Benlate, Blazer, Moncut, Quadris, Rovral, and Tilt were applied at rates of 1.0 lb, 0.25 lb, 1.0 lb, 0.25 lb, 1.0 pt, and 10.0 fl oz per acre, respectively. Collego was used as directed on the label. All Group A applications were made on 2 July 1999, all Group B applications were made on 9 July 1999, and all Group C applications were made on 16 July 1999. Collego was applied to all plots in Groups A, B, and C in mid-afternoon on 9 July 1999.

Data were collected beginning 9 July 1999 and thereafter for 6 wk at 10- to 14-day intervals. The effect of Collego on treated NJV plants was determined by indexing the severity of the disease caused by Collego on individual plants in each treatment on a scale of 1 to 5, where 1 = healthy and 5 = dead. The overall effects of the chemical treatments on development of the disease on NJV are expressed as an average disease index for the plants in each treatment averaged across all four plots for each date and treatment.

RESULTS AND DISCUSSION

The data collected from the 1999 test suggest a number of negative and neutral interactions of Collego with chemical pesticides. Application of Collego in mid-afternoon resulted in only moderate control of NJV. The average disease index ratings were 3.5 after 4 wk (Table 1). It is likely that control of NJV was only moderate owing to mid-afternoon applications. Previous experience (Smith, 1986) has shown that Collego is more effective when applied at dusk or in early evening.

Blazer and Tilt inhibited development of the disease on NJV caused by Collego at all applications (Table 1). Average disease ratings for NJV treated with Blazer and Tilt were 1.9 and 2.0, respectively, compared to 3.5 for Collego alone.

Benlate appeared to reduce the effectiveness of Collego when it was applied before or on the same day as Collego was applied (Table 1), but it did not appear to affect Collego when it was applied 7 days later. Disease ratings of the NJV plants treated with Benlate 7 days after Collego were higher than similar plants treated with Benlate 7 days before or on the same day as Collego.

Rovral did not appear to have any effect on the development of Collego on NJV when applied 1 wk before Collego, but this fungicide appeared to significantly reduce the effectiveness of Collego when it was applied on the same day or 1 wk after Collego (Table 1).

Two other fungicides tested in 1999, Moncut and Quadris, appeared to have had little, if any, effect on the development of Collego on NJV (Table 1).

These results should be considered conservatively and as preliminary information. It is too early to develop specific recommendations to producers who utilize these pesticides in rice production programs; however, based on these data, it appears that use of Quadris and Moncut to control rice diseases may not significantly reduce the effectiveness of Collego applied to control NJV.

Effective integration and use of Blazer, Benlate, Tilt, and Rovral with Collego will require additional research. The study conducted in 1999 suggests that 7-day delays between Collego and Blazer or Tilt are insufficient for effective use of Collego. These data also suggest that Benlate may be used after Collego is applied, while Rovral may be used before but not after application of Collego.

Additional research under consideration for 2000 includes testing treatments that lengthen the time between applications to 10 days, incorporating tank mixes of some fungicides with Collego, and testing additional rates of one or more of the chemical pesticides.

SIGNIFICANCE OF FINDINGS

The benefits to the producers using Collego in their production schedule includes the reduction or complete elimination of dockages levied on each bushel of rice produced and sold containing seeds of NJV and release from problems associated with the drift of chemical herbicides applied to control this weed onto sensitive crop and ornamental species growing nearby.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board and the Department of Plant Pathology, University of Arkansas. We also gratefully acknowledge the work and assistance of Mr. Roger Eason, Director, and Mr. Shawn Clark, Research Specialist, at the Pine Tree Branch Experiment Station, Colt.

LITERATURE CITED

Bowers, R.C. 1986. Commercialization of Collego™— an industrialist's view. Weed Sci. 34:24-25 (Suppl).

Klerk, R.A., R.J. Smith, Jr., and D.O. TeBeest. 1985. Integration of a microbial herbicide into weed and pest control programs in rice (*Oryza sativa*). Weed Sci. 33:95-99.

Smith, R.J. Jr. 1986. Biological control of northern jointvetch (*Aeschynomene virginica*) in rice (*Oryza sativa*) and soybeans (*Glycine max*)— a researcher's view. Weed Sci. 34:17-23 (Suppl).

Table 1. The impact of selected chemical pesticides on the effectiveness of Collego for the control of northern jointvetch.

Pesticide	Application rate[z]	NJV Control[y]			Average control[x]
		Before	Same Day	After	
	(product/acre)				
Blazer	0.25 lb	1.8	1.8	2.1	1.9
Benlate	1.0 lb	2.4	2.0	4.2	2.9
Tilt	10 oz	2.1	2.0	2.0	2.0
Quadris	0.25 lb	4.8	4.0	3.6	4.1
Rovral	1 pt	4.8	2.4	2.1	3.1
Moncut	1.0 lb	4.1	3.5	3.2	3.6
Collego	---	NA	3.5	NA	3.5

[z] The amount of commercial product applied per acre in 10 gallons of water. All materials were applied by backpack sprayer at constant pressure. Collego was resuspended in water and rehydrating agent as directed and applied at the rate directed on the label to deliver 2 million viable spores per ml.

[y] Value indicates the average disease index (scale = 1 to 5, where 1 equals healthy and 5 equals dead) of northern jointvetch plants treated with Collego and each pesticide combination indicated. Before, Same Day, and After mean that each pesticide was applied one week before, on the same day as, or one week after application of Collego, respectively, None of the chemicals were applied as a tank mix with Collego.

[x] Average control is the average level of control of northern jointvetch treated with Collego across all treatments for each pesticide.

HELPING ARKANSAS RICE FARMERS EXPLOIT MARKET OPPORTUNITIES BY IMPROVED USE OF SOYBEAN, WHEAT, AND CORN IN RICE ROTATIONS

M.M. Anders, T.E. Windham, H.D. Scott, K.A. Moldenhauer, R.K. Bacon, R.W. McNew, R.D. Cartwright, and L.O. Ashlock

ABSTRACT

A whole farm systems approach to crop production has been implemented by this project. The site where this study is being conducted was graded to a 0.15% slope in February 1999. All treatments were established, except for the no-till treatments, which will begin in the next crop. In the first year of the established rotations corn yields for the two varieties, 'Pioneer 31B13' and 'N75-T2(90)', were 135 bu/acre at both fertility levels. Grain yields for the rice variety 'Wells' were higher than those for 'LaGrue', while both varieties yielded less at the higher fertility level. Of the group V soybeans, 'Asgrow 5901' yielded 56 bu/acre while 'DP 5960' yielded 53 bu/acre. Yields from both soybean varieties were the same at standard and high fertility levels. Grain yields for the group IV soybean varieties, 'Asgrow 4702' and 'H4994RR' were the same (45 bu/acre) at both fertility levels. An error in applying Command herbicide resulted in severe damage to all short-duration rice plots. Winter wheat was sown during the first week in December, thus establishing the first no-till treatments. The consistently lower yields from the higher fertility plots for all crop species are attributed to plant growth constraints resulting from precision grading of the field earlier in the year. There were significant differences in crop yields between replications and considerable variation within plots in the upper part of the field, where much of the top soil was removed.

INTRODUCTION

Farm legislation enacted in 1996 was aimed at removing crop subsidies by 2002. In a general sense, this legislation allows farmers to grow what they want, with market prices being the primary determining factor in crop selection. For rice farmers, this creates a production environment that is different from the past. Historically, rice has been both subsidized and regulated; thus, farmers will need to depend less on government programs and more on markets. This change demands a degree of flexibility to which farmers are not accustomed. Nowhere will this change be manifested more than in rotation sequences and related changes to the natural resource base. This project was established with the following objectives: (1) provide a set of management guidelines that farmers can use to assist them in maintaining their profitability should they change their rotations; (2) explore the potential of using short-duration rice, soybean, wheat, and corn varieties in a range of crop rotations; (3) measure the effects of fertility levels and crop sequences on pest and disease incidence in existing and new rotations; (4) explore the use of conservation tillage in a range of rotations; (5) determine the feasibility of using corn in rice-based cropping systems; and (6) test existing cropping systems models that include the crop species used in this study.

Unique to this study is its long-term nature. Traditionally, fertility recommendations for rice have been developed using single- or double-season studies and a limited number of rotations. This study will test current recommendations along with examining increased fertility levels as a way to enhance the natural resource base. Linked to fertility issues will be the impact of no-till cultivation across the range of crops and rotations used. Measurements of organic matter will allow for comparisons across tillage, rotation, and fertility treatments. Once established, water use measurements will be taken.

PROCEDURES

In February 1999, the experimental area was precision graded to a 0.15% slope. Plots measuring 250 ft by 40 ft were laid out in a north-south direction. These plots were then divided in half east-west, with each side randomized as conventional or no-till treatments. Each tillage treatment was then split into a standard and high fertility treatment (Table 1). Two varieties of each crop species were planted in a continuous strip across the conventional- and no-till treatments. Because the field had been cut to grade, it was not possible to establish no-till treatments on the first seeding. Prior to seeding, soil samples were collected for weed counts, nematode counts, and fertility and soil structure measurements. The plots were then randomized with the following crop rotations: (1) continuous rice; (2) rice-soybean; (3) soybean-rice; (4) rice-corn; (5) corn-rice; (6) rice (wheat)-rice (wheat); (7) rice (wheat)-soybeans (wheat); (8) soybeans (wheat)-rice (wheat); (9) rice-corn-soybeans; and (10) rice-corn (wheat)-soybeans. Two fertility levels (Table 1) and two varieties of each species were used for each plot. The corn plots (rotation 5) were sown into rows spaced 32 in. apart on 14 April using a standard John Deer row crop planter. The two standard rice varieties ('LaGrue' and 'Wells') were sown into rows spaced 7.5 in. apart on 23 April using a John Deer 750 no-till drill. Maturity group V soybeans were sown into rows spaced 15 in. apart on 11 May using a John Deer750 no-till drill while the Maturity group IV varieties were sown on May 11 using the same drill and row spacings. The short-duration rice varieties were sown on 22 June using a small Hege drill set at 7.5-in. spacing. Weed control in the corn consisted of one AAtrex application at 1.25 lb ai/acre postemergence. All soybean plots received a single over-the-top Roundup application 3 to 4 wk after emergence. The full-season rice plots were treated with Stam and Facet prior to flooding, while the short-duration plots received a single Command application prior to seeding.

Corn harvesting was completed on 21 October. Full-season rice was harvested on 14 September and short-duration rice on 25 October. Group V soybeans were harvested on 21 October and group IV on 21 October. All yields were adjusted to a 12% moisture content.

RESULTS AND DISCUSSION

Precision leveling the field to grade resulted in a gradient of lower yields and more within-plot variation at the top of the field compared to higher yields and less variation within plots at the bottom of the field. The experimental design and location of the replications reduces the impact of this variation in comparing tillage, fertility, and variety treatments, yet allows for identifying yield trends across the field. Grain yields for the rice variety Wells were higher than for LaGrue over all plots and there was much less variation within the Wells plots. At the high fertility level, Wells yields were 212 bu/acre while LaGrue was 179 bu/acre. At the standard fertility level, yields were 215 bu/acre for Wells and 194 bu/acre for LaGrue. Wells out-yielded LaGrue by 30 bu/acre in the lowest yielding replication and 6 bu/acre in the highest yielding replication, indicating a possible additional advantage of using this variety in difficult fields. It was also noted that grain moisture levels of Wells dropped more quickly than those of LaGrue, and Wells may need to be closely monitored by farmers so that milling quality is not reduced. The shorter plant height of Wells resulted in less lodging in the high-fertility plots. Equal or lower grain yields in the high-fertility plots is attributed to growth constraints brought about by precision leveling the field. Yield differences between replications were more evident than those between fertility treatments.

Both group V soybean varieties grew well, with these treatments showing the least variation within plots. There were no significant differences between grain yields of the varieties and/or fertility levels. 'Asgrow 5901' yielded 54 bu/acre at the standard fertility level and 57 bu/acre at the high fertility level while 'DP 5960' yielded 53 and 52 bu/acre at the standard and high fertility levels, respectively. Excellent weed control was obtained with one over-the-top application of Roundup 4 wk after sowing. There was more lodging at harvest in the variety Asgrow 5901 than in DP5960. Grain yields for the group IV soybeans were similar but lower than the group V yields. Both varieties yielded 46 bu/acre at the standard fertility level and 43 bu/acre at the high-fertility level. As with the group V varieties, excellent weed control was achieved using a single over-the-top Roundup application at 4 wk after sowing. The variety 'Hartz 4994' lodged more than 'Asgrow 4702'. Unlike the earlier seeded group V varieties there was a considerable amount of variation within plots of the later seeded group IV varieties.

Of all the crop species used in this study, corn was the most sensitive to soil variations across the field. It was sown earlier and rainfall was adequate and well spaced during the first part of the season, so there were fewer variations within plots than with other crop species; however, there was a significant reduction in grain yield at the top of the field, where there had been deep cuts from leveling. Grain yields for both varieties and fertility levels were within two bushels of 135 bu/acre. Excellent weed control was obtained using a single over-the-top application of AAtrex plus crop oil before the corn had reached a height of 12 in.

SIGNIFICANCE OF FINDINGS

Results from the first year of this study highlight the potential of the recently released Wells rice variety. They should help farmers target where they might best use this variety and alert them to the need to carefully monitor the variety's drying down at the end of the season. The lack of increased yields in nearly all high-fertility treatments and a consistent yield gradient across the field highlight the difficulties in using increased fertilizer applications to compensate for soil physical and chemical problems brought about by bringing the field to grade. This study will continue to highlight a range of positive and negative results across the range of cropping systems and management practices being tested and, over time, provide a long-term perspective on sustaining yields and profits.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board, Arkansas Soybean Promotion Board, Arkansas Wheat Promotion Board, and Arkansas Corn and Sorghum Promotion Board for their support of this project. We would also like to thank Asgrow, Hartz, Novartis, and Pioneer for providing seed for this study.

1999 RICE RESEARCH VERIFICATION PROGRAM

W.B. Koen, N.A. Slaton, C.E. Wilson, Jr., and T.E. Windham

ABSTRACT

Ten commercial rice (*Oryza sativa* L.) fields participated in the 1999 Rice Research Verification Program (RRVP). The participating counties were Arkansas, Ashley, Chicot, Cross, Greene, Jefferson, Lawrence, Phillips, Prairie, and Pulaski. Agronomic and economic data for specified operating costs were collected for each RRVP field to evaluate the effectiveness and profitability of production recommendations. The 10 fields totaled 618 acres, with an average field size of 62 acres/field. Four cultivars were seeded ('Bengal', 'Cypress', 'Drew', and 'LaGrue'). Yield, adjusted to 12% moisture, averaged 155 bu/acre and ranged from 126 to 175 bu/acre. Economic analysis suggested that 1999 RRVP total specified production costs were comparable to estimated costs in 1999 rice production budgets from the extension services. Net returns from 1999 RRVP fields averaged $16.49/acre above total specified operating costs and land costs. Thus, the price per bushel required for growers to cover land rent and total specified costs was $3/bushel.

INTRODUCTION

The RRVP has been conducted on 165 commercial rice fields since it first began in 1983. It is an interdisciplinary program that stresses management intensity and integrated pest management to maximize net returns. The program objectives are to verify current research-based recommendations on grower fields, increase the potential for profitable rice production by identifying technology gaps in recommendations, accumulate a database for rice economic programs, and provide hands-on training for county extension agents and producers.

PROCEDURES

Each RRVP field and farm cooperator was selected prior to seeding. Farm cooperators agreed to pay production expenses, provide crop expense data for economic analysis, and implement the recommended production practices in a timely manner from seedbed preparation to harvest. A designated county agent from each participating county assisted the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the grower. Management decisions were made based on current University of Arkansas research-based extension recommendations. Additional assistance was provided by the appropriate extension specialist or researcher as needed.

The RRVP has historically worked with cooperating farmers for two consecutive years. This arrangement most often resulted in different RRVP fields with the same grower. The program was changed before the 1999 growing season so that only one field per cooperator would be enrolled for the duration of the RRVP. Thus, if rice is grown two consecutive years in the same field, the RRVP will be conducted for two consecutive years. If the RRVP field is rotated to soybean and then back to rice, the RRVP program would skip a year and return the following year when rice is grown.

Counties participating in the 1999 RRVP included Arkansas, Ashley, Chicot, Cross, Greene, Jefferson, Lawrence, Phillips, Prairie, and Pulaski. Four cultivars (Bengal, Cypress, Drew, and LaGrue) were seeded on the 10 fields totaling 618 acres (Table 1). University of Arkansas recommendations were used to manage each RRVP field. Management decisions were based on field history, soil test results, cultivar, and data collected from each individual field during the season. A summary of selected agronomic inputs, field characteristics, and soil test information is provided in Tables 1 to 4.

Small, replicated research studies were established in eight RRVP fields to evaluate nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) fertilization recommendations. Fertilizer treatments varied by field, since fertilization requirements were different among fields (Table 5). The untreated check treatment in each field was the actual fertilizer recommendation applied to the entire field (Table 3). All other treatments received the same fertilizers applied to the check plus the fertilizers, rates, and time of application specified in Table 5. At maturity, an 8-ft section of the four center rows (about19 ft^2/plot) were hand-harvested from each plot for yield determination. Yields were adjusted to 12% moisture.

Statistical analysis was preformed only on small-plot replicated fertilizer trials. Treatments were arranged as a randomized complete block design with three replications. Yield data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fisher's Protected Least Significant Difference Test at the 0.05 significance level.

RESULTS AND DISCUSSION

Grain yield in the 1999 RRVP averaged 155 bu/acre, with a range of 126 to 175 bu/acre (Table 1). All fields were seeded in April except for Cross and Phillips counties, which were seeded by early May. The 1999 RRVP yield was 18% greater than the estimated Arkansas state average of 131 bu/acre. Fields seeded to LaGrue produced the two highest grain yields during 1999 (Table1). The lowest yield (126 bu/Acre) was recorded in the Chicot County field. Although stand density averaged only 11 plants/ ft^2, the stand was uniform and should not have been a yield-limiting factor (Table 3). Other identifiable factors that would have limited yield at this location were not evident. A yield component study was initiated in 1999 to investigate situations in which yields were lower than expected. Unfortunately, yield components were taken from the Chicot County field. Data collected from the yield component study will be reported when additional field data are collected. Small research plots, established in the Chicot County field also failed to identify nutritional factors that may have limited yield (Table 5). The average yield obtained from the research plots (180 bu/A) was 43% higher than the field average yield. The yield difference between research plots and field average at other locations was generally less than 15%. Specific reasons for the large difference in yields in Chicot county are not known.

Season-long weed control was obtained from single herbicide application in five RRVP fields (Table 4). Acceptable grass control was obtained with a single preplant application of Command at two locations. The only grass control failure occurred in the Arkansas County field. The propanil-Facet tank mixture failed to control barnyardgrass, and Ordram 15G was applied after flooding. Barnyardgrass seed was submitted for herbicide-resistance testing. Results are not yet available. A second herbicide application was required for the control of yellow nutsedge and/or broadleaf weeds in four RRVP fields. The average number of herbicide applications/acre in 1999 RRVP fields was 1.67.

Neither false nor kernel smut was a major problem in the RRVP fields in 1999. This is possibly due to the fact that all of the RRVP fields were seeded early. Two of the RRVP fields (Jefferson and Pulaski) were treated with foliar fungicides for sheath blight, and one (Ashley) was treated for blast. Both of the fields treated for sheath blight were seeded with the cultivar Cypress. The field treated for blast was seeded with LaGrue.

The Prairie County field was treated with methyl parathion for stink bug control within 2 wk after 50% heading. Insect populations failed to reach the recommended treatment thresholds in all other RRVP fields.

Fertilization studies failed to document additional significant yield increases from extra fertilizer application (Table 5). Although not significant, application of extra preflood N actually tended to decrease yields at several locations. This suggests that preflood N rates applied to fields were adequate. This is not surprising because many RRVP fields were fertilized using the "Optimum Preflood" N rates (Table 3). Statistically significant differences among treatments were found only at the Greene County location. Application of extra P fertilizer reduced yields compared to the untreated check. Yield reductions from P fertilizer application to acid soils have previously been documented. The control plot and remainder of the field received P fertilizer before flooding. Small-plot data suggest that fertilizer rates verified in small-plot treatments were adequate for maximum yield production. By design, these studies were not able to compare the effectiveness of applied fertilizer to a true untreated control.

ECONOMIC ANALYSIS

The cost of herbicides ranged from $6.46 to 92.34/acre, with an average of $46.64/acre. The average cost of a single herbicide application (excluding application costs) was $19.20/acre. The average herbicide cost (excluding application costs) for fields with Command in the weed program was $13.09/acre compared to $36.71/acre in programs without Command. The average RRVP costs for fertilizer, insecticides, and fungicides (excluding application costs) were $36.23, $0.56, and $9.27/acre, respectively. Total specified operating costs (herbicides, application, fuel, drying, etc.) ranged from $244.22 to 361.29/acre and averaged 282.75/acre (Table 6). Estimates of total specified ownership costs ranged from $55.68 to 67.45/acre and averaged $60.14/acre. Total specified (direct and fixed) expenses averaged $342.89/acre. University of Arkansas rice production budget estimates for total specified expenses ranged from $332.32 to 354.62/acre. Estimated operating costs in 1999 RRVP fields were relatively close to these estimates. The average breakeven price, assuming a 25% crop share rent, was $3.00/bu. Based on a $3.14 cash price, the average across all fields showed a net profit of $16.49/acre. Four individual fields had a net negative return (Table 6).

SIGNIFICANCE OF FINDINGS

Data from the 1999 RRVP reflect the general trend of above-average rice yields and below-average returns for Arkansas growers during 1999. Extremely hot and dry weather made water management difficult for most of the year. A few growers did not have enough pumping capacity to deliver water to the required acreage in the absence of rainfall. Despite the weather, residual weed control programs used in the RRVP fields provided excellent grass control. Analysis of the RRVP data showed that the average grain yield was higher than the state average yield and production costs were equal to Cooperative Extension Service estimated rice production costs, and showed that on average net returns to rice growers were barely enough to cover land rent and production expenses. Production of high yields does not guarantee profitable rice production, especially when prices are low.

Table 1. County, acreage, soil series, previous crop, grain yield, cultivar, and seeding method of the 1999 RRVP.

County	Field Size	Soil Series	Previous Crop	Grain Yield	Cultivar	Seeding Method
	(acres)			(bu/acre)		
Arkansas	75	Crowley-Stuttgart silt loam	Soybeans	175	LaGrue	Drill
Ashley	80	Calhoun silt loam	Soybeans	165	LaGrue	Drill
Chicot	35	Sharkey clay	Soybeans	126	Drew	Drill
Cross	80	Crowley/ Hilleman silt loam	Soybeans	160	Bengal	Broadcast
Greene	65	Alligator silty clay loam	Soybeans	161	Bengal	Drill
Jefferson	50	Portland clay	Soybeans	152	Cypress	Drill
Lawrence	40	Dubbs silt loam	Rice	150	Drew	Drill
Phillips	90	Henry silt loam	Cotton	144	Drew	Broadcast
Prairie	50	Calhoun/ Calloway silt loam	Soybeans	141	Bengal	Drill
Pulaski	53	Rilla silt loam	Soybeans	152	Cypress	Drill
Average	61.8	-------	-------	155[z]	-------	-------

[z] Weighted average (the sum of individual yields multiplied by the individual acreage and divided by the total acreage).

Table 2. Soil test results from the 1999 Rice Research Verification Program fields[z].

County	Soil pH	Phosphorus	Potassium	Zinc	Calcium
		(lb/acre)			
Arkansas	7.4	44	186	4.7	4106
Ashley	6.5	53	199	1.7	1739
Chicot	6.5	46	613	5.1	6720
Cross	7.6	29	134	2.8	4122
Greene	6.3	16	276	2.8	3280
Jefferson	6.1	22	541	3.8	3702
Lawrence	7.0	51	194	5.1	1141
Phillips	6.6	52	215	2.8	2302
Prairie	6.7	23	102	15.9	1999
Pulaski	6.7	39	121	3.1	2303

[z] Reported soil test values are the mean of several composite soil test samples from each field.

Table 3. Stand density, seeding rates, fertilizer rates, and important dates of the 1999 RRVP.

County	Stand density	Seeding rate	Nitrogen applications urea (45%)[z]	Fertilization $N-P_2O_5-K_2O_5-Zn$	Seeding date	Emerge date
	(plants/ft^2)	(lb/acre)	(lb urea/acre)	(lb/acre)	------- (m/day)	-------
Arkansas	34.3	101	251-80	149-63-60-10	4/19	4/27
Ashley	25.1	112	200-100	135-0-0-1	4/28	5/8
Chicot	11.2	112	255-100	160-0-0-0	4/13	4/28
Cross	25.0	112	222-133	160-63-80-10	5/3	5/15
Greene	16.5	117	311-0	140-46-0-0	4/20	5/5
Jefferson	17.0	112	302-67	166-23-0-0	4/20	5/6
Lawrence	35.3	112	178-200	170-0-0-0	4/30	5/10
Phillips[y]	17.5	112	215-0	97-40-0-0	5/10	5/16
Prairie	19.6	108	245-80	146-40-80-0	4/19	5/3
Pulaski	28.0	99	211-167	170-40-80-0	4/20	4/29

[z] Values represent the split N applications as follows: Preflood - Midseason split 1; Midseason split 2.

[y] 2000 lb fresh chicken litter/acre was applied to this field.

Table 4. Pesticide timing, treatment (product), and formulation rate/acre for herbicides applied to the 1999 Rice Research Verification Program Fields.

County	Pesticide Timing, Treatments and Rates
Arkansas	**Early Post:** Propanil (3 qt) + Facet (0.4 lb) **Post Flood:** Ordram 15G (33 lb)
Ashley	**Early Post:** Propanil (4 qt) + Facet (0.33 lb)
Chicot	**Pre-Plant:** Command (0.4 lb) + Round-up (1.5 pt) **Post:** Permit (1 oz)
Cross	**Early Post:** Propanil (4 qt) + Facet (0.33 lb)
Greene	**Delayed Preemerge:** Prowl (2.4 pt) **Post:** Propanil (2 qt) + Facet (0.2 lb)
Jefferson	**Delayed Preemerge:** Facet (0.5 lb) + Prowl (2.4 pt) **Post:** Permit (1oz) 26 acres[z]
Lawrence	**Early Post:** Propanil (4 qt) + Facet (0.25 lb)
Phillips	**Preplant:** Command (0.275 lb)
Prairie	**Early Post:** Propanil (3 qt) + Facet (0.33 lb)
Pulaski	**Delayed Preemergence:** Facet (0.33 lb) + Prowl (2.4 pt) **Post:** Permit (1 oz) 4 acres

[z] If only a portion of a field was treated, the acreage is given; otherwise assume that the entire field was treated.

Table 5. Grain yield from replicated fertilizer trials[z] located in eight Rice Research Verification program fields.

County	Check	Urea, 30-0-0	Ammonium Sulfate, 30-0-0	P_2O_5, 0-20-0	P_2O_5 0-30-0	K_2O 0-0-30	$P_2O_5 + K_2O$ 0-20-30	1 lb Zn-EDTA/acre	Midseason Urea, 30-0-0	LSD (0.05)[y]
	(bu/acre)									
Arkansas	167	167	173	–	–	–	174	180	174	15.9
Ashley	157	147	150	165	–	148	–	–	157	34.0
Chicot	180	180	171	–	179	–	–	185	181	11.7
Greene	160	168	155	–	146	–	–	155	162	12.9*
Jefferson	181	167	175	–	177	–	–	179	191	22.9
Lawrence	135	141	144	–	–	–	145	–	–	29.3
Pulaski	160	151	141	165	–	150	–	153	–	24.8

[z] Treatments varied among fields. The check received the fertilizer recommended for the entire field listed in Table 3. Unless otherwise stated, all extra fertilizer treatments were applied to soil surface at the 4- to 5-leaf stage before flooding. Liquid Zn EDTA chelate applied to rice foliage.

[y] Significant differences (at the 0.05 level of probability) among treatments found only at the Greene County location (*P*-value = 0.044).

Table 6. Selected economic information for the 1999 Rice Research Verification Program.

County	Total Specified Operating Costs[z]	Total Specified Ownership Costs[y]	Break-Even Price[x]	Break-Even Price with Land Cost[w]	Returns Above Total Costs[v]
	------------ ($/acre) ------------		-------------- ($/bu) --------------		($/acre)
Arkansas	361.29	60.15	2.41	3.21	- 9.32
Ashley	285.81	67.45	2.14	2.85	35.32
Chicot	223.01	55.68	2.21	2.95	18.04
Cross	302.36	59.77	2.26	3.02	14.67
Greene	257.52	60.11	1.97	2.63	61.53
Jefferson	303.92	63.20	2.42	3.22	- 9.16
Lawrence	244.22	58.31	2.02	2.69	50.72
Phillips	253.47	58.51	2.17	2.89	27.14
Prairie	283.22	58.10	2.42	3.23	- 9.27
Pulaski	312.63	60.10	2.45	3.27	- 14.77
Average	282.75	60.14	2.25	3.00	16.49

[z] Specified out-of-pocket expenses, such as seed, fertilizer, herbicides, irrigation, etc.

[y] Ownership costs such as depreciation and interest on equipment, taxes, and insurance.

[x] Price/bushel required by the farmer to equal total operating and ownership costs.

[w] Breakeven price/bushel over total specified cost and a 25% crop share land rent.

[v] A 25% crop share rent was assumed as a land charge and a $3.14 (average September and October cash price as reported in the Grain and Livestock Market Newsletter) selling price was assumed. No cost sharing was assumed.

EFFECTS OF USING POULTRY LITTER AS A PREPLANT FERTILIZER IN RICE ON HIGH-pH SOILS

W.B. Koen, C.E. Wilson, Jr., N.A. Slaton, and R.J. Norman

ABSTRACT

Several Arkansas producers have started applying poultry litter to high-pH fields prior to seeding rice. Most of the information on rice response to poultry litter has come from research on fields that have been precision-leveled, with little information available on rice response to poultry litter on "undisturbed" fields that have not been precision-leveled. The objective of this study was to compare rice yield response to various rates of poultry litter and phosphorus (P) fertilizer on high pH soils. Field studies were conducted during 1998 and 1999 on alkaline DeWitt silt loam soils located in production fields in Arkansas County. The study had 16 total treatments, which were arranged as a randomized complete block design. The 16 treatments included fresh poultry litter, pelletized poultry litter, and P fertilizer (triple-super phosphate) applied at various rates and combinations. Zinc (Zn) fertilizer was also included in select treatments. In 1999, only fresh litter was used, and other treatments included P fertilizer rates and ammonium sulfate. Both poultry litter and P significantly increased grain yields in 1998. However, poultry litter provided no yield advantage compared to P alone, and application of both amendments together was no better than either product applied individually. In 1999, significant yield differences among treatments were not found. Poultry litter applied at the proper rates appeared to be an adequate source of P fertilizer. But since inorganic P fertilizer costs less than poultry litter, direct application of P fertilizer to these soils is preferred.

INTRODUCTION

Alkaline, or high-pH soils, have limited rice (*Oryza sativa* L.) yields in certain fields in Arkansas for several years. According to the1998 University of Arkansas Soil Test Laboratory summary, about 39% of the rice acreage in Arkansas has a pH of 6.5 or higher (Delong *et al.*, 1999). High-pH soil levels can decrease availability of nutrients such as P and Zn in the soil, which subsequently leads to the potential for deficiencies of these nutrients in rice (Wilson *et al.*,1996). Phosphorus and Zn fertilizers are recommended for rice grown on high-pH soils. Soil test recommendations for these elements are based on soil pH and/or soil test P.

Producers have recently started applying poultry litter to high-pH fields and believe that yields are higher than when only inorganic fertilizers are applied. The optimal soil pH range for P availability is between 6.0 and 6.5. While flooding generally increases P availability to rice when the soil is less than 6.5, flooding has less or no effect on P availability of alkaline soils (Wilson *et al.*, 1999). Data collected from 70 field studies conducted between 1994 and 1998 suggested that soil pH is a better indicator of P fertilizer response than the Mehlich 3 soil test P level. Therefore, Arkansas' P recommendations for rice were changed in 1999 to include pH as a determining factor for P fertilization.

Plant P uptake increases when P is added to the soil and decreases when the lime concentration goes up (Westermann, 1992). According to Ntamatungiro and Slaton (1998), a lime application to increase acid soil pH may result in reduced rice yields. Zinc and P fertilizers may need to be applied directly to rice in fields where lime has been recently applied. Qadar (1995) also found that the addition of P helps plants to offset the ill-effects of high-pH stress. However, a response to P application may only be expected on certain soils (Norman *et al.*, 1992). Subsequently, Wilson *et al.*, (1999) reported that soil pH is better correlated with P fertilizer response by rice than Mehlich 3 soil test P alone.

Poultry litter has been an effective soil amendment when applied on land that has been precision-leveled (Miller *et al.*, 1991). Although data are inconclusive, the effectiveness of poultry litter on leveled fields is credited primarily to the organic matter in the poultry litter (Huey *et al.*, 1989). Crops grown on productive, undisturbed soils do not typically respond to the poultry litter amendments over that obtained from commercial fertilizers (Miller *et al.*, 1991). Since commercial fertilizers tend to be less costly, they are the preferred source of nutrients for undisturbed soils. Poultry litter is recommended primarily on disturbed or leveled fields.

Fresh poultry litter costs an average of $30/ton delivered to the prairie region of central Arkansas. The average broiler litter contains about 48 lb of P/ton (Chapman and Snyder, 1992). The equivalent application of P in the form of triple-superphosphate would cost about $14/acre (D. Hornbeck, personal communication, 1998). While there is plenty of poultry litter in northwest Arkansas, it is currently not economical to transport litter to eastern Arkansas for use as a P fertilizer source. The objective of this study was to compare rice yield response to different rates of poultry litter and P on a high-pH soil.

PROCEDURES

Field tests conducted in 1998 and 1999 were established on a DeWitt silt loam (fine, smectitic, thermic Typic Albaqualfs) in two fields that had alkaline soil and both were located in Arkansas County. Soil samples from the plot area were taken prior to the seeding and fertilizer application each year (Table 1). Soil pH was 7.3 in 1998 and 7.8 in 1999. In 1998, a total of 16 treatments were compared including an untreated control, two poultry litter sources (fresh and pelletized), poultry litter rate (500, 1000, and 2000 lb/acre), foliar applied Zn EDTA (1 lb/acre), P fertilizer (40 lb P_2O_5/acre), P + Zn, and several combinations of P and poultry litter (Table 3). Nutrient fertilizer value of the fresh poultry litter was determined before application (Table 2). The pelletized litter had a guaranteed analysis of 3-4-3 (ie., %P_2O_5-%N-%K_2O).

The treatments were changed in 1999, but still included different rates of fresh poultry litter (Table 4). Various rates of P fertilizer, ammonium sulfate, and combinations of the treatments were also added. Since the comparison of litter sources in 1998 showed the same results as several past tests, this treatment was eliminated.

Plots were measured and flagged prior to seeding each year. All treatments, except Zn, were made just after seeding. Zinc EDTA was applied with a CO_2 backpack sprayer at the three- four-leaf growth stage just prior to flooding in a 10 gal/acre spray volume. The control treatment received only nitrogen fertilizer that was applied to the rest of the field and all plots.

'Cypress' and 'LaGrue' were drill-seeded in the fields during 1998 and 1999, respectively. The cooperating grower performed all other management practices (water management, weed control, nitrogen fertilizer, etc.) to the plots and surrounding field during the course of the growing season. Each individual plot was 8 ft. wide by 16 ft long. After stand establishment, individual plot boundaries were identified by rope-wick application of Round-Up Ultra (glyphosate) in 24-in. bands to kill rice and form alleys. This aided in locating the test and keeping the plots separated during the growing season.

The middle four rows (~30 ft^2) were harvested from each plot with a small-plot combine at maturity to determine grain yields. Approximately 1 ft of each end of the plots was removed prior to harvesting in order to diminish the edge effects. Each plot was measured to ensure that accurate plot lengths were used to calculate yield. Grain yields are reported on a 12% moisture basis.

Analysis of variance procedures were conducted with SAS. Mean separations were conducted using Fisher's Protected Least Significant Difference method at a 0.05 level of probability.

RESULTS AND DISCUSSION

Application of at least 1000 lb of fresh poultry litter/acre, but usually 2000 lb/acre, of fresh poultry litter was required to significantly increase grain yields compared to the control in 1998 (Table 3). Results of the processed poultry litter, when used alone, were erratic and only increased grain yields over the control when the 1000 lb/acre rate was applied or the 2000 lb/acre rate when applied with P. Although application of poultry litter did at times significantly increased grain yields, especially the fresh, the application of P fertilizer also frequently increased grain yields whether applied alone or in combination with poultry litter or Zn. Application of Zn resulted in numerically higher yields, but the increase was not statistically significant. When applied at equal rates, grain yield was not influenced by the source of poultry litter. Miller *et al.* (1990) also concluded that the application rate of litter and not the source (fresh or composted and pelletized) was the most important factor for reclamation of leveled soils. While the highest numerical yield was obtained from application of 2000 lb/acre of poultry litter plus 40 lb/acre P_2O_5, its yield was not significantly greater than yield from either amendment alone. The yield response from both P fertilizer and poultry litter suggests that the P was limiting yield in this field. Because the soil had high pH (7.3) and low extractable P (37 lb P/acre), the response to P fertilizer was expected (Wilson *et al.*, 1999). The Mehlich 3 extractable Zn was 8.2 lb Zn/acre, which is considered medium to high and suggests that Zn response on this soil should be marginal (Liscano, 1998). However, more information is needed on the relationship between soil test Zn and rice fertilizer response to Zn fertilization.

In 1999, significant differences among treatments were not found (Table 4). The excellent yields suggest rice growth was not limited by nutrient deficiencies associated with high soil pH. Application of poultry litter and/or P fertilizer did tend to increase yields above that of the control, with the highest numerical grain yields found with P fertilizer applied alone or in combination with poultry litter. Ammonium sulfate failed to significantly affect rice grain yield.

SIGNIFICANCE OF FINDINGS

Data suggest that poultry litter when applied at adequate rates is an effective alternative to inorganic P fertilizer for rice produced on alkaline soils that respond to P fertilization. Because of the cost difference between inorganic P fertilizer and poultry litter, inorganic P fertilizer is preferred, since it is most economical. In contrast, research has shown that poultry litter is the most cost-effective amendment on leveled soils because inorganic fertilizers seldom produce yields equal to that of poultry litter in these situations.

LITERATURE CITED

Chapman, S. L., and C.S. Snyder. 1992. Poultry manure as a substitute for commercial fertilizer. University of Arkansas Coop. Ext. Ser. Misc. Publ. 2-92.

Delong, R.E., S.D. Carroll, S.L. Chapman, W.E. Sabbe, and W.H. Baker. 1999. Soil test and fertilizer sales data: summary for the growing season—1998. *In:* W.E. Sabbe (ed.). Arkansas Soil Fertility Studies 1998. University of Arkansas Agricultural Experiment Station Reserach Series 463:9-24.

Huey, B.A., D.M. Miller, R.J. Norman, R.S. Helms, B.R. Wells, W.N. Miley, H.M. Chaney, and H.J. Mascagni. 1989. Growing rice on precision leveled soils. University of Arkansas Coop. Ext. Ser. Misc. Publ. 101.

Liscano, J.F. 1998. Determination of the availability of zinc from different sources. University of Arkansas M.S. Thesis.

Miller, D.M., B.R. Wells, and R.J. Norman. 1991. Fertilization of rice on graded soils using organic materials. *In:* W.E. Sabbe (ed.). Arkansas Soil Fertility Studies 1990. University of Arkansas Agricultural Experiment Station Research Series 411: 55-57.

Miller, D.M., B.R. Wells, R.J. Norman, and T. Alvisyahrin. 1990. Fertilization of rice on leveled soils. *In:* W.E. Sabbe (ed.). Arkansas Soil Fertility Studies 1990. University of Arkansas Agricultural Experiment Station Research Series 398:45-48.

Norman, R.J., C.A. Beyrouty, D.M. Miller, P.M. Moore, Y.H. Teo, and N.A. Slaton. 1992. Rice response to phosphorus fertilization on soils testing low in phosphorus. *In:* W.E. Sabbe (ed.). Arkansas Soil Fertility Studies 1990. University of Arkansas Agricultural Experiment Station Research Series 421:39-42.

Ntamatungiro, S. and N.A. Slaton. 1998. Rice response to lime, chicken litter, and phosphorus application. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies. University of Arkansas Agricultural Experiment Station Research Series 460:303-311.

Qadar, A. 1995. Requirement of rice crop for phosphorus and potassium at varying sodicity levels. Journal of Plant Nutrition 18(11):2291-2303.

Westermann, D.J. 1992. Lime effects on phosphorus availability in a calcareous soil. Soil Sci. Soc. Am. J. 56:489-494.

Wilson, C.E., Jr., N.A. Slaton, P.A. Dickson, and R.J. Norman 1996. Phosphorus fertilizer management for rice grown on alkaline soils. *In:* R.J. Norman and B.R. Wells (eds.). Arkansas Rice Research Studies. University of Arkansas Agricultural Experiment Station Research Series 453:196-200.

Wilson, C.E., Jr., N.A. Slaton, S. Ntamatungiro, and R.J. Norman. 1999. Phosphorus fertilizer management for rice produced on alkaline soils. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies. University of Arkansas Agricultural Experiment Station Research Series 468:310-316.

Table 1. Selected analysis of the DeWitt silt loam soils used.

	EC^z	pH	P	K	Ca	Mg	SO_4-S	Na	Fe	Mn	Zn	Cu	NO_3
		(lb/acre)											
1998	135	7.3	37	176	3715	463	18	166	322	241	8.2	2.8	25
1999	85	7.8	68	230	4248	463	13	82	333	155	23	3.0	16

†EC = electrical conductivity in µhos/cm [1:2 (soil:water ratio)].

Table 2. Select nutrient analysis of the poultry litter used.

	% on dry weight basis		% on "as-is" basis		lbs/ton on "as-is" basis	
	1998	1999	1998	1999	1998	1999
	(%)				(lb/ton)	
Total N	3.15	1.92	1.17	1.45	23.3	29.1
Total P	2.36	1.89	0.87	1.43	40.1	65.6
Total K	2.99	1.97	1.11	1.49	26.6	35.8
Total Ca	3.77	3.10	1.40	2.35	27.9	47.0

Table 3. Rice grain yields in descending order as influenced by application of poultry litter, P and Zn in 1998.

Fertilizer treatment[z]	Grain yield	
	(lb/acre)	(bu/acre)
2000 lb fresh PL[y] + 40 lb P_2O_5	9155	204
2000 lb fresh PL	8549	190
500 lb fresh PL + 40 lb P_2O_5	8526	190
40 lb P_2O_5	8427	187
2000 lb processed PL + 40 lb P_2O_5	8378	186
40 lb P_2O_5 + 1 lb chelated Zn	8223	183
1000 lb fresh PL	7059	177
1000 lb processed PL + 40 lb P_2O_5	7895	175
1000 lb processed PL	7615	169
1000 lb fresh PL + 40 lb P_2O_5	7594	169
1 lb chelated Zn	7380	164
2000 lb processed PL	7214	160
500 lb fresh PL	7060	157
500 lb processed PL	6922	154
500 lb processed PL + 40 lb P_2O_5	6766	150
Control	6068	135
LSD (0.05)	1755	39

[z] Fertilizer treatment amounts were applied on per acre basis.
[y] PL = poultry litter.

Table 4. Rice grain yields in descending order as influenced by application of poultry litter, P, and ammonium sulfate in 1999.

Fertilizer treatment[z]	Grain yield (lb/acre)	Grain yield (bu/acre)
40 lb P_2O_5	10,727	238
80 lb P_2O_5 + 2000 lb PL[y]	10,682	237
80 lb P_2O_5 + 1000 lb PL	10,668	237
80 lb P_2O_5	10,490	233
20 lb P_2O_5	10,440	232
20 lb P_2O_5 +1000 lb PL	10,321	229
2000 lb PL	10,289	229
40 lb P_2O_5 + 1000 lb PL	10,277	228
40 lb P_2O_5 + 100 lb AS[x]	10,255	228
40 lb P_2O_5 + 2000 lb PL	10,231	227
100 lb AS	10,161	226
20 lb P_2O_5 + 100 lb AS	9,906	220
20 lb P_2O_5 + 2000 lb PL	9,899	220
80 lb P_2O_5 + 100 lb AS	9,896	220
Control	9,783	217
1000 lb PL	9,690	215
LSD(0.05)	1,215	27

[z] Fertilizer treatment amounts were applied on per acre basis.
[y] PL = poultry litter.
[x] AS = ammonium sulfate.

EVALUATION OF SODIUM CHLORATE AS A HARVEST AID FOR RICE

C.E. Wilson, Jr., N.A. Slaton, S. Ntamatungiro, D.L. Frizzell, and R.J. Norman

ABSTRACT

Sodium chlorate is a dessicant applied to rice before harvest that is thought to increase harvest efficiency. However, the effects of sodium chlorate on rice grain are not well documented. Subsequently, a study was initiated during 1999 to evaluate the influence of sodium chlorate application on rice grain moisture, rice grain yield, head rice yield, and seed germination. Sodium chlorate was applied at either 0 or 6 lb a.i./ acre to ‘Bengal’, ‘Cocodrie’, ‘Drew’, and ‘Wells’ rice. Two seeding dates (circa 10 April and 10 May) were implemented at the Rice Research and Extension Center and the Southeast Research and Extension Center. The sodium chlorate was applied at 30, 35, or 40 days after 50% heading (40, 45, or 50 days after 50% heading for Bengal) and harvested 3 and 7 days after application. Grain harvest moisture declined following sodium chlorate application from 1 to 5 %. However, grain yields, head rice yields, and seed germination were essentially unaffected by sodium chlorate application. Head rice yields were reduced when grain moisture at harvest declined below 16% for Bengal and 15% for Drew and Wells. In contrast, head rice yields of Cocodrie were not as dependent upon grain harvest moisture, but grain harvest moisture of milled Cocodrie was not below 15%.

INTRODUCTION

Several producers use sodium chlorate each year as a harvest aid for rice (*Oryza sativa* L.). The desiccant allows faster “dry-down” of the rice foliage (leaves), which may possibly reduce harvest loss, increase timeliness of harvest, and reduce ‘green’ stems and leaf tissue in the harvested rice. Also, the drier vegetative tissue tends to reduce wear on combines because it is easier to thrash. Although sodium chlorate is commonly used, questions are raised each year to extension agents, specialists, and researchers concerning use guidelines for sodium chlorate and its effect on rice yield and quality. Little information is available to answer these questions. The questions that need to be addressed include time of application, time between application and harvest, potential harvest timeliness effects, effects of seed quality in seed rice fields, and effects on grain and milling yields. The objective of the current study was to determine the effects of sodium chlorate and harvest timing on rice grain yields, milling yields, and seed germination.

PROCEDURES

The study was conducted during 1999 at the Rice Research and Extension Center (RREC), located near Stuttgart on a Dewitt (Crowley) silt loam (fine, smectitic, thermic Typic Albaqualfs) and at the Southeast Research and Extension Center–Rohwer Division (SEREC) on a Perry clay (very fine, smectitic, thermic Chromic Epiaquerts). Field studies were implemented by seeding four rice cultivars (Bengal, Cocodrie, Drew, and Wells) into nine-row plots 15 ft long on two dates. The plots were seeded on 7-in. row spacing at the RREC and 6-in. row spacing at the SEREC. The seeding dates at RREC were 13 April and 10 May. At SEREC, the rice was seeded on 10 April and 10 May. To determine the effects of sodium chlorate applications to rice, the treatments consisted of two rates of sodium chlorate (0 and 6 lb a.i./acre), three application times (30, 35, and 40 days after 50% heading for long grains and 40, 45, and 50 days after 50% heading for Bengal), and two harvest dates (3 and 7 days after application).

For each appropriate harvest date, two rows of each plot were collected and thrashed with a Vogel thrasher to obtain grain yields. Grain moisture content and grain yield (corrected to 12% moisture) were determined for each treatment. Milling yields were determined on each cultivar from the 10 May seeding date at RREC. The experiment was arranged in a split-plot design, with sodium chlorate and application time in a factorial arrangement as the main plot and harvest date was the subplot. The study was replicated four times.

RESULTS

Based on visual observations, the moisture content of the rice foliage was significantly reduced following sodium chlorate application. Obvious differences between sodium chlorate rates could be observed within 24 to 48 hr after application. Sodium chlorate reduced harvest grain moisture for all cultivars and seeding dates at the RREC from 1 to 5% (Table 1). While all were not significantly different, sodium chlorate tended to reduce harvest moisture for all cultivars at the SEREC. Rice grain moisture was also significantly influenced by time of harvest (Table 2). Harvest grain moisture significantly decreased for all cultivars at both locations, as harvest or sodium chlorate application was delayed. Of the four cultivars evaluated, grain harvest moisture of Bengal and Cocodrie was least affected by sodium chlorate application and time of harvest. It is interesting to note that among the three long-grain cultivars, Cocodrie is the earliest to reach 50% heading, but harvest moisture, especially at the RREC, tended to be higher for a longer period of time (Table 2).

Grain yields generally were not affected by sodium chlorate application at either location (Table 3). The only exception was Bengal, seeded on 10 May at RREC. This suggests that sodium chlorate can safely be applied to rice as a harvest aid without significantly reducing grain yield. However, it should be noted that sodium chlorate was generally applied when rice grain moisture was less than 28% (data not shown). Other studies have suggested that dessicating rice foliage when grain moisture is above 25% can significantly reduce grain yield (P.K. Bollich, personal communication, 1999).

The effect of time of sodium chlorate application on grain yields was varied (Table 4). Delaying the application until 35 or 40 days after 50% heading tended to produce the highest numerical grain yields for long-grain cultivars. If grain fill, especially on the lower one-third of the panicle, is not completed at the time of sodium chlorate application, it is possible that plant dessication will prevent further grain fill, and thus a yield loss, when applied too early. This would account for studies that have reported reduced grain yields when rice dessicants were applied too early (P.K. Bollich, personal communication, 1999).

Application of sodium chlorate did not significantly affect head or total rice yields for any of the cultivars evaluated (data not shown). However, warm, dry weather conditions during 1999 harvest were favorable for quick, efficient harvest operations. Years when more precipitation occurs during harvest, and specifically after rice dessication, may detrimentally affect head rice yields. The alternate wetting and drying (shrinking and swelling) of the grain may result in grain fissures (hair-line cracks) that result in lower head rice yields (Cnossen *et al.*, 1999). Additional research under different harvest environments (years) is needed to characterize the effects of rice dessication on milling quality. Grain harvest moisture as affected by time of harvest had the most significant impact on head rice in this study. Head rice yields of Bengal, Drew, and Wells started to decline after a critical harvest moisture was reached (Fig. 1). However, head rice yields of Cocodrie appeared to be the least affected by harvest moisture (Fig. 2). However, harvest grain moisture of Cocodrie never dropped below 15% for the milled sampled, and conclusions on harvest moisture on head rice yield can not be made. For Bengal, the data suggest that head rice yields decline significantly when the harvest moisture drops below 16 to 17%. For Drew and Wells, this decline was observed at 15%. The data from this study suggest that these three cultivars should be harvested above these critical moisture contents to maintain head rice yield.

Sodium chlorate rate did not have a significant effect on subsequent seed germination after harvest (Table 5). This suggests that seed producers may use sodium chlorate without significantly influencing seed germination. Again, more data under various weather conditions need to be collected before final conclusions are made.

SIGNIFICANCE OF FINDINGS

The data from this study suggests that sodium chlorate can be safely applied as a harvest aid to rice. Vegetative tissue was dessicated within 24 to 48 hr after application. Negative effects from dessication were not observed for grain yield, head rice yield, or seed germination. However, dessication of rice foliage also significantly reduced harvest grain moisture. Head rice yields were only influenced by harvest moisture, regardless of whether sodium chlorate was applied. For this reason, sodium chlorate should not be applied to more acreage than can be harvested within a 3- to 5-day period.

LITERATURE CITED

Cnossen, A.G., T.J. Siebenmorgen, and J.D. Reid. 1999. Characterization of fissure occurrence and kernel size and moisture content distribution of milled 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 468:330-334.

Table 1. Influence of sodium chlorate on harvest moisture of grain of four rice cultivars at two locations during 1999.

	Harvest Grain Moisture							
	April Planting Date[z]				10 May Planting Date			
Sodium chlorate rate	Bengal	Cocodrie	Drew	Wells	Bengal	Cocodrie	Drew	Wells
(lb/acre)	(% moisture)							
Rice Research and Extension Center, Stuttgart								
0	19.9	18.5	14.9	17.4	19.1	24.4	19.5	20.0
6	18.0	15.1	12.7	14.2	18.1	19.9	14.7	15.5
LSD	1.1	1.3	0.3	0.6	0.8	0.7	1.1	1.1
Southeast Research and Extension Center, Rohwer Division, Rohwer								
0	16.3	16.7	16.3	17.3	15.5	15.7	14.9	15.7
6	15.2	16.3	16.1	16.0	13.9	14.5	13.3	14.8
LSD	NS	NS	NS	1.1	1.2	1.0	0.9	NS

[z] April planting date for the Rice Research and Extension Center was 13 April; for the Southeast Research and Extension Center 10 April.

Table 2. Influence of sodium chlorate application timing on harvest moisture of grain of four rice cultivars at two locations during 1999.

	Harvest Grain Moisture							
	April Planting Date[z]				10 May Planting Date			
Sodium chlorate timing	Bengal	Cocodrie	Drew	Wells	Bengal	Cocodrie	Drew	Wells
(dah[y])	(% moisture)							
Rice Research and Extension Center, Stuttgart								
30	22.9	19.4	16.0	17.8	21.1	25.5	20.5	21.8
35	17.6	16.6	13.1	16.5	19.2	21.7	18.6	19.0
40	16.4	14.3	12.2	13.1	15.6	19.3	12.2	12.4
LSD	1.3	1.5	0.4	0.7	1.0	0.9	1.3	1.3
Southeast Research and Extension Center, Rohwer Division, Rohwer								
30	19.4	18.0	18.0	18.5	15.2	16.3	16.8	16.2
35	17.3	16.6	16.3	15.6	14.7	15.6	13.6	16.1
40	11.0	15.0	14.4	15.5	14.3	13.3	12.0	13.5
LSD	3.0	1.9	1.6	1.4	NS	1.2	1.1	1.8

[z] April planting date for the Rice Research and Extension Center was 13 April; for the Southeast Research and Extension Center 10 April.
[y] dah = days after 50% heading, Bengal timing = 40, 45, and 50 days after 50% heading.

Table 3. Influence of sodium chlorate on grain yields of grain of four rice cultivars at two locations during 1999.

Sodium chlorate rate	Grain yield							
	April Planting Date[z]				10 May Planting Date			
	Bengal	Cocodrie	Drew	Wells	Bengal	Cocodrie	Drew	Wells
(lb/acre)	(lb/acre)							
Rice Research and Extension Center, Stuttgart								
0	7244	8070	7423	7741	7670	7798	7389	7902
6	7166	7954	7363	7562	7324	7690	7171	7758
LSD	NS	NS	NS	NS	5.2	NS	NS	NS
Southeast Research and Extension Center, Rohwer Division, Rohwer								
0	8527	8177	8172	8104	7285	7611	7064	7179
6	8445	8378	8077	7814	7414	7251	6604	7058
LSD	NS	NS	NS	NS	NS	NS	NS	NS

[z] April planting date for the Rice Research and Extension Center was 13 April; for the Southeast Research and Extension Center 10 April.

Table 4. Influence of sodium chlorate application timing on grain yields of grain of four rice cultivars at two locations during 1999.

	Grain yield							
	April Planting Date[z]				10 May Planting Date			
Sodium chlorate timing	Bengal	Cocodrie	Drew	Wells	Bengal	Cocodrie	Drew	Wells
(dah[y])	(lb/acre)							
Rice Research and Extension Center, Stuttgart								
30	6944	7675	7335	7516	7528	7445	7044	7608
35	7230	8347	7473	7580	7637	7703	7297	7845
40	7460	8031	7369	7858	7329	8084	7498	8083
LSD	NS	473	NS	301	286	205	NS	248
Southeast Research and Extension Center, Rohwer Division, Rohwer								
30	8716	8336	7995	8031	7137	7280	7331	7378
35	7492	8612	7628	7990	7624	7629	6583	6956
40	8298	7881	8664	7821	7297	7364	6626	7022
LSD	NS	729	845	NS	NS	NS	NS	NS

[z] April planting date for the Rice Research and Extension Center was 13 April; for the Southeast Research and Extension Center 10 April.
[y] dah = days after 50% heading, Bengal timing = 40, 45, and 50 days after 50% heading.

Table 5. Influence of sodium chlorate on germination of produced seed during 1999.

Sodium chlorate rate	Seed germination[z]							
	Rice Research and Extension Center				Southeast Research and Extension Center			
	Bengal	Cocodrie	Drew	Wells	Bengal	Cocodrie	Drew	Wells
(lb/acre)	(%)							
0	93.5	92.0	93.7	92.3	88.6	90.2	97.5	94.9
6	95.7	90.5	96.5	94.8	90.7	92.8	97.5	96.9
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS

[z] Percent germination after 7 d incubation for seed harvested from the 13 April seeding date.

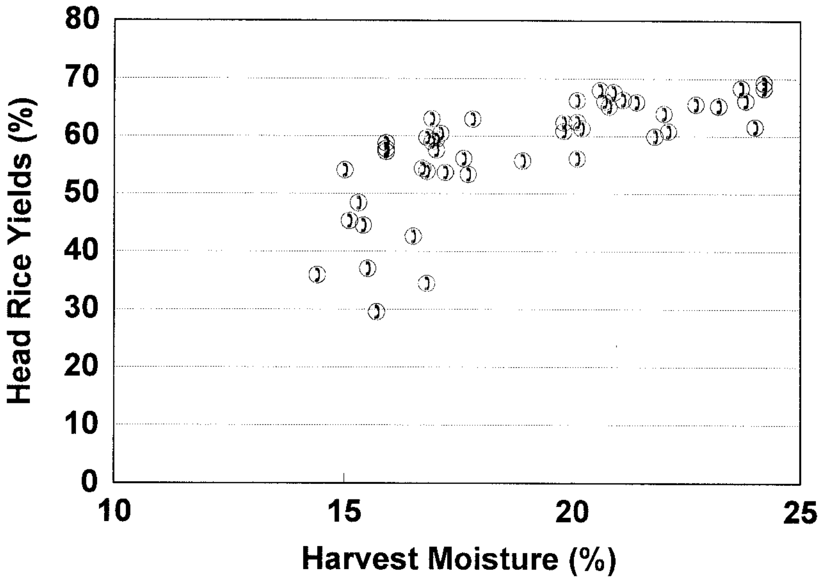


Fig. 1. Influence of grain moisture at harvest of Bengal rice on head rice yields from studies at RREC during 1999.

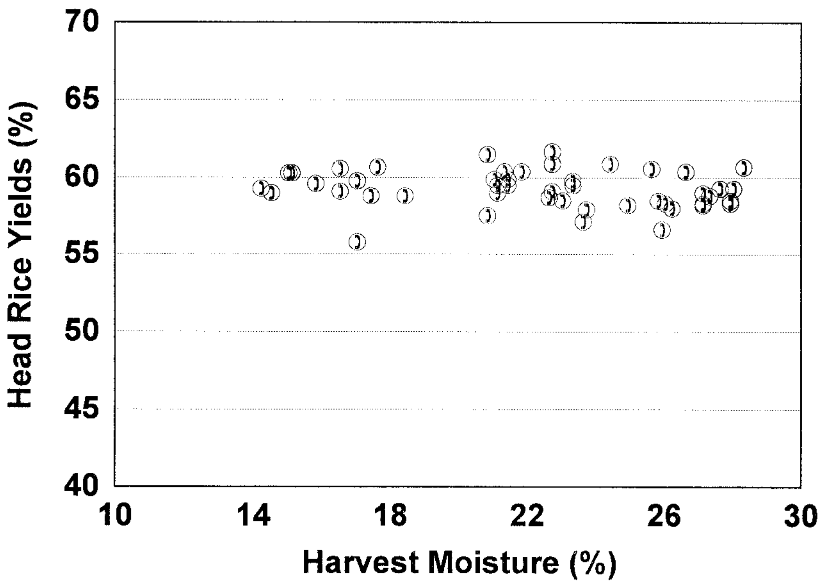


Fig. 2. Influence of grain moisture at harvest of Cocodrie rice on head rice yields from studies at RREC during 1999.

GRAIN YIELD PERFORMANCE OF RICE CULTIVARS GROWN IN NORTHEAST ARKANSAS AS INFLUENCED BY SEEDING DATE

R.J. Norman, N.A. Slaton, D.C. Cox, and D.L. Boothe

ABSTRACT

Rice cultivars grown in Arkansas are temperature-dependent, and therefore the date at which they are seeded greatly influences their maturity and grain yield. A study has been initiated at the Northeast Research and Extension Center, Keiser, to determine the best seeding dates for rice growers in this region of the state. Ten of the most widely grown rice cultivars were studied over three seeding dates. The cultivars generally showed a trend of fewer days required from emergence to 50% heading as seeding date was delayed from 23 April to 3 May; however, only 'Cypress' and 'LaGrue' had significantly fewer days between emergence and 50% heading for the 3 May compared to the 23 April seeding date. When seeding date was delayed until 22 June, only Cypress, 'Drew', and 'Madison' had an increase in number of days to reach 50% heading. Most cultivars had no significant increase in number of days from emergence to 50% heading when seeding date was delayed from 3 May to 22 June. In general, the grain yields of the various cultivars were either similar or slightly larger for the 3 May seeding date compared to the 23 April seeding date. The 22 June seeding date was much too late for this location, as shown by the very low yields. 'Cocodrie', LaGrue, 'Priscilla', and 'Wells' had the largest grain yields of the rice cultivars studied.

INTRODUCTION

Rice cultivars grown in Arkansas are temperature-dependent, and therefore the date at which they are seeded greatly influences their maturity and grain yield (Norman *et al.*, 1999). The short-season cultivars are not necessarily the best cultivars to seed late, and visa versa. Consequently, seeding date studies are very important in determining the best seeding date window for a particular cultivar and a particular region. A seeding date study that is inherently incorporated in the annual DD50 Program Study is conducted on newly released rice cultivars at the Rice Research and Extension Center, near Stuttgart. Being somewhat centrally located in the rice-growing region of Arkansas, data from the the DD50 study and other seeding date studies at this location are extrapolated across the rest of the rice-growing region based on known temperature differences across the region. Recently, the extrapolation of the data collected at Stuttgart to growing conditions in northeast Arkansas has been questioned by rice producers and extension personnel in that area. Although data indicate only a 3 to 4 °F temperature difference between east central and northeast Arkansas, producers in northeast Arkansas believe this is not a true reflection of growing condition differences between the two areas. Their practical field experience suggests that cutoff dates for the rice cultivars ‘Bengal’ and Cypress may be as much as 10 days late. These producers indicate that late-seeded fields produce rice that has excessive blanking and reduced yields, as well as lower milling yields. Because of this concern, a seeding date study has been initiated at the Northeast Research and Extension Center, Keiser, with the objective of determining the influence of seeding date on grain yield of important rice cultivars grown in northeast Arkansas.

PROCEDURES

This seeding date study was conducted on a Sharkey clay (Vertic Haplaquepts). Ten of the most widely grown rice cultivars were studied: Bengal, Cocodrie, Cypress, Drew, ‘Jefferson’, ‘Kaybonnet’, LaGrue, Madison, Priscilla, and Wells. The cultivars were arranged in a randomized complete block design with four replications and were studied over three seeding dates (23 April, 3 May, and 22 June 1999). The rice was drill-seeded in 9-row (7-in. spacing) wide plots, 25 ft in length. Nitrogen (N) fertilizer (urea) was applied preflood at a rate of 150 lb N/acre at the four- to five-leaf growth stage, a flood immediately established, and maintained until maturity. Emergence and 50% heading dates were recorded to determine the influence of seeding date on maturity. At maturity, 20 ft of the center four rows of each plot were harvested with a small plot combine, the moisture content and weight of the grain were determined. Grain yields are expressed on a 12 % moisture basis in bu/acre; a bushel is equal to 45 lb. Statistical analyses were conducted with SAS and mean separations were based upon protected least significant difference ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

The rice cultivars generally showed a trend of fewer days required from emergence to 50% heading as seeding date was delayed from 23 April to 3 May; however, only Cypress and LaGrue had significantly fewer days between emergence and 50% heading for the 3 May compared to the 23 April seeding date (Table 1). When seeding date was delayed until 22 June, only Cypress, Drew, and Madison had an increase in number of days to reach 50% heading. Most cultivars had no significant increase in number of days from emergence to 50% heading when seeding date was delayed from 3 May to the 22 June. The overall average number of days between emergence and 50% heading ranged from 85 days for Cocodrie to 96 days for Madison.

In general, the grain yields of the rice cultivars were either similar or slightly larger for the 3 May seeding date compared to the 23 April seeding date (Table 2). The 22 June seeding date was much too late for this location, as shown by the very low yields (<35 bu/acre) for all of the cultivars, except Jefferson. Interestingly, Jefferson had a grain yield of 64 bu/acre for the 22 June seeding, which was at least double the grain yield achieved by most of the other cultivars seeded at this date. Cocodrie, LaGrue, Priscilla, and Wells had the largest grain yields of the rice cultivars studied. Wells (192 bu/acre), followed by LaGrue, Priscilla, and Cocodrie was the order of highest to lowest yields for these four cultivars at the 23 April seeding date. For the 3 May seeding, the order from highest to lowest yields for the four were LaGrue (180 bu/acre), Cocodrie, Priscilla, and Wells. Cypress had the lowest grain yields of the cultivars over the three seeding dates, with Kaybonnet and Drew not yielding significantly better and Madison yielding better only at the 3 May seeding. Bengal also did not perform well at the 23 April seeding.

SIGNIFICANCE OF FINDINGS

The rice cultivars generally showed a trend of fewer days required from emergence to 50% heading as seeding date was delayed from 23 April to 3 May, however only Cypress and LaGrue had significantly fewer days between emergence and 50% heading for the 3 May compared to the 23 April seeding date. When seeding date was delayed until 22 June, only Cypress, Drew, and Madison had an increase in number of days to reach 50% heading. Most cultivars had no significant increase in number of days from emergence to 50% heading when seeding date was delayed from 3 May to 22 June. In general, the grain yields of the rice cultivars were either similar or slightly larger for the 3 May seeding date compared to the 23 April seeding date. The 22 June seeding date was much too late for this location as shown by the very low yields. Cocodrie, LaGrue, Priscilla, and Wells had the largest grain yields of the rice cultivars studied.

ACKNOWLEDGMENT

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

LITERATURE CITED

Norman, R.J., N.A. Slaton, and K.A.K. Moldenhauer. 1999. Development of the DD50 database for new rice cultivars. *In:* RJ Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:250-256.

Table 1. Number of days from emergence to 50% heading for 10 rice cultivars as influenced by seeding date in 1999 at the Northeast Research and Extension Center, Keiser.

Cultivar	Seeding date April 23	May 3	June 22	Average across seeding dates
	(Days from Emergence to 50% Heading)			
Bengal	88	86	93	89
Cocodrie	89	86	79	85
Cypress	90	86	102	93
Drew	93	90	99	94
Jefferson	85	82	78	82
Kaybonnet	90	87	86	88
LaGrue	95	89	89	91
Madison	93	93	102	96
Priscilla	90	90	89	90
Wells	90	87	91	89
C.V., %	2.7	2.5	5.6	--
LSD(0.05)	3.6	3.2	7.6	--

Table 2. Grain yields of ten rice cultivars as influenced by seeding date in 1999 at the Northeast Research and Extension Center, Keiser.

Cultivar	Seeding date 23 April	3 May	22 June	Average across seeding dates
	(Grain yield bu/acre)			
Bengal	148	165	33	115
Cocodrie	170	179	28	126
Cypress	148	141	12	100
Drew	161	155	25	114
Jefferson	141	161	64	122
Kaybonnet	145	149	28	107
LaGrue	184	180	26	130
Madison	146	163	11	107
Priscilla	171	177	31	126
Wells	192	173	33	133
Average	160.6	164.3	29.1	--
C.V., %	7.1	6.3	40.9	--
LSD(0.05)	19.1	16.1	17.4	--

INFLUENCE OF SEEDING DATE ON THE DEGREE DAY 50 THERMAL UNIT ACCUMULATIONS AND GRAIN YIELD OF NEW RICE CULTIVARS

R.J. Norman, N.A. Slaton, K.A.K. Moldenhauer, and D.L. Boothe

ABSTRACT

The Degree-Day 50 (DD50) computer program must be continually updated as new rice cultivars are named and released. DD50 thermal unit accumulations and grain yield performance of each new cultivar/variety were evaluated over three seeding dates in the dry-seeded management system. Cultivars/varieties evaluated in 1999 were 'Cocodrie', 'Drew', 'Jefferson', 'Madison', 'Priscilla', 'Wells', RU9701041 (Arkansas), RU9801148 (Arkansas), RU9801081 (Arkansas), RU9801030 (Arkansas), and RU9602074 (Louisiana). In general, the days and DD50 thermal unit accumulations required from emergence to internode elongation and 50% heading decreased as seeding date was delayed from April to May and then increased or stayed the same as seeding date was delayed further until June. Data from this study will be combined with data from previous years to formulate updated DD50 thermal unit threshold values for each of the aforementioned cultivars in the 2000 DD50 computer program. Grain yields of all released rice cultivars decreased as seeding date was delayed. Cocodrie, Priscilla, and Wells had the best grain yields across all seeding dates and the best yields when seeded in April and May of the released cultivars. Drew and Wells, followed by Cocodrie, yielded the best of the released cultivars when seeding was delayed until 10 June.

INTRODUCTION

The DD50 computer program has been one of the most successful programs developed by the University of Arkansas Division of Agriculture. Approximately 70%

of the Arkansas rice farmers utilize this program as a production management tool. The program requires data for all cultivars with plant development based on accumulation of DD50 thermal units from date of seedling emergence. These data are acquired from yearly studies of promising experimental varieties and all newly released rice cultivars for at least 3 years. When a new cultivar is released to farmers, the data from these studies are used to provide threshold DD50 thermal units in the DD50 computer program to enable predictions of dates when plant development stages will occur and dates when management practices should be performed. Therefore, the objective of this study is to develop databases for promising new rice cultivars, to verify databases for existing cultivars and to assess the effect of seeding date on DD50 thermal unit accumulations. In addition, the influence of seeding date on a cultivar's grain yield performance was measured to determine the most optimum time to seed each of the new cultivars.

PROCEDURES

The 1999 study was conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, on a Crowley silt loam soil. Eleven rice cultivars/experimental varieties [Cocodrie, Drew, Jefferson, Madison, Priscilla, Wells, RU9701041 (Arkansas), RU9801148 (Arkansas), RU9801081 (Arkansas), RU9801030 (Arkansas), and RU9602074 (Louisiana)] were drill-seeded at a rate of 110 lb/acre in nine-row (7-in. spacing) wide plots, 15 ft in length. The seeding dates were 13 April, 27 May, and 10 June 1999. An initial seeding on 10 May emerged erratically, so it was not used for computation of DD50 thermal unit accumulations but was used for yield comparisons. A later seeding on 27 May was used for computation of DD50 thermal unit accumulations as well as for yield comparisons. The normal cultural practices for drill-seeded delayed flood rice culture were followed. All plots received 100 lb N/acre as urea in a single preflood application when the rice was at the four- to five-leaf stage, immediately flooded and remained flooded until the rice was mature. The design of the experiment for each seeding date was a randomized complete block with three replications. Data collected included maximum and minimum daily temperatures, length of elongating internodes at 3-day intervals beginning 35 days after seedling emergence, date of beginning internode elongation, date of 0.5-in. internode elongation, date of 50% heading, and date of physiological maturity. The temperature data were converted into DD50 thermal unit accumulations from seedling emergence until maturity. At maturity, 12 ft of the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as bu/acre at 12% moisture. A bushel of rice weighs 45 lb. Statistical analyses were conducted with SAS and mean separations were based upon protected least significant difference ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

Rice seeded on 13 April, 27 May, and 10 June required 12, 9, and 13 days to emerge, respectively (Table 1). As was stated earlier, an initial seeding on 10 May emerged unevenly, and thus the data could not be use in computation of valid DD50 thermal unit accumulations and a reseeding was performed on 27 May. The number of days from emergence to flooding was about twice as long (26 days) for the April seeding date than the May and June seeding dates, which required only 11 and 14 days, respectively. This is contrary to what we usually observe, where the number of days required from seeding to flooding is mostly affected by the days required for seedling emergence.

The days and DD50 thermal unit accumulations required after emergence, for each of the cultivars/varieties, to reach 0.5-in. internode elongation are shown in Tables 2 and 3, respectively. Usually the DD50 thermal unit accumulations required from emergence to 0.5-in. internode elongation decreases as seeding date is delayed from April to May and then increases as seeding date is delayed until June. This pattern was observed for all of the cultivars in the 1999 DD50 Study (Table 3). The days required from emergence to 0.5-in. internode elongation also decreased as seeding date was delayed from April to May, but then the days required from emergence to 0.5-in. internode elongation either increased or were similar to the May seeding date, as the seeding was delayed further until June (Table 3). This is because the difference between the May and June seeding was not that great. In addition, the days in late June and July, which affected the 10 June seeding date the most, accumulate more DD50 thermal units compared to the days in early June following emergence of the 27 May seeding date. Overall, the average number of days required for the cultivars/varieties to reach 0.5-in. internode elongation ranged from 41 to 51 days, with most requiring between 48 to 50 days. Cocodrie, by far, required the fewest days (only 41 days). The average number of DD50 thermal unit accumulations required for the cultivars/varieties to reach 0.5-in. internode elongation over the three seeding dates ranged from 1101 to 1392, with most requiring between 1295 to 1366 units. Cocodrie only required on average 1101 DD50 thermal units between emergence and 0.5-in. internode elongation. The extremely short period Cocodrie requires to reach the reproductive growth stage will make it difficult to drain for straighthead and easier to miss the midseason N fertilizer application time window compared to other cultivars. Growers of Cocodrie should probably not seed it on soils prone to cause straighthead in susceptible cultivars and should use the "Optimum Preflood N Application Method" so as not to have to apply midseason N fertilizer.

The days and DD50 thermal unit accumulations required after emergence, for each of the cultivars/varieties, to reach 50% heading are shown in Tables 4 and 5, respectively. As is the norm, the number of days and DD50 thermal unit accumulations required from emergence to 50% heading decreased as seeding date was delayed from April to May and then increased as seeding date was delayed further until June. Overall, the average number of days required for the cultivars/varieties to reach 50% heading ranged from 70 to 81 days, with most requiring between 76 to 79 days. Jefferson and experimental variety RU9801081 only required 70 and 71 days, respectively, to reach 50% heading. The average number of DD50 thermal unit accumulations required for the cultivars/varieties to reach 50% heading over the three seeding dates ranged from 1961 to 2291, with most requiring between 2139 to 2240 units. Jefferson required the fewest DD50 thermal units and experimental variety RU9701041 the most to reach 50% heading.

Grain yields of all released rice cultivars decreased as seeding date was delayed (Table 6). Cocodrie, Priscilla, and Wells had the best grain yields across all seeding dates and the best yields when seeded in April and May of the released cultivars. Drew and Wells, followed by Cocodrie, did the best of the released cultivars when seeding was delayed until June 10.

Grain yields of the experimental varieties also displayed a decreasing trend as seeding date was delayed (Table 6). RU9602074 had the highest yields of all the experimental varieties with a high yield of 225 bu/acre when seeded in April and an average grain yield of 181 bu/acre over the four seeding dates. Average grain yields of the other experimental varieties over the four seeding dates ranged from 156 to 161 bu/acre. RU9602074 yielded the best when seeded in April, followed by RU9701041 and RU9901030. The experimental varieties had somewhat similar yields for the May 10 seeding. As seeding date was delayed until late May and early June, RU9602074 was the most stable high yielder followed by RU9701041 for the 27 May seeding date and RU9801081 and RU9901030 for the 10 June seeding. RU9801148 and especially RU9701041 showed the most decline in grain yield as seeding was delayed until 10 June.

SIGNIFICANCE OF FINDINGS

The data from 1999 will be used to refine the DD50 thermal unit thresholds for Cocodrie, Drew, Jefferson, Madison, Priscilla, and Wells. The grain yield data will be used to inform producers as to which cultivars are best to seed when seeding in early April and June and which should be seeded at the recommended, optimum time between 15 April and 15 May.

ACKNOWLEDGMENT

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

Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 1999 at the Rice Research and Extension Center, Stuttgart.

Parameter	Seeding date		
	13 April	27 May	10 June
Emergence date	25 April	5 June	23 June
Flood date	21 May	16 June	7 July
Days between seeding and emergence	12	9	13
Days between seeding and flooding	38	20	27
Days from emergence to flooding	26	11	14

Table 2. Number of days from emergence to ½ inch internode elongation as influenced by rice cultivar/experimental variety and seeding date in 1999 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ Variety[z]	Seeding date			Average across seeding dates
	April 13	May 27	June 10	
	(days)			
Cocodrie	51	34	38	41
Drew	56	42	45	47.6
Jefferson	56	40	41	45.6
Madison	62	45	47	51.3
Priscilla	60	40	45	48.3
Wells	58	43	42	47.6
RU9602074	60	43	47	50
RU9701041	59	43	42	48
RU9801148	59	44	44	49
RU9801081	57	40	42	46.3
RU9901030	56	40	44	46.6
C.V., %	1.5	4.9	3.9	--
LSD(0.05)	1.5	3.4	2.8	--

[z] Entries preceeded with an RU are experimental rice varieties that are not for sale.

Table 3. DD50 thermal unit accumulations from emergence to ½ inch internode elongation as influenced by rice cultivar/experimental variety and seeding date in 1999 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ Variety[z]	Seeding date April 13	May 27	June 10	Average across seeding dates
	(DD50 thermal unit accumulations)			
Cocodrie	1183	992	1127	1101
Drew	1309	1206	1369	1295
Jefferson	1323	1160	1251	1245
Madison	1471	1287	1417	1392
Priscilla	1420	1153	1376	1316
Wells	1355	1234	1271	1287
RU9602074	1420	1250	1429	1366
RU9701041	1388	1242	1284	1305
RU9801148	1404	1267	1347	1339
RU9801081	1352	1158	1279	1263
RU9901030	1320	1163	1345	1276
C.V., %	1.8	5.1	3.8	--
LSD(0.05)	41	101	83	--

z Entries preceeded with an RU are experimental rice varieties that are not for sale.

Table 4. Number of days from emergence to 50% heading as influenced by rice cultivar/experimental variety and seeding date in 1999 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ Variety[z]	Seeding date April 13	May 27	June 10	Average across seeding dates
	(days)			
Cocodrie	85	71	78	77
Drew	87	71	81	79
Jefferson	77	65	69	70
Madison	89	74	82	81
Priscilla	85	67	76	76
Wells	87	74	77	78
RU9602074	86	73	76	78
RU9701041	89	77	79	81
RU9801148	86	74	77	78
RU9801081	80	62	74	71
RU9901030	82	68	74	74
C.V., %	1.3	3.8	2.1	--
LSD(0.05)	1.9	4.5	2.8	--

z Entries preceeded with an RU are experimental rice varieties that are not for sale.

Table 3. DD50 thermal unit accumulations from emergence to ½ inch internode elongation as influenced by rice cultivar/experimental variety and seeding date in 1999 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ Variety[z]	Seeding date April 13	May 27	June 10	Average across seeding dates
	(DD50 thermal unit accumulations)			
Cocodrie	1183	992	1127	1101
Drew	1309	1206	1369	1295
Jefferson	1323	1160	1251	1245
Madison	1471	1287	1417	1392
Priscilla	1420	1153	1376	1316
Wells	1355	1234	1271	1287
RU9602074	1420	1250	1429	1366
RU9701041	1388	1242	1284	1305
RU9801148	1404	1267	1347	1339
RU9801081	1352	1158	1279	1263
RU9901030	1320	1163	1345	1276
C.V., %	1.8	5.1	3.8	--
LSD(0.05)	41	101	83	--

[z] Entries preceeded with an RU are experimental rice varieties that are not for sale.

Table 4. Number of days from emergence to 50% heading as influenced by rice cultivar/experimental variety and seeding date in 1999 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ Variety[z]	Seeding date April 13	May 27	June 10	Average across seeding dates
	(days)			
Cocodrie	85	71	78	77
Drew	87	71	81	79
Jefferson	77	65	69	70
Madison	89	74	82	81
Priscilla	85	67	76	76
Wells	87	74	77	78
RU9602074	86	73	76	78
RU9701041	89	77	79	81
RU9801148	86	74	77	78
RU9801081	80	62	74	71
RU9901030	82	68	74	74
C.V., %	1.3	3.8	2.1	--
LSD(0.05)	1.9	4.5	2.8	--

[z] Entries preceeded with an RU are experimental rice varieties that are not for sale.

GRAIN YIELD RESPONSE OF NEW RICE CULTIVARS TO NITROGEN FERTILIZATION

R.J. Norman, C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, D.L. Boothe, S.D. Clark, and A.D. Cox

ABSTRACT

The cultivar x nitrogen (N) fertilizer interaction study determines the proper N fertilizer rates for the new rice cultivars across the array of soil and climatic conditions which exist in the Arkansas rice growing region. 'Cocodrie', 'Madison', 'Priscilla', and 'Wells' were the new rice cultivars studied in 1999, along with two experimental rice varieties RU9701041 and RU9801148. Similar to other cultivars released lately, all six of the new cultivars and experimental varieties responded equally or better in terms of grain yield when the N fertilizer was applied in a single preflood application compared to the traditional split applications. Because application of N in a single application results in similar or better grain yields with less N than the split application method, the single preflood application method has been renamed the "Optimum Preflood Method." This is due to the fact that applying any less N fertilizer than recommended for the Optimum Preflood Method could lead to yield loss that cannot be regained from N fertilizer applied at midseason. In addition, all of the cultivars required at least 30 lb N/acre more N fertilizer to reach full yield potential on the clay soils than on the silt loam soils, and thus the revised N fertilizer recommendation for rice grown on clay soils in 2000 will be to increase the preflood N rate by 30 lb N/acre.

INTRODUCTION

The major strength of the rice-soil fertility research program has been the delineation of N fertilizer response curves for promising new rice cultivars. This study measures the performance of the new cultivars under varying N fertilizer rates on clay and silt loam soils and determines the proper N fertilizer rates for new cultivars across the array of soils and climatic conditions that exist in Arkansas. Promising new rice selections from breeding programs in Arkansas, California, Louisiana, Mississippi, and Texas are entered into this study. The Arkansas program had the new short-stature long-grain cultivar Wells, and the Louisiana program had the new semi-dwarf long-grain cultivar Cocodrie; both were in the study for the second year in a row. In addition, the Mississippi and Texas programs had the new semi-dwarf long-grain cultivars Priscilla and Madison, respectively, in the study for the second year. Two experimental varieties, RU9701041 and RU9801148, from the Arkansas program were included in the study in 1999 to evaluate their performance on a clay and silt loam soil with the variable of N fertilizer rates applied in a single preflood application as well as in split applications.

PROCEDURES

Locations where the cultivar x N rate studies were conducted and corresponding soil series are as follows: Northeast Research and Extension Center (NEREC), Keiser, Sharkey clay (Vertic Haplaquepts); Pine Tree Branch Experiment Station (PTBES), Colt, Calloway silt loam (Glossaquic Fragiudalfs); Rice Research and Extension Center (RREC), Stuttgart, DeWitt silt loam (Typic Albaqualfs); and the Southeast Branch Experiment Station (SEBES), Rohwer, Perry Clay (Vertic Haplaquepts). The experimental designs were a randomized complete block at the RREC and a split-plot at the NEREC, PTBES, and SEBES. Four replications were used in each experimental design. In the split-plot design, the main plot was application method and the subplot was N fertilizer rate. The two N application methods used in both experimental designs were the recommended single optimum preflood (SPF) and the two-way split (2WS) application methods. The 2WS method has at least 50% of the N fertilizer applied preflood and 50% or 60 lb N/acre (whichever is less) applied between beginning internode movement and 0.5-in. internode elongation. Nitrogen fertilizer rates were 0, 60, 90, 120, 150, and 180 lb N/acre. The rice cultivars studied were Cocodrie, Madison, Priscilla, and Wells, as well as the two experimental rice varieties, RU9701041 and RU9801148. The rice was drill-seeded at a rate of 100 lb/acre in plots nine rows wide (row spacing of 7 in.) and 15 ft. in length. Plots were flooded at each location when the rice was at the four- to five-leaf stage and remained flooded until the rice was mature. At maturity, 12 ft. of the center four rows of each plot was harvested, the moisture content and weight of the grain were determined, and yields were calculated as lb/acre at 12% moisture. Statistical analyses were conducted with SAS and mean separations were based upon protected least significant difference ($P = 0.05$) where appropriate.

RESULTS AND DISCUSSION

Cocodrie, the new semi-dwarf long-grain cultivar from Louisiana, had peak grain yields in the 1999 cultivar x N fertilizer interaction studies of over 9000 lb/acre (Table 1). There was a significant interaction between N fertilizer method and rate on grain yields of Cocodrie at all four locations where it was studied in 1999. On the silt loam soils at RREC and PTBES, Cocodrie achieved maximum grain yields when 90 lb N/acre was applied in a SPF application compared to 120 to 150 lb N/acre applied in the 2WS application. On the clay soils at SEBES and NEREC, Cocodrie required 150 or 180 lb N/acre to achieve maximum grain yields when the N fertilizer was applied in a SPF or 2WS application, respectively. Thus, at all four locations in 1999, Cocodrie achieved similar maximum grain yields with both N application methods, but the SPF application method required at least 30 lb N/acre less than the 2WS application method. Furthermore, Cocodrie required 30 lb N/acre more on the clay soils compared to the silt loam soils to reach maximum grain yield. As will be seen with the other cultivars studied in 1999 and in years past, rice grown on clay soils seems to require at least 30 lb N /acre more than when they are grown on silt loams to achieve maximum grain yield. Consequently, a revised N fertilizer recommendation for rice in 2000 will be to increase the recommended preflood N rate by 30 lb N/acre when rice is grown on a clay soil.

Madison, the new semi-dwarf long-grain released by Texas, had maximum grain yields in the 1999 studies of over 8500 lb/acre. Madison had similar grain yields when the N fertilizer was applied in a SPF compared to a 2WS application on the silt loam soil at the PTBES (Table 2) and showed no significant increase in grain yield when more than 150 lb N/acre was applied (Table 3). There was a significant interaction between N fertilizer method and rate on grain yields of Madison at the other three locations (Table 4). On the silt loam soil at RREC, Madison showed no significant grain yield increase when more than 90 lb N/acre was applied in a SPF application, but required 120 lb N/acre to achieve a similar grain yield when the 2WS application method was used. Similar to Cocodrie, Madison required 30 to 60 lb N/acre more N fertilizer on the clay soil at the SEBES and NEREC than on the silt loam soil at RREC to achieve maximum grain yield. Grain yields of Madison appeared to be peaking on the clay soils at the SEBES and NEREC when 150 lb N/acre was applied in a SPF application and 180 lb N/acre with the 2WS application. In 1998, Madison also required less N fertilizer to reach maximum grain yields when it was applied in a SPF compared to a 2WS application (Norman *et al.*, 1999).

Priscilla, the new semi-dwarf long-grain released by Mississippi, had maximum grain yields of over 9000 lb/acre. Priscilla showed a similar grain yield response when the N fertilizer was applied in a SPF compared to a 2WS application at the RREC, but yielded higher when all of the N was applied in a SPF application at the NEREC (Table 5). Grain yields of Priscilla did not significantly increase when more than 150 lb N/acre was applied at the RREC but were still increasing when up to 180 lb N/acre was applied at the NEREC (Table 6). These data reinforce previous observations that a larger amount of N fertilizer is required on the clay soils compared to the silt loams to achieve maximum rice grain yields. There was a significant interaction between N fertilizer method and rate on grain yields of Priscilla at the SEBES and the PTBES (Table 7). On the silt loam soil at PTBES, Priscilla showed no significant grain yield increase when more than 120 lb N/acre was applied in a SPF application, but required 150 lb N/acre to achieve a similar grain yield when the 2WS application method was used. At the SEBES, grain yields of Priscilla were still increasing when up to the maximum N rate of 180 lb N/acre was applied with either N application method. However, grain yields of Priscilla were climbing faster and higher when the N fertilizer was applied in a SPF compared to a 2WS application. Priscilla also reponded better in 1998 when the N fertilizer was applied in a SPF application (Norman *et al.*, 1999).

Wells, the new long-grain cultivar released by the Arkansas breeding program, had maximum grain yields of over 8500 lb/acre. Wells responded better when the N fertilizer was applied in a SPF compared to a 2WS application on the silt loam soil at the SEBES (Table 8) and displayed no significant grain yield increase when more than 150 lb N/acre was applied at this location (Table 9). There was a significant interaction between N fertilizer method and rate on grain yields of Wells at the other three locations (Table 10). On the silt loam soils at RREC and PTBES, Wells showed no significant grain yield increase when more than 90 or 120 lb N/acre, respectively, were applied in a SPF application, but required 120 or 150 lb N/acre, respectively, to achieve similar grain yields when the 2WS application method was used at these two locations. On the clay soil at the NEREC, grain yields of Wells appeared to peak when 120 lb N/acre was applied in a SPF application and 150 lb N/acre was applied as a 2WS application. Similar to Cocodrie, Madison required at least an additional 30 lb N/acre more N fertilizer on the clay soil at the SEBES and NEREC than on the silt loam soil at RREC. In 1998, Wells also responded better when the N fertilizer was applied in a SPF compared to a 2WS application or reached maximum grains at a lower N rate with the SPF compared to the 2WS application method (Norman *et al.*, 1999).

Grain yields of the two Arkansas experimental rice varieties, RU9701041 and RU9801148, displayed a significant interaction between N fertilizer method and rate (Table 11). Both experimental varieties had similar or higher grain yields with less N when the N fertilizer was applied in a SPF application compared to in a 2WS application.

Rice grown on the clay soils at the NEREC and SEBES always require at least 30 lb N/acre more than on the silt loam soils at the RREC and PTBES to produce comparable rice grain yields. Consequently, the revised N fertilizer recommendation for rice grown on clay soils in 2000 will be to increase the preflood N rate by 30 lb N/acre compared to rice grown on silt loam soils.

SIGNIFICANCE OF FINDINGS

The six new rice cultivars and experimental varieties studied in 1999 over four locations produced similar or greater grain yields with less N fertilizer when the N fertilizer was applied in a SPF application compared to in a 2WS application. Because this observation has been repeatedly reenforced for so many years with these new shorter stature varieties, the single preflood method has been renamed the "Optimum Preflood Method." This is due to the fact, that applying any less N fertilizer than recommended for the Optimum Preflood Method could lead to yield loss that cannot be regained from N fertilizer applied at midseason. In almost every instance, all of the cultivars required more N fertilizer to reach full yield potential on the clay soils compared to the silt loam soils; usually requiring at least 30 lb N/acre more. Thus, the revised N fertilizer recommendation for rice in 2000 will be to increase the preflood N rate by 30 lb N/acre for rice grown on clay soils compared to silt loam soils.

ACKNOWLEDGMENT

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

LITERATURE CITED

Norman, R.J., C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, and A.D. Cox. 1999. Grain yield response of new rice cultivars to nitrogen fertilization. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:257-267.

Table 1. Influence and interaction of nitrogen (N) fertilizer rate and application method on grain yields of Cocodrie rice at four locations in 1999.

Application rate	Grain yields							
	RREC[z]		SEBES		PTBES		NEREC	
	SPF[y]	2WS	SPF	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	(lb/acre)							
0	3366		3578	3996	3767	4247	1636	1906
60	7450	6720	5729	6617	6685	5857	5489	4282
90	8086	6944	6709	7168	7471	6919	6484	4984
120	7973	7580	8566	7747	7770	7241	7511	6187
150	8207	8239	9248	7048	7742	7732	8045	7107
180	7643	8383	8880	9279	7038	7898	8008	7918
$LSD_{(0.05)\ w/in\ N\ method}$	615*[x]		823*		813*		665*	
$LSD_{(0.05)\ between\ N\ methods}$			943*		805*		644*	

[z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser.

[y] SPF = Single preflood; 2WS = Two-way split.

[x] * indicates significance at the P=0.05 level.

Table 2. Influence of nitrogen (N) fertilizer application method on grain yields of Madison rice at the Pine Tree Branch Experiment Station in 1999.

Application method	Grain yields
	(lb/acre)
SPF[z]	6447
2WS	6007
$LSD_{(0.05)}$	472

[z] SPF = single preflood; 2WS = Two-way split.

Table 3. Influence of nitrogen (N) fertilizer rate on grain yields of Madison rice at the Pine Tree Branch Experiment Station in 1999.

Application Rate	Grain yields
(lb N/acre)	(lb/acre)
0	3250
60	5624
90	6541
120	7084
150	7394
180	7470
$LSD_{(0.05)}$	384*[z]

[z] * indicates significance at the P=0.05 level.

Table 4. Influence and interaction of nitrogen (N) fertilizer rate and application method on grain yields of Madison rice at three locations in 1999.

	Grain yields					
	RREC[z]		SEBES		NEREC	
N Rate	SPF[y]	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	(lb/acre)					
0	2936		1464	2009	1459	1303
60	6345	5185	4325	4056	4803	3674
90	7417	5709	4007	5621	5262	4361
120	7481	7260	6544	6740	6120	5021
150	7600	7743	8520	7281	6531	6235
180	7398	7861	8610	8295	6585	6643
$LSD_{(0.05)\ w/in\ N\ method}$	934*[x]		1097*		622*	
$LSD_{(0.05)\ between\ N methods}$			1093*		580*	

[z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer, NEREC = Northeast Research and Extension Center, Keiser.

[y] SPF = Single preflood; 2WS = Two-way split.

[x] * indicates significance at the P=0.05 level.

Table 5. Influence of nitrogen (N) fertilizer application method on grain yields of Priscilla rice at two locations in 1999.

Application method	Grain yields	
	RREC[z]	NEREC
(lb N/acre)	---------- (lb/acre) ----------	
SPF[y]	6856	5711
2WS	6763	4947
$LSD_{(0.05)}$	358	523*[x]

[z] RREC = Rice Research and Extension Center, Stuttgart; and NEREC = Northeast Research and Extension Center, Keiser.
[y] SPF = Single preflood; 2WS = Two-way split.
[x] * indicates significance at the P=0.05 level.

Table 6. Influence of nitrogen (N) fertilizer rate on grain yields of Priscilla rice at two locations in 1999.

Application rate	Grain yields	
	RREC[z]	NEREC
(lb N/acre)	---------- (lb/acre) ----------	
0	3504	1922
60	5669	3886
90	7138	4967
120	7273	6196
150	7866	7005
180	7922	7526
$LSD_{(0.05)}$	636*[y]	510*

[z] RREC = Rice Research and Extension Center, Stuttgart; and NEREC = Northeast Research and Extension Center, Keiser.
[y] * indicates significance at the P=0.05 level.

Table 7. Influence and interaction of nitrogen (N) fertilizer rate and application method on grain yields of Priscilla rice at two locations in 1999.

Application rate	Grain yields			
	SEBES[z]		PTBES	
	SPF[y]	2WS	SPF	2WS
(lb N/acre)	(lb/acre)			
0	2515	2409	3374	3007
60	4692	4711	5917	4372
90	6802	6353	6960	5430
120	7346	6399	7940	6964
150	8633	7009	7884	7871
180	9320	8683	8198	8255
$LSD_{(0.05)\ w/in\ N\ method}$	665*[x]		892*	
$LSD_{(0.05)\ between\ N\ methods}$	671*		872*	

[z] SEBES = Southeast Branch Experiment Station, Rohwer, PTBES = Pine Tree Branch Experiment Station, Colt.
[y] SPF = Single preflood; 2WS = Two-way split.
[x] * indicates significance at the P= 0.05 level.

Table 8. Influence of nitrogen (N) fertilizer application method on grain yields of Wells rice at the Southeast Branch Experiment Station in 1999.

Application method	Grain yields
	(lb/acre)
SPF[z]	6442
2WS	5844
$LSD_{(0.05)}$	416*[y]

[z] SPF = Single preflood; 2WS = Two-way split.
[y] * indicates significance at the P = 0.05 level.

Table 9. Influence of nitrogen (N) fertilizer rate on grain yields of Wells rice at the Southeast Branch Experiment Station in 1999.

Application rate	Grain yields
(lb N/acre)	(lb/acre)
0	1781
60	4504
90	6157
120	7213
150	8450
180	8754
$LSD_{(0.05)}$	367*[z]

[z] * indicates significance at the P = 0.05 level.

Table 10. Influence and interaction of nitrogen (N) fertilizer rate and application method on grain yields of Wells rice at three locations in 1999.

	Grain yields					
	RREC[z]		PTBES		NEREC	
Application rate	SPF[y]	2WS	SPF	2WS	SPF	2WS
(lb N/acre)			(lb/acre)			
0	3996		1908	2120	1570	1707
60	6926	6364	5085	4133	4594	3874
90	8170	7440	6569	5037	6008	4706
120	8066	8004	7789	6746	6593	5133
150	7368	8112	7332	7328	6577	6570
180	7379	7668	7020	7377	6506	6437
$LSD_{(0.05)\ w/in\ N\ method}$	502*[x]		1080*		909*	
$LSD_{(0.05)\ between\ N\ methods}$			1018*		971*	

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser.
[y] SPF = Single preflood; 2WS = Two-way split.
[x] * indicates significance at the P = 0.05 level.

Table 11. Influence and interaction of nitrogen (N) fertilizer rate and application method on grain yields of experimental rice varieties RU9701041 and RU9801148 at two locations in 1999.

Applicationrate	Grain yields							
	RU9701041[z]				RU9801148			
	RREC[y]		SEBES		RREC		SEBES	
	SPF[x]	2WS	SPF	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	(lb/acre)							
0	3891		1679	1567	4045		2516	2117
60	7124	5935	4485	3630	8281	7101	4947	4378
90	7078	6863	5411	4514	8523	7420	7526	5348
120	7669	7165	7386	5414	8737	8430	9063	6680
150	7706	7043	7847	7124	8284	8310	10617	8384
180	7674	7953	8719	7493	7894	8571	10512	9995
$LSD_{(0.05)\ w/in\ N\ method}$	475*[w]		683*		494*		845*	
$LSD_{(0.05)\ between\ N\ methods}$			878*				814*	

[z] Entries preceeded with an RU are experiment rice varieties that are not for sale.
[y] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rowher.
[x] SPF = Single preflood; 2WS = Two-way split.
[w] * indicates significance at the P = 0.05 level.

INFLUENCE OF NITROGEN FERTILIZER TIMING AND RATE ON RICE GROWTH

H.J. Pulley, C.A. Beyrouty, R.J. Norman, and N.A. Slaton

ABSTRACT

The rate and timing of nitrogen (N) fertilization plays an important role in achieving higher grain yields in rice. If N is supplied during critical stages of plant development, it will stimulate growth. The second year of a 2-year study was conducted to evaluate the influence of N rates and timing on the growth of two rice cultivars. Nitrogen was applied as a single or three-way split with or without an additional application at booting. A single preflood (SPF) application of N resulted in higher shoot dry weight and N uptake than a three-way split application. Root length was decreased with added N, suggesting that the soil had high residual soil N. Increased yields associated with application of N at booting differed for the 2 years, although boot N had no effect on shoot or root growth or N uptake. These preliminary results suggest a single application of N is sufficient to maintain healthy rice growth, alleviating the need for additional N applications after flooding. Rice may respond to N applied as late as booting, but only when the rice is N limited and not severely N stressed.

INTRODUCTION

Timing of fertilizer N to rice is critical to maximizing uptake as well as yields. Research in the United States and Asia suggest that the rice plant has the capability to absorb late season N and utilize that N for enhanced yields. However, currently our latest N applications occur within 7 to 10 days following 0.5-in. internode elongation (IE). The newer cultivars appear to have a greater capacity to absorb larger quantities of N than some of the earlier cultivars.

Our research has shown that rice root length increases rapidly during vegetative development, reaching a maximum at or near booting (Slaton *et al.*, 1990; Beyrouty *et al.*, 1988). Root length remains at this maxima until heading, after which it decreases. This fact is important to our understanding of root growth and to the way we manage fertilizers and water to take advantage of this uniqueness in growth.

Late-season fertilizer N application is a technique used by some farmers in the United States and is a routine management practice in parts of Asia such as Japan (Shigenori Morita, University of Tokyo, personal communication). Timing of this N is important in order to take advantage of application when roots are still most active and when the plant can metabolize the additional N and convert it into high-quality rice grain yield. It is important to identify the true windows of opportunity in which we can apply N to rice and expect significant uptake and increased yields and quality. Previous research on rice in Arkansas showed how various N applications altered the growth of rice roots and N uptake by the plant (Beyrouty *et al.*, 1994; Grigg *et al.*, 2000). The purpose of this study was to quantify the effects of late-season N application on plant growth and N uptake by rice.

PROCEDURES

A field study was conducted in 1998 and 1999 on a Crowley silt loam at the Rice Research and Extension Center near Stuttgart. Two cultivars, 'Cypress' and 'LaGrue', were seeded in nine-row plots measuring 15 ft long with 7-in. spacing between rows. Plots were seeded on 1 June 1998 and 11 May 1999. Each cultivar was subjected to five pre-boot N fertilizer and two boot N fertilizer treatments. The treatments were as follows: (1) 0 lb N/acre, (2) 80 lb N/acre SPF, (3) 120 lb N/acre SPF, (4) 160 lb N/acre SPF, (5) 80 lb N/acre split application (40-20-20) with the splits at preflood, 0.5-in.IE, and 5 days after 1/2-inch IE, (6) 120 lb N/acre split application (60-30-30), and (7) 160 lb N/acre split application (100-30-30). The two boot N treatments were 0 lb N/acre and 40 lb N/acre applied 5 days prior to 50% heading.

Immediately after planting, a mini-rhizotron tube was inserted into each plot in the 3rd row at a 45° angle to a depth of 26 in. below the soil surface. A video camera was used to record images of roots growing along the upper two sides of each tube. These image measurements were made at four physiological stages of plant development: 0.5-in. IE, booting (B), heading (HD), and physiological maturity–harvest (H). Images were converted to total root length (TRL) and root length density (RLD). At each sampling date except at H, plant height (PHT) was measured and a 1.6-ft length of row was harvested from each plot and shoot dry weight (SDW) and leaf area (LA) were measured. Plant samples were ground to pass a 1-mm sieve prior to analysis for total N by the Kjeldahl method.

At maturity, 12 ft of the center four rows were hand-harvested, threshed, dried to 120 g/kg moisture content and weight of the grain was determined. After drying, a 150-g sample of rough rice from each plot was milled. The milling procedure consisted of hulling the rough rice with a McGill huller, milling the brown rice with a McGill No. 2 miller, and separating the white rice into head rice (kernels having three-fourths or more original kernel length) and brokens using a Seedburo sizing machine with a No. 13 top screen and a No. 12 bottom screen. Total white rice yield and head rice yield were expressed as a percentage of the original rough rice sample. Statistical analyses were conducted with SAS, and mean separations were based upon protected least significant difference where appropriate.

RESULTS AND DISCUSSION

Yields were affected by cultivar, N rate, and timing of application (Table 1). Fertilizer N increased yields above the zero N control, with LaGrue producing higher yields than Cypress at all N fertilizer rates. Maximum yields were obtained for both cultivars at 160 lb N/acre, although 120 lb N/acre SPF produced the same yield in Cypress. For LaGrue, 160 lb N/acre produced the highest yield when applied as a split application, but a SPF application of 160 lb N/acre did not increase yields when compared to 120 lb N/acre split or 80 lb N/acre SPF.

The effect of boot N application on grain yield was dependent on the growing season (Table 2). In 1998, application of N at booting did not increase yields for either cultivar, while in 1999 boot N increased yields by approximately 10%. Overall, yields for 1999 were 30% higher as compared to 1998, regardless of N applications.

Grain quality was affected by rate and timing of pre-boot N, but not by N applied at booting (data not shown). Maximum head rice yield was greatest for Cypress in 1998 when N was split applied at 160 lb N/acre or applied as a single preflood at 80 or 160 lb N/acre. There were no treatment differences in head rice yields for Cypress in 1999. In contrast, maximum head rice yields for LaGrue in 1998, occurred with a single preflood application of 80 or 160 lb N/acre or a split application of 160 lb N/acre, while in 1999, only a single preflood application of 160 lb N/acre maximized head rice yields.

Shoot dry weight increased with increasing N rates (Table 3). Maximum shoot dry weight was measured both years in response to160 lb N/acre as a single preflood application. At the 80 lb/acre rate, a single preflood application produced greater root length and more shoot biomass than a split application. This indicates rice obtained a greater benefit from the single application, resulting in less N-stressed plants. These less-stressed plants were able to produce higher yields in response to an application of N at booting, as compared to rice fertilized with a split application. There was no SDW response to boot N by either cultivar.

Root length was reduced when N was split-applied at 80 lb/acre or applied SPF at 160 lb/acre (Table 3). Typically, addition of N fertilizer increases root length if N is limiting in the soil; however, the reduction in root length with application of N indicates that there may have been residual N in these plots. It is not known why root lengths were reduced with all fertilizer treatments. Boot N had no effect on root length, which is not surprising since maximum length is generally produced before or at booting.

Maximum uptake of N (reported for 1998 only) at all N rates occurred at IE. Compared to the zero N control, application of N fertilizer increased uptake for all treatments (Table 3). Maximum N uptake occurred with the 160 lb N/acre applied as a SPF. Application of N at booting did not affect N uptake.

SIGNIFICANCE OF FINDINGS

Results from 2 years of this study suggest that maximum rice yields differ by cultivar and N rate. Cypress achieved maximum yield with a SPF application of 120 lb N/acre, while LaGrue required 160 lb N/acre as a split application. However, addition of N as a SPF application proved to be adequate to sustain healthy rice and yield. Application of boot N did not result in an increase in grain yield for 1998 but did in 1999, indicating that late-season N is dependent on environmental factors, such as residual soil N and planting date, to produce an increase in rice yield. However, it seems likely that late-season N application might be useful in countering N limitations. This observation requires additional study.

LITERATURE CITED

Beyrouty, C.A., B.R. Wells, R.J. Norman, J.N. Marvel, and J.A. Pillow. 1988. Root growth dynamics of a rice cultivar grown at two locations. Agron. J. 80:1001-1004.

Beyrouty, C.A., B.C. Grigg, R.J. Norman, and B.R. Wells. 1994. Nutrient uptake by rice in response to water management. J. Plant Nutr. 17:39-55.

Grigg, B.C., C.A. Beyrouty, R.J. Norman, E.E. Gbur, M.G. Hanson, and B.R. Wells. 2000. Rice responses to water and N management in southern USA. Field Crops Research (in press).

Slaton, N.A., C.A. Beyrouty, B.R. Wells, R.J. Norman, and E.E. Gbur. 1990. Root growth and distribution of two short-season rice genotypes. Plant Soil. 121:269-278.

Table 1. Average grain yield of two rice cultivars subjected to different rates and timing of N. Means within the same column followed by the same letter are not significantly different at P=0.05. Means within a row followed by an * are significantly different at P=0.05.

	Cultivar	
N Treatment[1]	Cypress	LaGrue
(lb N/acre)	---------------------- (bu/acre)	----------------------
0	68 c	73 e
80 Split	110 c	126 d*
80 SPF	119 b	145 c*
120 Split	120 b	148 c*
120 SPF	135 a	155 b*
160 Split	136 a	160 a*
160 SPF	137 a	149 c*

[z] Split = 50% urea applied preflood, 25% applied at ½-inch internode elongation (IE), and 25% applied at IE + 5 days. SPF = single preflood application.

Table 2. Average grain yield of rice subjected to different applications of boot N for two growing seasons. Means within the same column followed by the same letter are not significantly different at P=0.05. Means within a row followed by an * are significantly different at P=0.05.

	Year	
Boot N	1998	1999
(lb N/acre)	------------------- (bu/acre)	-------------------
0	108 a	138 b*
40	111 a	151 a*

Table 3. Average shoot dry weight, root length, and N uptake of rice subjected to different rates and timing of N. Means within a column followed by the same letter are not significantly different at P=0.05.

N Treatment[z]	Shoot Dry Weight	Root Length	N Uptake
(lb N/acre)	(g)	(cm)	(kg/ha)
0	35 e	212 a	62 d
80 Split	49 d	194 b	84 c
80 SPF	54 c	214 a	96 c
160 Split	62 b	205 a	114 b
160 SPF	73 a	186 b	140 a

[z] Split = 50% urea applied preflood, 25% applied at ½-inch internode elongation (IE) and 25% applied at IE + 5 days. SPF = single preflood application.

ESTIMATION OF SEASONAL RICE EVAPOTRANSPIRATION

F. Renaud, J.A. Ferguson, H.D. Scott, and D.M. Miller

ABSTRACT

Evapotranspiration (ET_c) was calculated by four methods for a flood-irrigated rice field in the Delta region of Arkansas. ET_c estimates from emergence to harvest averaged 4.4 and 4.8 mm/day when estimated with the Kimberly-Penman (K-P) equation or with an empirical method developed by Cahoon *et al.* (1990), respectively. Cumulative ET_c values were 609 and 663 mm for the entire crop season with the K-P and Cahoon methods, respectively. During the 78 days when the field was flooded, ET_c averaged 5.6, 6.4, and 9.3 mm/day with the K-P equation, the Cahoon method, and a pan evaporation-based empirical relation method (E-P), respectively. There were statistical differences between all the methods. During the 62 days when the field was not flooded, ET_c was 2.8, 2.6, and 2.2 mm/day with the K-P equation, the Cahoon method, and a water balance method that used time domain reflectometry (TDR) to monitor soil volumetric water changes, respectively. There were no significant differences between the K-P and Cahoon methods. These two methods gave significantly higher estimates of ET_c than did the TDR method. Results indicate that the relatively simple Cahoon method is appropriate to estimate ET_c, while the TDR method, with some modifications, could also prove a valuable tool during the non-flooded periods.

INTRODUCTION

Rice is produced in Arkansas mainly in the eastern part of the Mississippi Delta region. Rice fields are flooded using predominantly groundwater sources, and large quantities of water are pumped annually during the growing season. Pumping costs represent a large proportion of the annual expenditure in the production of rice. The continued use of large amounts of groundwater has also created water quality problems. Scott *et al.* (1998) reported that use of groundwater in Arkansas in 1994 was 3.36 times greater than that in 1965. This can lead to water quality problems, because as the upper, higher quality portions of the aquifer are depleted, farmers are forced to pump from deeper areas, where the water tends to be of lower quality. In Eastern Arkansas, such low-quality groundwater is sometimes used to irrigate crops (Baker *et al.*, 1996). Water-saving practices would, therefore, probably be welcomed by farmers and would also put less pressure on the depletion of groundwater resources in some areas. Before water-saving practices can be investigated, it is important to determine ET_c with fairly good precision for the climatic environment of the Delta.

The objectives of this study were to (1) compare four methods for calculating ET_c in the production rice field, and (2) obtain ET_c data characteristic of the study area.

PROCEDURES

Experimental Setup

The study was implemented on a private farm within the Mississippi Alluvial Valley, in Cross County, east central Arkansas. It was located approximately 16 km west of Crowley's Ridge within the Western Lowlands, and approximately 3 km west of the L'Anguille River. The soil was a Calloway silt loam (fine-silty, mixed, thermic Aquic Fragiudalfs) with five characteristic horizons, including a traffic pan (0.09 to 0.19 m below the soil surface) and a fragipan (0.52 to 0.72 m). The fragipan acted as a hydraulic barrier that limited water transfer in the soil (data not shown).

Volumetric water content (θ_v) was continuously monitored from seeding until 2 wk after harvest using TDR. Time steps varied from every 15 minutes to every hour, but for most of the season measurements were taken every 30 minutes. Data were stored in dataloggers *in situ* and regularly downloaded. The TDR waveguides, 0.2 m long, were placed horizontally in the soil profile at depths of 0.05 m (Ap1 horizon), 0.09 m (interface between Ap1 and Ap2), 0.14 m (Ap2), 0.26 m, and 0.45 m (E), 0.6 m (Btx), 0.8 m, and 1.0 m (Bt1). Each TDR sensor was composed of three parallel waveguides. A weather station located approximately 25 m from the monitoring area collected climatic parameters every 30 minutes throughout the season, and data were stored in dataloggers *in situ* and regularly downloaded. Measurements included rainfall, wind speed, global solar radiation, air temperature, and relative humidity.

The cultivar 'Drew' was seeded on 9 April 1998, emerged on 17 April and was harvested on 3 September or 140 days after emergence (DAE). The field was flooded twice, between 36 to 45 DAE and between 57 to 124 DAE.

Evapotranspiration Estimation

Evapotranspiration was estimated by using (1) the combination-theory K-P equation (Wright, 1982); (2) an empirical formulation developed by Cahoon *et al.* (1990); (3) a simple regression model developed by Tomar and O'Toole (1979) for South and Southeast Asia, but used by Pennington and Wolf (1989) in Mississippi; and (4) the θ_v readings from the TDR.

The K-P for an alfalfa reference crop has the following form:

$$\lambda ET_{rc} = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma}[6.43W_f(e_s - e_a)] \quad [1]$$

where ET_{rc} is the reference crop ET (alfalfa); Δ is the slope of the vapor pressure-temperature curve (kPa °C^{-1}); γ is the psychrometer constant (kPa °C^{-1}); R_n is the net radiation (MJ m^{-2} d^{-1}); G is the soil heat flux to the surface (MJ m^{-2} d^{-1}); λ is the latent heat of vaporization of water (MJ kg^{-1}); W_f is the wind function; and e_s-e_a is the mean daily vapor pressure deficit (kPa), with e_s the saturation water pressure (kPa) and e_a the partial pressure of water vapor in the air (kPa). All the parameters needed to calculate ET_c were either directly measured or estimated following published procedures (Wright and Jensen, 1972; Wright, 1982; Allen *et al.*, 1989; Shuttleworth, 1993). To obtain ET_c from ET_{rc}, ET_{rc} needed to be multiplied by a crop coefficient (K_c).

Cahoon *et al.* (1990) favored a commonly used formulation based on pan evaporation:

$$ET_c = E_p K_c K_p \quad [2]$$

where ET_c is daily evapotranspiration (mm/day); E_p is daily pan evaporation (mm); and K_p is a pan coefficient dependent on relative humidity and daily wind run (km/day). Cahoon *et al.* (1990) proposed a simple approach to calculating E_p using maximum air temperature and day length:

$$E_p = 25.4[A + B(1.8T + 32)^2 + C(1.8T + 32) + D\,(DYL)] \quad [3]$$

where A, B, C, and D are empirical regional parameters, T is the maximum daily temperature (°C), and DYL is the day length. In this study, E_p was estimated using regional parameters developed for the University of Arkansas Northeast Research and Extension Center (NEREC), Keiser, and the Rice Research and Extension Center (RREC), Stuttgart. The maximum daily air temperature was that of the experimental site. The average of the two values of E_p was then calculated as the E_p for the experimental site.

Calculating ET_c with Eq. [1] and [2] requires the use of crop coefficients. Those proposed by Doorenbos and Pruitt (1977) were modified to account for dry soil conditions and crop development. Calculation of K_c was based on leaf area index, which was determined by calculating the ratio between total plant leaf area as measured from samples taken in the field in the same year (Dr. Merle Anders, personal communication) and an estimated seeding density of 188 plants/m^2 (CES, 1996). The method used to estimate K_c is summarized in Fig. 1.

The expression derived by Tomar and O'Toole (1979), is very similar to Eq. [2], and is only valid for flooded conditions:

$$ET_c = 1.2E_p \qquad [4]$$

Pan evaporation data from Keiser were used for this purpose. The coefficient of 1.2 is equivalent to K_cK_p in Eq. [2].

Finally, ET_c was estimated by determining daily averaged changes of θ_v in the soil profile. The soil profile above the fragipan was divided into five sections (0-0.07, 0.07-0.11, 0.11-0.19, 0.19-0.355, and 0.355-0.520 m). It was assumed that θ_v, as measured by the TDR sensor of the section, was homogeneous throughout the section. This assumption is the most important one because TDR sensors measure θ_v accurately only in the immediate vicinity of the waveguides (Baker and Lascano, 1989) and because bulk density was variable within each section. The first TDR sensor, placed at a depth of 0.05 m, is unlikely to have provided an accurate estimation of θ_v toward the soil surface. Other assumptions were that there was no movement of water by capillarity, and that the flow of water through the fragipan was negligible (the fragipan had a very low saturated hydraulic conductivity and only slight changes in θ_v were observed throughout the season). ET_c was then calculated as follows:

$$ET_c = \sum_{n-1}^{5} \Delta\,(\theta_n L_n) - R \qquad [5]$$

where Δ is the change of water stored from one day to the other; n is the number of sections; R is rainfall (mm); and L is the thickness of the section (mm) in the soil profile. R was subtracted to compensate for the fact that some rainfall water may not have been accounted for close to the soil surface by the shallowest TDR sensor.

RESULTS AND DISCUSSION

The K-P and Calhoon methods allowed for an estimation of ET_c over the entire cropping season; the pan method was used only during the second, permanent flood; and the TDR estimate of ET_c was only used in the absence of a flood. ET_c with the K-P equation and with the Cahoon method was influenced by the seasonal variability of K_c (Figs. 2 and 3). Both methods gave similar estimates of ET_c, which increased steadily up to the first flood, peaked during the permanent flood, and decreased upon removal of the permanent flood (Fig. 3). Average ET_c was 4.1 and 4.5 mm/d (entire monitoring period), 4.4 and 4.8 mm/day (entire rice cropping season), 5.6 and 6.4 mm/day (flooded periods), and 2.8 and 2.6 mm/day (non-flooded periods between emergence and harvest) for the K-P and Cahoon methods, respectively (Table 1). There were significant differences for all the periods considered, except during the non-flooded periods. Statistical comparisons were made by using a *t*-test ($\alpha = 0.05$) on the hypothesis that the average difference in ET_c between two methods was zero. The difference in ET_c estimate during the flooded periods was due to several storms that considerably lowered R_n in Eq. [1] but did not affect T in Eq. [3] significantly. This difference was enough to lower ET_c in the K-P method, but it did not significantly affect ET_c with the Cahoon method. With an average ET_c estimate of 9.3 mm/day during the floods, the pan method gave a significantly higher average ET_c than the K-P and Cahoon methods (Table 1 and Fig. 3). It is likely that the coefficient of 1.2 used in Eq. [4] is not appropriate to the climatic conditions of the lower Mississippi Delta region. Lowering the coefficient to 0.81 and 0.94 in Eq. [4] resulted in no significant differences between the pan, and the K-P and Cahoon methods, respectively. The value of 0.94 is lower than the coefficients reported by Shah *et al.* (1986) in Thailand but similar to the 0.93 value reported by Yoshida (1979) for the Philippines. Also, E_p measurements at NEREC were highly variable from one day to the next (Fig. 4). When E_p at NEREC was calculated with Eq. [3], no significant differences were found between measured and calculated E_p for NEREC, even though E_p exhibited much less daily variability when calculated with Eq. [3]. This had two implications: (1) the Cahoon method was adequate for estimating E_p over periods of several days, and therefore ET_c; and (2) taking the daily average E_p between the NEREC and RREC stations allowed for a better characterization of ET_c at our research site.

Finally, the average ET_c as estimated by the TDR method during the rice-cropping season was 2.2 mm/day and was significantly lower than that of the K-P and Cahoon methods (Table 1 and Fig. 5). TDR estimates of ET_c were not consistent with the estimates provided by the K-P and Cahoon methods except during the "dry-down" period at the end of the cropping cycle (Fig. 5). The limitations of the TDR method to estimate ET_c at other times can be explained by the fact that large changes in θ_v could have taken place at the soil surface (small rainfall and water loss through evaporation) without affecting the shallowest TDR sensor.

Average ET_c values as estimated by the Cahoon method during the flood correspond favorably with those reported by Roel *et al.* (1999) in Texas and by Shih *et al.* (1982) in Florida. Values estimated with the K-P method were lower because of several storms. However, under non-flooded conditions, estimated ET_c was smaller than the estimate of Roel *et al.* (1999). This can be explained by the fact that Roel *et al.* (1999) flushed their experimental site four times before permanently flooding the fields, while at our location only one flush was used, yielding drier soils and limiting ET_c. As calculated, average ET_c values during most of the flooded periods were high enough to require an additional source of energy other than net solar radiation. Because the K-P equation required the calculation of net radiation and soil heat flux, the energy balance equation could be solved for sensible heat (neglecting the energy used in photosynthesis):

$$R_n = ET + S + G \quad [6]$$

where S is the sensible heat flux (the energy used to heat the air). It appeared that sensible heat had to be positive (i.e., be a source of energy rather than a sink) for Eq. [6] to balance during parts of the flooded periods. This would indicate that advection of warm air took place, which is a common phenomenon when wet areas (flooded rice fields) are surrounded by drier areas (non-irrigated soybean fields, fallow fields, roads, etc.).

Cumulative ET_c for the entire cropping season were 609 and 663 mm with the K-P and Cahoon methods, respectively. Shih *et al.* (1982) reported values of 740 to 880 mm during flooding in Florida and McCauley (1990) reported a range of 754 to 906 mm for an entire rice crop grown in east Texas. Although year-to-year variability in cumulative ET_c is to be expected, it seems reasonable to conclude that both the K-P and Cahoon methods are adequate to estimate ET_c for the Delta region of Arkansas. The Cahoon method is much simpler to use than the K-P method even if it seems to overestimate ET_c during stormy days. More testing should be done to confirm this preliminary conclusion.

SIGNIFICANCE OF FINDINGS

This research project allowed for a complete characterization of rice evapotranspiration in the Delta region of Arkansas. Even though calculations were made only over a 1-year period, results indicate that the empirical Cahoon method for estimating ET_c is appropriate. Furthermore, the TDR method could also prove a valuable tool, particularly if long waveguides (e.g., 0.5 m long) are inserted vertically in the soil profile to determine average changes in θ_v from the soil surface to the fragipan.

ACKNOWLEDGMENTS

We thank the Arkansas Rice Research and Promotion Board and the Soybean Promotion Board for financing the project. We also thank Mr. Darryl Schlenker for allowing us to work on his farm.

LITERATURE CITED

Allen, R.G., M.E. Jensen, J.L. Wright, and R.D. Burman. 1989. Operational estimates of reference evapotranspiration. Agron. J. 81:650-662.

Baker, J.M., and R.J. Lascano. 1989. The spatial sensitivity of time domain reflecto-

metry. Soil Sci. 147(5):378-384.
Baker, W.H., J.S. Yadon, S.D. Carroll, C.E. Wilson, S.L. Chapman, B. Teague, and C.E. Tacker. 1996. Extent of saltwater intrusion into ground water used for irrigating rice and soybeans in Arkansas. *In:* R.J. Norman and B.R. Wells (eds.) Rice Research Studies, 1995. University of Arkansas Agricultural Experiment Station Research Series 453:163-168.
Cahoon, J., J. Ferguson, D. Edwards, and P. Tacker, 1990. A microcomputer-based irrigation scheduler for the humid mid-south region. Applied Eng. Agric. 6(3):289-295.
Doorenbos, J. and W.O. Pruitt. 1977. Crop water requirements. FAO Irrigation and Drainage Paper No.24. Food and Agriculture Organization, Rome, 144 pp.
McCauley, G.N. 1990. Sprinkler vs. flood irrigation in traditional rice production regions of southeast Texas. Agron. J. 82:677-683.
Pennington, D.A., and R. Wolf. 1989. Potential for use of rainfall during permanent flood of rice in Mississippi. Bulletin 962, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, 10p.
Roel, A., J.L. Heilman, and G.N. McCauley. 1999. Water use and plant response in two rice irrigation methods. Agric. Water Manag. 39:35-46.
Scott, H.D., J.A. Ferguson, L. Hanson, T. Fugitt, and E. Smith. 1998. Agricultural water management in the Mississippi Delta Region of Arkansas. University of Arkansas Agricultural Experiment Station, Research Bulletin 959. 98 pp.
Shah, M.H., M.A. Bhatti, and J.R. Jensen. 1986. Crop coefficient over a rice field in the Central Plain of Thailand. Field Crops Res. 13:251-256.
Shih, S.F., G.S. Rahi, and D.S. Harrison. 1982. Evapotranspiration studies on rice in relation to water use efficiency. Trans. A.S.A.E. 26(5):702-707.
Shuttleworth, W.J. 1993. Evaporation. *In:* D.R. Maidment, ed. Handbook of Hydrology. McGraw-Hill, New York. pp. 4.1-4.53.
Tomar, V.S. and J.C. O'Toole. 1979. Evapotranspiration from rice fields. IRRI Research Paper Series No. 34, The International Rice Research Institute, Los Baños, Philippines, 15 p.
Wright, J.L. 1982. New evapotranspiration crop coefficients. J. Irrig. Drain. Div., Am. Soc. Civ. Eng. 108:57-74.
Yoshida, S. 1979. A simple evapotranspiration model of a paddy field in tropical Asia. Soil Sci. Plant Nutr.25(1):81-91.

Table 1. Total and average ET_c as estimated with several methods.

	K-P equation[z]		Cahoon method		Pan method		TDR method	
Statistics	Total[y]	Average	Total	Average	Total	Average	Total	Average
	(ET_c estimates in mm)							
Entire study[x]	631	4.1	694	4.5				
Rice season	620	4.4	678	4.8				
Flooded periods	437	5.6	502	6.4	733	9.1		
Non-flooded periods[w]	171	2.8	163	2.6			135	2.2

[z] Kimberly-Penman equation.

[y] 13, 10, 3, 10 days missing for entire study, rice season, flooded periods, and non-flooded periods, respectively (for K-P Equation and Cahoon method). 8 days missing for Pan method. 37 days missing for TDR method. To calculate total ET_c, the average ET_c of each period considered was multiplied by the total number of days in this period. Because the number of days missing was different whether the field was flooded or not, the sum of flooded and non-flooded periods does not necessarily corresponds to the total ET_c given for the rice season.

[x] 3 < DAE < 154.

[w] Non-flooded periods from emergence until harvest.

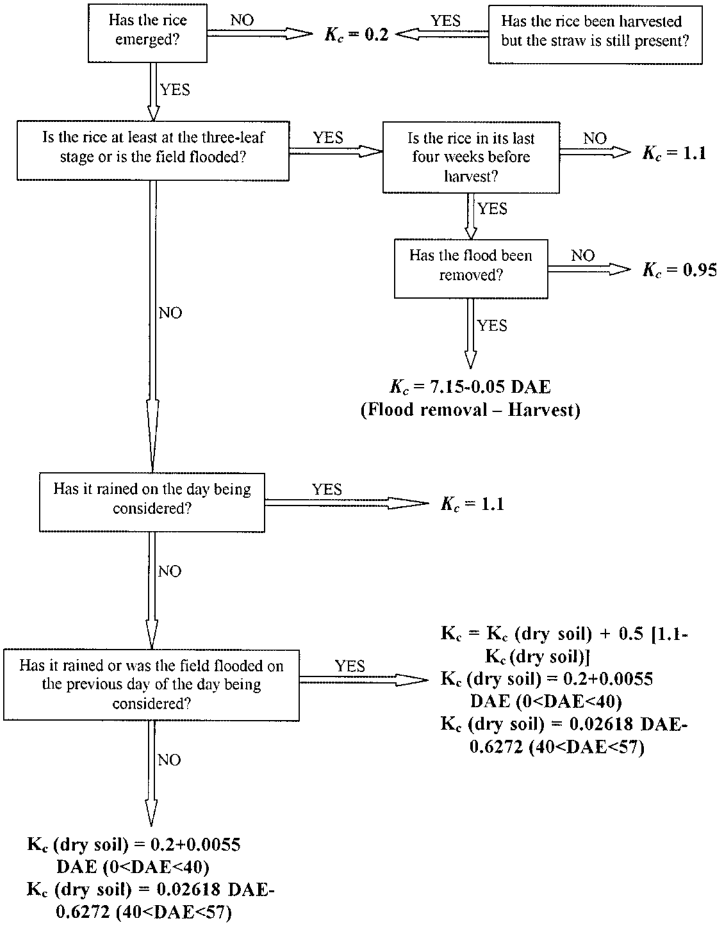


Fig. 1. Method used to estimate the crop coefficient (K_c). DAE = days after emergence.

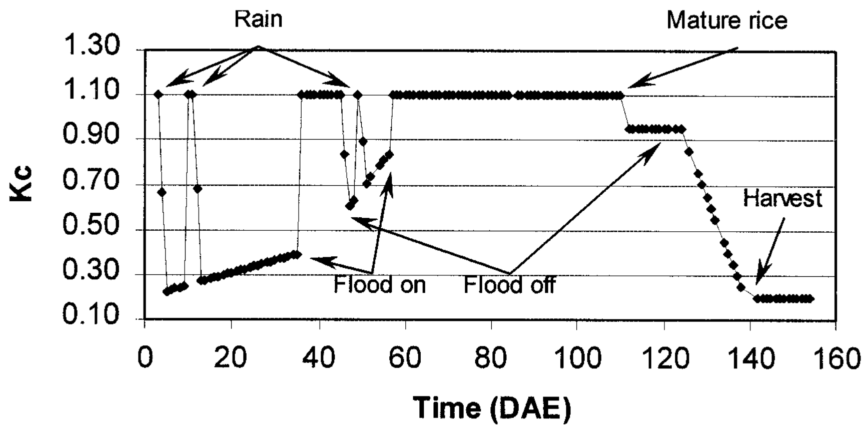


Fig. 2. Crop coefficient (K_c) values as a function of time. DAE = Days after emergence.

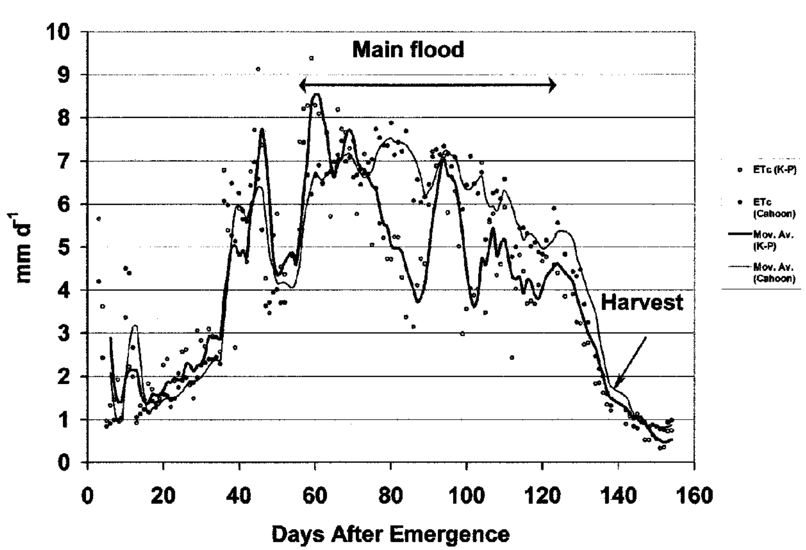


Fig. 3. *ET_c* estimated by the Kimberly-Penman equation and by the empirical method developed by Cahoon *et al.* (1990) as a function of days after emergence (DAE). The lines represent four-point moving averages.

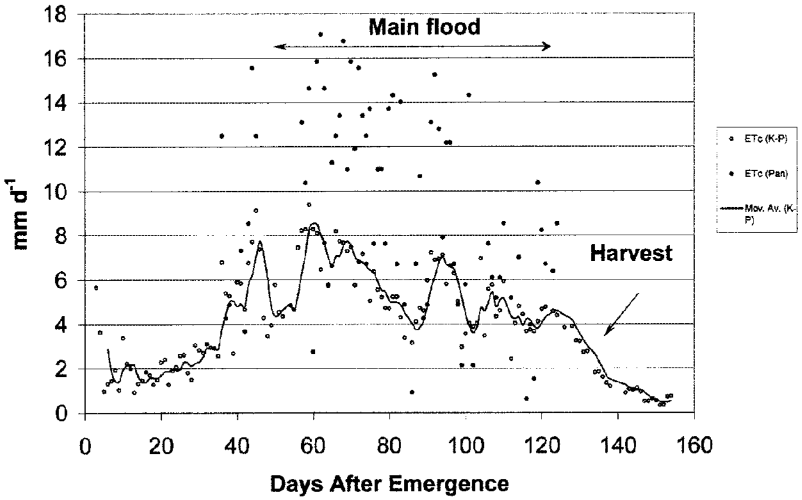


Fig. 4. ET_c estimated by the Kimberly-Penman equation and by the pan method as a function of days after emergence (DAE). The lines represent four-point moving averages for the Kimberly-Penman method.

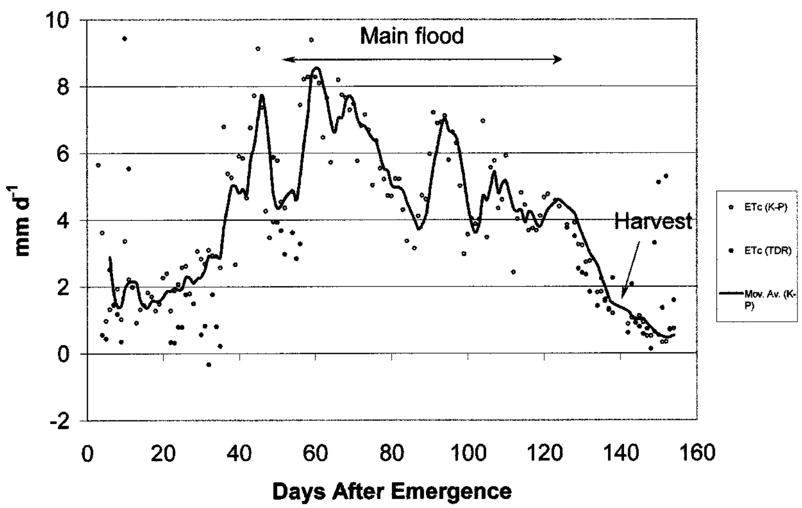


Fig. 5. ET_c estimated by the Kimberly-Penman equation and by the TDR method as a function of days after emergence (DAE). The lines represent four-point moving averages for the Kimberly-Penman method.

EFFECTS OF PREVIOUS CROP AND PHOSPHORUS FERTILIZATION RATE ON RICE

N.A. Slaton, S. Ntamatungiro, C.E. Wilson, Jr., R.J. Norman, and D.L. Boothe

ABSTRACT

The flooded soil conditions used for rice production are known to limit the availability of phosphorus (P) to upland crops following rice in rotation. Little information is available concerning how rotational crop P fertilization practices influence rice P nutrition. The primary objective of this study was to examine how previous crop and previous crop P fertilization rate influenced rice P nutrition and soil test P. A soybean-rice rotation and a continuous rice rotation were established on two silt loam soils that differed in soil pH. Phosphorus fertilizer rates of 0, 20, 40, 80, and 120 lb P_2O_5/acre were applied in three manners: (1) only the first year; (2) only the second year; or (3) during both years of the 2-year crop rotation cycle. Soil test P levels were lowest when soil samples were taken following rice in the rotation. Application of high P fertilizer rates failed to increase soil test P following rice. Increasing the P fertilizer rate applied to soybean also increased soil test P. Rice and soybean yields were not affected by P fertilization in either year. Total P uptake data suggest the residual availability of P fertilizer applied to previous crops grown on acid soils is very good.

INTRODUCTION

Rice (*Oryza sativa* L.) is commonly grown in rotation with soybean (*Glycine max* L.) throughout the southern United States rice-producing area. Precision agriculture (i.e., grid soil sampling) has increased grower awareness of soil fertility and fertilizer recommendations for all crops grown in rotation. Our current understanding of rice response to P fertilization is compromised by the inability of common soil test methods to accurately predict rice response to P fertilization (Wilson *et al.*, 1999).

The effect of previous crop and P fertilization of the previous crop on soil test P and current crop response to P fertilization have not been investigated for the rice-soybean rotation. Ntamatungiro *et al.* (1999) suggested that soil pH influences rice and soybean P nutrition differently. They also showed Mehlich 3 extractable P tended to be lower following rice in rotation compared to following soybean, regardless of initial soil test P, soil pH, or P fertilization rate. The flooded soil conditions used for rice production are known to limit the availability of P to upland crops following rice in rotation. Brandon and Mikkelsen (1979) reported P deficiency in rotation crops following rice despite adequate soil test P. Phosphorus deficiency in crops grown after rice eventually disappear with time. The availability of P fertilizer applied to previous crops in rotational systems including rice and/or soybean needs to be addressed. Therefore, the primary objective of this study was to examine how previous crop and previous crop P fertilization rate influences rice P nutrition and soil test P.

PROCEDURES

Phosphorus fertilizer and rotation studies were established at the Rice Research and Extension Center (RREC), located near Stuttgart, and at the Pine Tree Branch Experiment Station (PTBES), located near Colt, in 1998. The soil series at PTBES and RREC were a Calloway silt loam (fine-silty, mixed, thermic, Glossaquic Fragiudalfs) and DeWitt silt loam (fine, smectitic, thermic, Typic Albaqualfs), respectively. Selected soil chemical properties from each location are listed in Table 1.

Rice ('Drew') and soybean ('Hutcheson') were seeded at both locations in 1998 to establish the crop rotation for 1999. Phosphorus rates of 0, 20, 40, 80, and 120 lb P_2O_5/acre were applied to the soil surface prior to seeding in 1998 and after seeding in 1999 so that each P fertilizer rate was applied either in 1998 only, 1999 only, or during both years. In 1999, Drew rice was drill-seeded into the previous crop stubble (no-till) to complete the 2-year soybean-rice and continuous rice rotation. Rice was drill-seeded (7-in. row spacing) at a rate of 110 lb/acre in individual plots 20 ft in length and 10 ft wide. For all studies with rice, nitrogen (N) was applied as urea to the dry soil surface at the rate of 120 lb N/acre immediately before flooding at the five-leaf growth stage. In 1999, N fertilizer rates were not adjusted for previous crop. Preplant broadcast applications of zinc (Zn) (10 lb Zn/acre, 31% Zn-CoZinco $ZnSO_4$) and potassium fertilizer (100 lb 0-0-60) were made in 1998 and 1999, respectively.

Rice tissue (whole plant) samples were collected about 30 days after flooding by removing all of the above-ground plant tissue in a 3-ft row section of the second inside row. The time of plant sampling corresponded to the panicle initiation growth stage. Samples were dried at 60°C to a constant weight, weighed, and ground in a Wiley mill to pass a 2-mm sieve. Ground tissue (0.5 gram subsample) was digested with concentrated HNO_3 and 30% H_2O_2 for determination of whole plant elemental composition (Jones and Case, 1990). Elemental analysis of plant digests was performed by Inductively Coupled Argon Plasma Spectrophotometry (Soltanpour *et al.*, 1996). At maturity, 12 ft of the center four rows of each plot were harvested for grain yield with a small-plot combine. Reported grain yields were adjusted to 12% moisture.

Soil samples were taken from each individual plot immediately before fertilizer application in 1998 and again in February of 1999. Approximately 6 months elapsed between draining rice for harvest and collection of soil samples. Soil samples were analyzed for P and extractable cations by Mehlich 3 extraction (Mehlich, 1984). Soil pH was determined in a 1:2 soil water suspension with a glass electrode.

The 1999 (plant data) experimental design was a split-plot 3 (fertilizer application time, year) x 5 (P fertilizer rate) factorial design with four replications. The crop grown in 1998 was the main plot and the time and P fertilizer rate combinations were the subplots. The experimental design for soil test data was a split plot design with four replications. The crop grown in 1998 was the main plot and P fertilizer rate applied in 1998 was the subplot. All statistical analysis were analyzed by location. Mean separation was done by using the Fisher's Least significant Difference at the 0.05 level of probability.

RESULTS

Mehlich 3 Extractable P

The main plot and subplot effects of 1998 crop and P fertilizer rate significantly affected soil test P in the spring of 1999 at the PTBES (Table 2 and 3). Soil test P was greater following soybean in rotation. The initial soil test P values were different between crops at each location in 1998, but not within each plot area (Table 1). Because of the original differences in Mehlich 3 extractable P between areas where rice and soybean were seeded the difference between 1998 and 1999, soil test P was examined to obtain a better estimate of the 1998 crop effect on soil test P in 1999. Again, the 1998 crop and P fertilizer rate were significant (Tables 2 and 3). Mehlich 3 extractable P from February 1999 samples failed to increase when rice was grown in 1998, but increased following soybean (Table 2). Each incremental increase in P fertilizer rate applied in 1998 tended to increase the spring 1999 soil test P, regardless of the previous crop (Table 3).

At the RREC, a significant previous crop x P fertilizer rate interaction occurred for both soil test P and difference (Table 4). Soil test P did not increase with increasing P fertilizer rate following rice in rotation. Soil test P actually declined in samples taken in February 1999. Soil samples following soybean in rotation showed an incremental increase in soil test P as P fertilizer rate increased. The different soil test P results between locations and previous crops suggest that soil pH, oxygen status (aerobic/anaerobic), or other soil properties may influence both soil and fertilizer P availability. This data indicates that the continuous flooded culture of rice production affects soil test P differently than upland crops.

Neither rice nor soybean yields were significantly effected by P fertilization in 1998 at either location (Table 5 and 6). Rice yields averaged 139 and 103 bu/acre at the RREC and PTBES, respectively. Soybean yields at RREC were low as a result of poor stand establishment and hot, dry weather conditions. Phosphorus fertilizer rate did not significantly increase rice and soybean total dry matter (TDM) or tissue P concentration (Tables 5 to 7). Tissue P concentration tended to be lower for the high pH soil at PTBES. Application of 80 and 120 lb P_2O_5/acre at the RREC significantly increased total phosphorus uptake (TPU) compared to the control. Increasing the P fertilizer rate also showed a trend to increase TPU at PTBES suggesting that a dilution effect occurred for tissue P concentration. A dilution effect occurs when additional nutrient uptake does not increase nutrient concentration because of increased plant growth.

In 1999, rice yields were not significantly affected by P fertilizer rate applied in 1998 or 1999 at either location (data not shown). Previous crop had a significant affect on rice grain yield at both locations (data not shown). Rice grown following soybean produced 39 and 8% higher yields than rice grown following rice at the PTBES and RREC, respectively. Compared to continuous rice, rice following soybean also produced 27 and 14% more TDM at the panicle differentiation growth stage for the PTBES and RREC, respectively.

Time of P fertilization, regardless of year or rate of application, did not affect rice tissue P concentration at either location in 1999. Previous crop was the only variable that affected P concentration (Table 8). Tissue P was greater following rice in rotation on the acid soil at the RREC but higher following soybean on the alkaline soil at the PTBES. At the PTBES, TPU was also significantly greater following soybean in rotation. However, TPU at the RREC was not significantly affected by previous crop. Total P uptake at the RREC was effected by the interaction of P application rate and year of application (Table 9). In general, P fertilizer applied directly to soybean in 1998, rice in 1999 or to both crops each year increased rice TPU in 1999 compared to the control.

Recent changes in P fertilizer recommendations for rice grown on acid soils ($pH < 6.5$) have raised concern over "mining" the soil of P. The current P fertilizer recommendation for acid soils ($pH < 6.5$) with Mehlich 3 extractable $P \leq 30$ and > 30 lb/acre are 20 and 0 lb P_2O_5/acre, respectively. In comparison, 60- and 40-lb P_2O_5/acre are recommended for neutral-to-alkaline soils ($pH \geq 6.5$) with Mehlich 3 extractable $P \leq 30$ and 31 to 50 lb/acre, respectively. Crop removal of P for rice yielding 150 bu/acre is about 50 lb P_2O_5/acre (Slaton and Wilson, unpublished data). Thus, current P fertilizer recommendations result in a net deficit of 30- to 50-lb P_2O_5/acre on acid soils, but generally equal crop removal rate on neutral and alkaline soils.

Phosphorus fertilizer recommendations were reduced for acid soils because rice yield was either not increased or decreased with P fertilization (Wilson *et al.*, 1999). Our data from the RREC suggest that application of extra P fertilizer to the soybean crop to compensate for rice and soybean P removal may be feasible. Although soil test P was found to decrease on the acid soil at RREC, TPU increased from P fertilizer applied the previous year, suggesting that P fertilizer applied to acidic soils provides some residual P for the following rice crop (Table 9). The lack of a significant increase in TPU as P fertilization rate increased for the alkaline soil at PTBES is confusing. Rice tissue concentration of other nutrients (e.g., zinc and potassium) were sufficient for normal yield and rice growth (data not shown). Additional research is needed to increase our understanding of P nutrition on all soils used for rice production.

SIGNIFICANCE OF FINDINGS

Findings have provided valuable insight concerning the effect of P fertilization practices in a soybean-rice and continuos rice rotation. Although rice yield responses were not found in these studies, soil test P data collected in 1999 suggest that soil pH or another soil chemical property controls the amount of P extracted by the Mehlich 3 soil test method. Although our understanding of P availability in soils used for both rice and soybean production is still poor, these results suggest that application of extra P fertilizer to soybean grown in rotation with rice on acid soils may be appropriate, since P applied to soybean tended to increase TPU in the following rice crop.

LITERATURE CITED

Brandon, D.M., and D.S. Mikkelsen. 1979. Phosphorus transformations in alternately flooded soils: I. Cause of plant phosphorus deficiency in rotation crops and correctional methods. Soil Sci. Soc. Am. J. 43:989-994.

Jones, J.B. and V.W. Case. 1990. Sampling, handling, and analyzing plant tissue samples. pp. 389-428. *In:* R.L. Westerman (ed.). Soil testing and plant analysis. 3rd edition. SSSA Book Series 3. SSSA, Madison, WI.

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

Ntamatungiro, S., N.A. Slaton, C.E. Wilson, Jr., M. Daniels, J.R Robinson, L. Ashlock, and T. Windham. 1999. Effects of lime, phosphorus, and zinc application on rice and soybean production. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:268-276.

Soltanpour, P.N., G.W. Johnson, S.M. Workman, J. B. Jones, Jr., and R.O. Miller. 1996. Inductively coupled plasma emission spectrometry and inductively coupled plasma-mass-spectroscopy. pp. 91-140. *In:* D.L. Sparks (ed.). Methods of Soil Analysis. Part 3. SSSA Book Ser. 5. SSSA. Madison, WI.

Wilson, C.E., Jr., N.A. Slaton, S. Ntamatungiro, and R.J. Norman. 1999. Phosphorus fertilizer management for rice produced on alkaline soils. *In:* R.J. Norman and T.H. Johnston (eds.). B.R. Wells Rice Research Studies 1998. University of Arkansas Agricultural Experiment Station Research Series 468:310-316.

Table 1. Selected beginning soil test parameters from phosphorus rotation studies at the Rice Research and Extension Center (RREC) and the Pine Tree Branch Experiment Station (PTBES).

Soil Test[z] Parameter	Units	Soil Test Level			
		PTBES		RREC	
		Rice[y]	Soybean[y]	Rice	Soybean
pH	---	7.5	7.4	6.4	5.9
P	lb/acre	34	51	26	15
K	lb/acre	163	182	285	226
Ca	lb/acre	3734	3377	2401	2048
Mg	lb/acre	650	696	299	246
Zn	lb/acre	4.1	2.8	3.0	2.3

[z] Soil test extractant was Mechlich 3. Soil pH is water pH in a 1:2 (soil weight:water volume) ratio.

[y] Crop grown in the first year of the rotation.

Table 2. Effect of previous crop on 1999 soil test P and difference in soil test P between 1998 and 1999 at the Pine Tree Branch Experiment Station.

Previous Crop	Soil Test P	Difference in Soil Test P[z]
	------------- (lb Mehlich 3 P/acre)	-------------
Rice	33.7	-0.3
Soybean	80.1	29.0
LSD(0.05)	24.8	21.4
C.V. %	28.9	110.3
P-value	0.0095	0.02

[z] Difference calculated by subtracting original soil test P in 1998 (before P application) from spring 1999 soil test P.

Table 3. Effect of phosphorus fertilizer rate applied in 1998 on spring 1999 Mehlich 3 extractable P and difference between 1998 and 1999 Mehlich 3 extractable P at the Pine Tree Branch Experiment Station.

1998 P Fertilizer Rate	Soil Test P	Difference[z]
	------------ (lb Mehlich 3 P/acre)	------------
0	41.0	-1.2
20	48.4	5.9
40	53.8	10.8
80	62.4	20.2
120	79.0	36.0
LSD(0.05)	11.6	11.2
C.V.%	28.9	110.3
P-value	0.0001	0.001

[z] Difference calculated by subtracting original soil test P in 1998 (before P application) from spring 1999 soil test P.

Table 4. Effect of phosphorus (P) fertilizer rate applied to either soybean or rice crop in 1998 on soil test P in spring of 1999 at the Rice Research and Extension Center.

	Soil Test P		Difference[z]	
1998 P Rate	Rice Previous Crop	Soybean Previous Crop	Rice Previous Crop	Soybean Previous Crop
(lb P_2O_5/acre)	-------------------- (lb Mehlich 3 Extractable P/acre)		--------------------	
0	11.1	22.1	-12.2	6.8
20	11.0	28.4	-16.3	12.9
40	11.0	29.8	-13.6	13.5
80	13.4	42.0	-15.3	27.9
120	12.6	44.7	-13.2	30.1
LSD(0.05)	6.4		7.1	
C.V.%	34.3		451	
P-value	0.0015		0.0003	

[z] Difference calculated by subtracting original soil test P in 1998 (before P application) from spring 1999 soil test P.

Table 5. Influence of phosphorus (P) fertilizer rate on soybean yield and whole plant concentration in 1998 at the Rice Research and Extension Center (RREC) and the Pine Tree Branch Experiment Station (PTBES).

	Soybean Yield		Soybean Tissue P Concentration	
P Fertilizer Rate	PTBES	RREC	PTBES	RREC
(lb P_2O_5/acre)	-------- (bushels/acre) --------		----------- (mg P/kg) -----------	
0	38.3	27.2	0.278	0.176
20	39.4	31.9	0.254	0.192
40	40.8	24.8	0.265	0.179
80	40.2	25.4	0.269	0.214
120	40.7	24.9	0.252	0.198
LSD(0.05)	6.2	7.8	0.025	0.032
C.V.%	16.6	23.5	9.1	17.8
P-value	0.87	0.13	0.12	0.09

Table 6. Influence of phosphorus (P) fertilizer rate on rice grain yield and total dry matter (TDM) in 1998 at the Rice Research and Extension Center (RREC) and the Pine Tree Branch Experiment Station (PTBES).

	Rice Yield		Rice TDM	
P Fertilizer Rate	PTBES	RREC	PTBES	RREC
(lb P_2O_5/acre)	---------- (bushels/acre) ----------		---------- (lb/acre) ----------	
0	101.5	140.3	2925	2441
20	105.1	142.2	2979	2333
40	99.3	139.6	3376	2546
80	104.5	143.2	3181	2717
120	106.6	142.2	3487	2604
LSD(0.05)	NS	NS	456	290
C.V.%	9.7	7.0	14.6	13.4
P-value	0.92	0.92	0.05	0.11

Table 7. Influence of phosphorus (P) fertilizer rate on rice tissue P concentration at panicle differentiation and total P uptake (TPU) in 1998 at the Rice Research and Extension Center (RREC) and the Pine Tree Branch Experiment Station (PTBES).

	Rice Tissue P Concentration		Rice TPU	
P Fertilizer Rate	PTBES	RREC	PTBES	RREC
(lb P_2O_5/acre)	------------ (mg P/kg) ------------		------------ (lb/acre) ------------	
0	0.228	0.266	6.53	6.41
20	0.234	0.266	6.94	5.99
40	0.234	0.259	6.93	6.36
80	0.225	0.269	7.13	7.33
120	0.236	0.266	7.78	6.96
LSD(0.05)	NS	NS	NS	0.96
C.V.%	6.6	5.8	20.5	17.4
P-value	0.36	0.62	0.35	0.08

Table 8. Influence of previous crop rice tissue phosphorus (P) and total P uptake at panicle differentiation in 1999 at the Rice Research and Extension Center (RREC) and the Pine Tree Branch Experiment Station (PTBES).

	Rice Tissue P Concentration		Rice T PU	
Previous Crop	PTBES	RREC	PTBES	RREC
	------------ (mg P/kg) ------------		------------ (lb P/acre) ------------	
Rice	0.269	0.301	8.50	15.89
Soybean	0.308	0.279	12.34	16.81
LSD(0.05)	0.027	0.015	1.26	NS
C.V.%	8.8	6.8	18.6	19.8
P-value	0.036	0.015	0.004	0.58

Table 9. Influence of phosphorus (P) fertilizer time and rate of application on total P uptake at the Rice Research and Extension Center (RREC) during 1999.

P Fertilizer Rate (Year 1 - Year 2)	Rice TPU
(lb P_2O_5/acre)	(lb P/acre)
0-0	12.74
0-20	16.48
0-40	18.12
0-80	14.80
0-120	15.68
20-0	17.61
40-0	16.94
80-0	15.14
120-0	15.29
20-20	15.10
40-40	17.12
80-80	18.31
120-120	17.88
LSD(0.05)	2.56
C.V.%	19.9
P-value	0.018

ZINC SEED TREATMENTS FOR RICE

N.A. Slaton, C.E. Wilson, Jr., S. Ntamatungiro, R.J. Norman, and D.L. Boothe

ABSTRACT

Zinc (Zn) seed treatments for rice (*Oryza sativa* L.) were evaluated as an alternative to soil- or foliar-applied Zn by researchers in the early 1970s. Recommendations concerning the effectiveness of Zn-seed treatments, based on this research, were never clearly stated. Studies were initiated to evaluate the utility of Zn-seed treatments for supplying Zn to seedling rice grown on silt loam soils prone to Zn deficiency. Since tissue Zn concentration among cultivars did not differ in response to Zn treatments, a single cultivar, 'Drew', was used in 1999 studies at two locations. An untreated check and the standard soil-applied Zn recommendation were compared to seed treated with three rates of $ZnSO_4$ and a liquid 9% EDTA Zn chelate. Analysis showed net seed concentrations of 0.10, 0.22, and 0.47 lb $ZnSO_4$-Zn/cwt seed and 0.14, 0.28, and 0.57 lb EDTA-Zn/cwt seed. Severe Zn deficiency occurred at both locations. Measurements of total dry matter (TDM) production, tissue Zn concentration, and grain yield showed that Zn-treated seed performed equal to or better than soil-applied Zn in the presence of severe Zn deficiency. These data suggest that seed Zn concentrations between 0.22 to 0.57 lb Zn/cwt seed are an economical alternative to soil-applied Zn.

INTRODUCTION

Zinc seed treatments were evaluated in rice as an alternative to soil- or foliar-applied Zn by several researchers in the early 1970s with limited success (Haghighat and Thompson, 1982; Mengel *et al.*, 1976; Rush, 1972). Because of the limited amount of research, Zn-seed treatments for rice and recommendations concerning their effectiveness were never clearly stated. Despite the lack of formal recommendations, Zn-treated seed rice is available throughout the southern United States rice-growing area.

In Arkansas, Zn fertilizer recommendations for rice are currently based on soil pH and soil texture. Zinc is recommended for rice, regardless of soil test Zn levels, grown on silt and sandy loam soils having pH > 6.5. Sedberry *et al.* (1980) and Wells (1980) both found soil pH to be the best predictor of rice response to Zn fertilization during the early 1970s. However, much of this research was conducted before widespread use of Zn fertilizers. Since development of Zn fertilizer recommendations, the low native soil Zn concentrations have increased appreciably as a result of repeated broadcast applications of inorganic Zn sources to each rice crop. Subsequently, the frequency of both Zn deficiency symptoms and documented rice yield responses to Zn fertilization has declined (Slaton *et al.*, 1995; Thompson and Kasireddy, 1975). Until a critical soil test Zn level for Zn fertilizer recommendations is established, alternative methods of supplying Zn to the rice crop on high pH soils are being investigated. Since application of small amounts of Zn to rice seed would be more economical and convenient than either soil or foliar applications, studies were conducted to evaluate the effect of Zn seed treatments on dry matter production, tissue Zn concentration, and grain yield of rice.

PROCEDURES

In 1999, studies were conducted at the Rice Research & Extension Center (RREC), near Stuttgart (Latitude, 34.30 N), on a DeWitt silt loam (fine, smectitic, thermic, Typic Albaqualfs) and at the Pine Tree Branch Experiment Station (PTBES), near Colt (Latitude, 35.08 N), on a Calloway silt loam (fine-silty, mixed, thermic, Glossaquic Fragiudalfs). Selected soil chemical properties are listed in Table 1. Soil samples, collected before seeding, were analyzed for extractable cations (including Zn^{2+}) by Mehlich 3 extraction (Mehlich, 1984). Soil pH was determined in a 1:2 soil water suspension with a glass electrode. Experiments conducted in 1998 failed to show Zn deficiency symptoms, therefore 2000 lb lime ($CaCO_3$)/acre was applied at the RREC (Slaton *et al.*, 1999). Soil calcium and magnesium levels were higher at the PTBES location, and lime was not applied. Split applications of 138 lb P_2O_5/acre were made prior to seeding and again before establishment of the permanent flood at both locations to enhance the likelihood of Zn deficiency. Potassium fertilizer was broadcast across all treatments as needed according to soil analysis.

The cultivar Drew was seeded at the RREC and PTBES on 20 May and 22 April, respectively. Rice was seeded at a rate of 110 lb/acre in plots consisting of nine rows 15 ft long spaced 7 in. apart. Treatments included an untreated control, 10 lb Zn/acre (ZnSO4-31% Zn, CoZinco Sales. Inc., Denver, Colorado) applied to the soil and preplant incorporated (PPI) and six treatments having varying amounts of Zn applied to seed. Zinc was applied to seed at three different rates of either a $ZnSO_4$ solution or liquid 9% EDTA Zn. The $ZnSO_4$ solution was prepared by dissolving 400 g of reagentgrade $ZnSO_4 \cdot 7H_2O$ in 1 L H_2O. The seed was then treated by mixing 113.5 g seed with 7.5 ml of the $ZnSO_4$ solution. For the EDTA treatment, 113.5 g seed was mixed with a total volume of 100 ml of EDTA solution of which 100, 50, or 25 ml was 9% EDTA Zn.

To determine the amount of Zn coated on the seed, treated and untreated seed were digested with HNO_3 and 30% H_2O_2 (Jones and Case, 1990) and analyzed by Inductively Coupled Argon Plasma Spectrophotometry (ICAP) (Soltanpour *et al.*, 1996). Seed analysis showed net Zn coating content of 0.10, 0.22, and 0.47 lb $ZnSO_4$-Zn/cwt seed and 0.14, 0.28, and 0.57 lb EDTA-Zn/cwt seed. Therefore, approximately one-half of the added Zn was retained on the seed.

For all studies, 130 lb N/acre was applied as urea to the dry soil surface immediately before flooding at the four-leaf growth stage. Plant samples were collected 14 days after flooding by removal of the above-ground plant tissue in a 3-ft section of the second inside row. Tissue samples were immediately washed in deionized water, 0.1 M HCl, and rinsed in deionized water prior to drying to remove possible sources of contamination (Wells, 1980). Samples were dried at 60°C to a constant weight, weighed, and ground in a Wiley mill to pass a 2-mm sieve. Ground tissue (0.5-g subsample) was digested with concentrated HNO_3 and 30% H_2O_2 for determination of whole-plant elemental composition (Jones and Case, 1990). Elemental analysis of plant digests was performed by ICAP. At maturity, 28 ft^2 from the center four rows of each plot was harvested for grain yield with a small-plot combine. Reported grain yields were adjusted to 12% moisture.

During 1999, treatments at each location was arranged in a randomized complete block design with four replications. Each location was analyzed separately. All data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fisher's Protected Least Significant Difference at the 0.05 significance level.

To evaluate the effect of Zn seed treatment on seed viability, treated and untreated seed from 1999 field studies were placed in a germinating chamber at 68°F approximately 8 months after treatment. Seed was stored in paper envelopes at room temperature during this period. Fifty seeds from each treatment were placed in a petri dish, and 3 ml of deionized water was added to each dish. Each treatment was replicated three times. Germination of seeds were checked at 6, 8, and 10 d. A seed with a visible radicle and/or coleoptile was counted as germinated. Germination data are reported as the percentage of seed germinated. At the 10-day measurement, the emerged radicle and coleoptile of 10 randomly selected germinated seeds were measured from each treatment replicate.

Treatments were arranged as a randomized complete block design with three replications. All data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fisher's Protected Least Significant Difference at the 0.05 significance level.

RESULTS AND DISCUSSION

Zinc deficiency symptoms similar to those described by Sedberry *et al.* (1978) were observed at both locations in 1999. Symptoms were most severe in the control plots, while few or no symptoms were observed in the 0.47 lb Zn-$ZnSO_4$/cwt seed and 0.57 lb Zn-EDTA/cwt seed plots. Deficiency symptoms were most severe at the RREC. Thus, the response of rice TDM among Zn treatments differed between locations for some treatments (Table 2).

At the PTBES, all seed treated with Zn, except the 0.14-lb Zn-EDTA/cwt treatment, produced significantly greater TDM by 14 days after flooding than both the control and 10-lb Zn/acre PPI. It is unclear why Zn-deficiency symptoms occurred in the 10-lb Zn/acre PPI treatment. The random occurrence of deficiency symptoms within each 10-lb Zn/acre PPI plot suggests that uniform fertilizer distribution at the applied rate could not supply plants physically located between fertilizer granules with adequate Zn nutrition. Both the control and 10-lb Zn/acre PPI treatments recovered from the early Zn-deficiency symptoms within a couple of weeks after plant samples were taken. Within the Zn seed treatments, TDM tended to increase as Zn application rate increased (Table 2).

At the RREC, TDM for 10-lb Zn/acre PPI was significantly greater than the control and 0.14-lb EDTA-Zn/cwt seed and equal to all other treatments (Table 2). Stand loss occurred in two of four replications of the control plots at RREC. Based on TDM data from both locations, Zn seed treatments should be applied at rates between 0.25 and 0.58 lb Zn/cwt seed for optimum growth under Zn deficient conditions, with the higher rate being preferred.

Grain yield was significantly affected by Zn-fertilizer treatment (Table 2). Nearly all treatments with Zn-treated seed or the 10-lb Zn/acre PPI produced significantly higher yields than the control at the RREC. All Zn-seed treatments produced equal yields compared to the standard recommendation of 10 lb soil Zn/acre. Although the 0.14 Zn-$ZnSO_4$/cwt seed treatment tended to increase grain yield, it was not significantly greater than the control. At the PTBES, all Zn-treated seed, except the 0.22-lb Zn-$ZnSO_4$/cwt seed treatment, increased grain yield compared to the control. The standard 10-lb Zn/acre PPI failed to significantly increase grain yield but was equal to most Zn-treated seed yields. The 0.57-lb Zn-EDTA/cwt and 0.47-lb Zn-$ZnSO_4$/cwt seed treatments significantly increased grain yield compared to both the control and standard 10-lb Zn/acre PPI treatments, suggesting that in some cases Zn-treated seed may be better than broadcast Zn applications. When applied to the seed and assuming uniform application to the seed, Zn application is uniform across a field compared to broadcast Zn fertilizer applications where Zn fertilizer granules may be several feet apart. Although the amount (0.25 to 0.5 lb Zn/cwt) of Zn applied on the seed may seem insufficient, the straw and grain of a mature rice crop only contains about 0.5 lb Zn/acre. Thus, relatively low rates of Zn applied to the seed are capable of furnishing the entire Zn requirement for rice grain and straw production.

Rush (1972) found significant rice grain yield increases from Zn-seed treatments, but also observed that some Zn products and application rates were toxic and reduced stand density. Rasmussen and Boawn (1969) also noted a delay in germination, emergence, and reduced seedling vigor for kidney bean from some Zn seed treatments. Plant population measurements were not made in our field studies, but visual differences were not noticed among treatments. Germination data from seed used in these tests did suggest that Zn seed treatments could influence stand establishment (Table 3). Although germination among treatments by 6 days was not significant, the general order of germination established by 8 days was evident. By 8 days, germination of untreated seed was significantly lower than all Zn-coated seed treatments. By 10 days, germination of untreated seed and the 0.57 lb EDTA-Zn/cwt seed was lower than all other treatments which were not different. The decrease in germination of seed treated with EDTA-Zn was likely due to fungal growth. Fungal growth completely covered some EDTA-Zn treated seed by 10 days, thus hiding the radicle or coleoptile from view. The trend for percentage of germination to decline as EDTA-Zn rate increased was representative of the increased fungal growth. Despite good initial germination of seed treated with EDTA-Zn, the potential may exist for this product to reduce seedling vigor and should be further evaluated before used as a Zn seed treatment.

Radicle and coleoptile measurements were made only on germinated seed at 10 days (Table 3). Radicle length of untreated seed was greater than all treatments, except the 0.14-lb EDTA-Zn/cwt seed. Radicle length tended to decrease as Zn rate increased, suggesting that Zn may inhibit radicle elongation. Coleoptile length was different only for seed treated with EDTA-Zn. Seed treated with $ZnSO_4$-Zn, regardless of rate, and untreated seed had significantly longer coleoptiles than seed treated with all rates of EDTA-Zn. The coleoptile length of seed treated with EDTA-Zn also tended to decline as rate increased. More germination and seedling vigor tests are needed to evaluate the effect of Zn application rate, Zn source, temperature, and storage time on seed vigor and viability. These preliminary data illustrate the importance of thorough testing of new recommendations, especially when stand failure is a potential risk. Although stand establishment problems were not observed in 1999 field studies with any Zn seed treatment, environmental conditions in future years could favor development of seedling disease and stand loss. Growers and seed dealers are encouraged to use Zn seed treatments, but they should use only products that have been tested and deemed safe and effective.

SIGNIFICANCE OF FINDINGS

Grain yield, tissue Zn concentration (data not shown), and TDM data generated at two locations in 1999 support the use of Zn-treated seed as a safe, effective means of fertilizing rice grown on Zn-deficient soils. In general, grain yield was significantly improved by use of Zn seed treatment compared to the control and equal to the yield from the standard recommendation of 10 lb Zn/acre PPI. Application of relatively low rates of Zn to rice seed has potential for substantial cost savings to producers when compared with conventional broadcast soil or foliar Zn fertilization methods. Additional studies are needed to develop recommendations for the best application rate and Zn source, possible interactions with other seed treatment chemicals, and the detrimental effects that have been observed with Zn seed treatments for the vast number of Zn products that are available. Tentative guidelines for use of Zn-treated seed (as an alternative to soil or foliar applied Zn in high-pH silt and sandy loam fields) should consider both seed Zn application rate and soil test Zn (Mehlich 3 Zn) or field history of Zn fertilization. If a field has a history of continuous broadcast Zn fertilizer applications and the soil test Zn is above 10 lb/acre, then a seed application rate of 0.25 lb/cwt seed is likely adequate. However if the soil test Zn is low (< 10 lb Zn/acre) and the soil pH is high, Zn application rate to the seed should be about 0.38 to 0.50 lb Zn/cwt seed. Always use the higher rate of Zn seed treatment when severe Zn deficiency is anticipated. The product called "Zn Starter" (32.5 % Zn) is the most commonly used product. Until more products are tested in the field and germination chamber, growers and seed dealers should use this product to apply Zn to seed. Application of 8, 12, or 16 oz Zn starter/cwt seed theoretically provides approximately 0.25, 0.38, and 0.50 lb Zn/cwt seed, respectively.

LITERATURE CITED

Haghighat, N.G., and L.F. Thompson. 1982. Zinc seed coating studies with rice. pp. 74-75. *In:* Proceedings 19th Rice technical Working Group. Univ. of Arkansas. Hot Springs, AR.

Jones, J.B. and V.W. Case. 1990. Sampling, handling, and analyzing plant tissue samples. pp. 389-428. *In:* R.L. Westerman (ed.). Soil testing and plant analysis. 3rd edition. SSSA Book Series 3. SSSA, Madison, WI.

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

Mengel, D.B., W.J. Leonards, and J.E. Sedberry, Jr. 1976. Effect of zinc oxide seed treatment on stand establishment, leaf zinc concentrations, and yield of Saturn rice. p.62-63. *In:* 68th Annual Progress Report, Rice Exp. Stn. Crowley, Louisiana. Louisiana State Univ. Agric. Exp. Stn. Crowley, Louisiana. Louisiana State Univ, Baton Rouge.

Rasmussen, P.E. and L.C. Boawn. 1969. Zinc seed treatment as a source of zinc for beans. Agron. J. 61:674-676.

Rush, M.C. 1972. Effects of seed treatment with four zinc sources on stand and yield of Saturn rice. pp. 269-270. *In:* 64th Annual Progress Report Rice Experiment Station Crowley, Louisiana. Louisiana State Univ., Baton Rouge.

Sedberry, J.E., Jr., F.J. Peterson, F.E. Wilson, D.B. Mengel, P.E. Schilling, and R.H. Brupbacher. 1980. Influence of soil reaction and applications of zinc on yields and

zinc contents of rice plants. Commun. Soil Sci. Plant Anal. 11(3):283-295.
Sedberry, J.E., Jr., P.G. Schilling, F.E. Wilson, and F.J. Peterson. 1978. Diagnosis and correction of zinc problems in rice production. Louisiana. Agric. Exp. Stn. Bull. 708. Louisiana State Univ, Baton Rouge.
Slaton, N.A., S. Ntamatungiro, C.E. Wilson, Jr., and R.J. Norman. 1999. Evaluation of zinc seed treatments for 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 468:298-303.
Slaton, N.A., C.E. Wilson, Jr., B.R. Wells, R.J. Norman, and R.S. Helms. 1995. Evaluation of zinc deficiency of rice produced on alkaline soils. *In:* W.E. Sabbe (ed.). Arkansas Soil Fertility Studies 1994. University of Arkansas Agricultural Experiment Station Research Series 443:32-35.
Soltanpour, P.N., G.W. Johnson, S.M. Workman, J. B. Jones, Jr., and R.O. Miller. 1996. Inductively coupled plasma emission spectrometry and inductively coupled plasma-mass-spectroscopy. pp. 91-140. *In:* D.L. Sparks (ed.). Methods of Soil Analysis. Part 3. SSSA Book Ser. 5. SSSA. Madison, Wisconsin.
Thompson, L.F. and N.R. Kasireddy. 1975. Zinc fertilization of rice by seed coating. Rice J. 78(7):28-29.
Wells, B.R. 1980. Zinc nutrition of rice growing on Arkansas soils. University of Arkansas Agricultural Experiment Station Bulletin 848.

Table 1. Selected soil chemical properties 1999 fertility studies.

Factor[z]	RREC[y]	PTBES[x]
Soil pH[w]	6.6	6.8
P, lb/acre	30	26
K, lb/acre	226	146
Ca, lb/acre	2698	3832
Mg, lb/acre	258	684
Zn, lb/acre	1.8	2.6

[z] Values are the average of four composite samples taken from control plots in each replication. Mehlich 3 soil extractant used for elements.
[y] RREC, Rice Research and Extension Center, near Stuttgart, Arkansas.
[x] PTBES, Pine Tree Branch Experiment Station, Colt, Arkansas.
[w] Soil weight to water volume ratio was 1:2.

Table 2. Effect of Zn seed treatment source and rate on rice total dry matter at 14 d after flooding and grain yield compared to an untreated control and standard zinc fertilizer check at two locations in 1999.

	Total Dry Matter		Grain Yield	
Zn Fertilizer Treatment	PTBES	RREC	PTBES	RREC
	----------- (lb/acre) -----------		---------- (bu/acre) ----------	
Untreated control	589	337	130	114
Check: 10 lb Zn/acre PPI[z]	632	899	143	158
0.10 lb Zn-$ZnSO_4$/cwt seed	881	733	145	136
0.22 lb Zn-$ZnSO_4$/ cwt seed	940	943	142	146
0.47 lb Zn-$ZnSO_4$/cwt seed	1055	992	163	152
0.14 lb Zn-EDTA/cwt seed	758	502	147	148
0.28 lb Zn-EDTA/cwt seed	1065	853	158	151
0.57 lb Zn-EDTA/cwt seed	1024	1100	151	143
LSD(0.05)	246	302	15	24
C.V., %	19.3	25.8	6.7	11.6
P-value	0.0017	0.0004	0.01	0.04

[z] Standard check: 10 lb Zn/acre soil applied preplant incorporated, PPI.

Table 3. Effect of Zn seed treatment on rice seed germination, radicle length, and coleoptile length approximately 8 months after zinc application.

Zn Source	Germination 6 d	Germination 8 d	Germination 10 d	Radicle Length 10 d	Coleoptile Length 10 d
	(%)			(mm)	
Untreated control	45.3	55.3	62.0	19.6	11.9
0.10 lb Zn-$ZnSO_4$/cwt seed	66.7	88.0	92.7	14.4	9.9
0.22 lb Zn-$ZnSO_4$/ cwt seed	54.7	92.0	92.7	13.3	10.5
0.47 lb Zn-$ZnSO_4$/cwt seed	52.0	85.3	91.3	10.6	10.1
0.14 lb Zn-EDTA/cwt seed	47.3	82.0	90.0	9.4	6.6
0.28 lb Zn-EDTA/cwt seed	48.7	82.0	81.3	8.6	4.2
0.57 lb Zn-EDTA/cwt seed	52.0	72.7	61.3	4.4	2.5
LSD(0.05)	NS	13.6	17.4	6.0	3.1
C.V., %	22.0	9.6	12.0	29.4	22.0
P-value	0.40	0.002	0.003	0.036	0.0002

EVALUATION OF NEW VARIETIES TO STRAIGHTHEAD SUSCEPTIBILITY

N.A. Slaton, C.E. Wilson, Jr., S. Ntamatungiro, R.J. Norman, and D.L. Boothe

ABSTRACT

Straighthead affects only a small percentage of the Arkansas rice (*Oryza sativa* L.) acreage each year. However, a considerable acreage is drained and dried for straighthead prevention, especially in counties where rice is grown on silt and sandy loam soils. The objectives of this study were (1) to provide growers with updated information on the susceptibility of new varieties to straighthead and (2) to investigate the effect of delayed flooding as an alternative for straighthead prevention. Eight varieties, 'Bengal', 'Cocodrie', 'Cypress', 'Drew', 'Jefferson', 'Madison', 'Priscilla', and 'Wells', were seeded on 21 May 1999 at the Rice Research and Extension Center, near Stuttgart. Four water management schemes were used to evaluate susceptibility to straighthead including continuous flood at the five-leaf stage, drained and dried for straighthead prevention, 10-day delayed nitrogen (N) fertilizer and continuous flood, and 20-day delayed N fertilizer and continuous flood. Comparison of grain yields from the drain-and-dry to the continuous flood water treatments showed yield loss of 79, 94, 45, 42, 17, 43, 26, and 28% for Bengal, Cocodrie, Cypress, Drew, Jefferson, Madison, Priscilla, and Wells, respectively. Delaying N application and flooding by 10 or 20 days failed to prevent significant yield losses because straighthead affected highly susceptible varieties. These data should help growers in variety selection and/or water management for fields with a history of straighthead.

INTRODUCTION

Straighthead is a physiological disorder of rice that, when severe, can result in nearly total yield loss. Classic straighthead symptoms as described by Atkins (1974) are currently reported on a very low percentage of the Arkansas rice acreage. However, an estimated 10 to 20% of the acreage is drained for straighthead prevention. According to Collier (1912), approximately 20% of the U.S. rice acreage suffered significant yield losses from straighthead in the early 1900s. To date, the only two methods of straighthead control available include variety selection and removal of flood water at a critical growth stage (Atkins, 1974). Variety selection is considered the first and best method of prevention, since the effectiveness of draining the flood water and thoroughly drying the soil may fail as a result of untimely precipitation. Other preventative, conservation-minded management strategies for straighthead control are needed.

Helms *et al.* (1992) found significant benefits from delaying early N application and subsequent flooding for 14 days for five cultivars differing in straighthead susceptibility. Delaying flood establishment for 7 days was sufficient for moderately resistant cultivars. The 7-day delay improved yield of susceptible cultivars compared to the continuous flood, but significant yield losses occurred compared to the standard drain-and-dry treatment. The ability to delay flood would benefit many growers, since draining, drying, and reflooding fields increases labor and water requirements. Additional research is needed to verify the effectiveness and develop recommendations of delayed flooding for straighthead control.

The objectives of this study were to provide growers with updated information on the susceptibility of new varieties to straighthead and to investigate the effect of delayed flooding as an alternative for straighthead prevention management.

PROCEDURES

Eight varieties, Bengal, Cocodrie, Cypress, Drew, Jefferson, Madison, Priscilla, and Wells were drill-seeded on 17 May 1999 at the Rice Research and Extension Center. The herbicide MSMA was applied at a rate of 6 lb ai/acre on 14 May and immediately incorporated to induce straighthead. All varieties were subjected to four different water management regimes, including continuous flood, drain, and dry; 10-day delay flood; and 20-day delay flood. Rice cultivars were drill-seeded at a rate of 110 lb/acre in nine-row plots (7-in. row spacing), 15 ft in length. The drain-and-dry and continuous flood treatments were both flooded at the five-leaf growth stage on 11 June. The delayed flood treatments were flooded either 10 or 20 days later. All plots received 130 lb N/acre of urea applied in a single application immediately before flooding. The flood was removed from the drain-and-dry treatment 7 days after flooding and reflooded on 28 June. Five stems from each Wells and Cocodrie replicate were collected on 6 July, split, and measured for internode elongation to determine how water management influenced maturity. Internode length is reported as the total distance (millimeters) for all internodes that had moved. Visual numerical ratings for straighthead severity were made for each plot prior to harvest as described by Helms *et al.* (1992). At maturity, three interior rows (12 ft in length) were harvested with a small-plot combine equipped with an air flow system, grain weight and moisture were measured, and all yields were adjusted to 12% moisture content.

The experimental design was a split-plot with four replications. The main plot was water management method, and the subplot was cultivar. Data were analyzed with the PROC GLM procedure of SAS. Differences among treatments were identified using Fisher's Protected Least Significant Difference Test at the 0.05 significance level.

RESULTS

Results from this study suggest that delay of the early flood is not a viable alternative to the standard recommendation of draining and drying for highly susceptible varieties like Cocodrie and Bengal (Table 1 and 2). Although yield increases were found for very susceptible varieties, they were unacceptable for profitable rice production. Delay of the flood also delayed internode movement (Table 3) and eventually heading. It remains possible that a different early-water and N management strategy may be suitable for straighthead prevention. Yield data from this and other previous studies suggest that straighthead studies should include drain-and-dry and/or continuous flood treatments with no MSMA application, since yields in the drain-and-dry treatment are low for some varieties that normally have excellent yield potential. The susceptibility of some varieties may be underestimated without these treatments. Data from Gravois and Helms (1996) also show that yield of some varieties is below average in drain-and-dry plots.

Comparison of the drain-and-dry and continuous flood water regimes suggest that Jefferson, Priscilla, and Wells are moderately tolerant to straighthead (15 to 30% yield loss); Cypress, Drew, and Madison are susceptible (30 to 50% yield loss); and Bengal and Cocodrie are very susceptible suffering more than 75% yield loss (Table 1).

Straighthead is often associated solely with kernel distortion termed "parrot beaking." However, distorted kernels are only noted on moderately severe cases of straighthead. A significant amount of erect panicles from blanking and yield loss may be present without kernel distortion. An additional symptom of straighthead was noted in several grower fields and confirmed in plots of these studies. Near maturity, new tillers are often observed emerging from the base of plants with straighthead. In 1999, new tillers also emerged from nodes higher on the plant. These symptoms are easily confused with Roundup drift, which is an increasing problem because Roundup Ready soybeans are often seeded in fields adjacent to rice fields.

Our current knowledge concerning the factors that increase the likelihood of straighthead is vague. Information concerning relationships between straighthead, plant nutrition, and soil fertility are nearly nonexistent. It is recommended that future studies attempt to identify plant and soil nutritional factors that may potentially be effective in preventing or reducing damage from straighthead and continue periodically evaluating new varieties for susceptibility.

SIGNIFICANCE OF FINDINGS

Data concerning straighthead susceptibility of new varieties like Cocodrie, Priscilla, and Wells should be beneficial to rice growers who intend to grow these varieties. Results show that Cocodrie is highly susceptible and may be devastated by straighthead, even where preventive water management practices are used. Priscilla and Wells are more tolerant to this disorder, but may also suffer significant yield losses. Jefferson was found to have good tolerance to straighthead. Study results have been incorporated into the most recent varietal disease ratings available to the growers.

ACKNOWLEDGMENT

Research was partially funded by rice grower checkoff contributions administered by the Arkansas Rice Research and Promotion Board.

LITERATURE CITED

Atkins, J.G. 1974. Rice diseases of the Americas. USDA Agric. Handb. 448. p.58-63.

Collier, J.S. 1912. Rice blight. Illinois Agricultural Experiment Station Cir. 156. Urbana, IL.

Gravois, K.A. and R.S. Helms. 1996. Quantifying yield and milling losses in rice due to straighthead. *In:* R.J. Norman and B.R. Wells (eds.). Arkansas Rice Research Studies 1995. University of Arkansas Agricultural Experiment Station Research Series 453:133-138.

Helms, R.S, R.H. Dilday, R.J. Norman, and B.R. Wells. 1992. Management strategies for control of straighthead. *In:* B.R. Wells (ed.). Arkansas Rice Research Studies 1991. University of Arkansas Agricultural Experiment Station Research Series 422:101-103.

Table 1. Grain yield of eight rice varieties as affected by water management regime for a straighthead evaluation study conducted at the Rice Research and Extension Center during 1999.

Variety	Grain Yield				Yield Loss[z]
	Continuous Flood	Drain & Dry	10 d Delay Flood	20 d Delay Flood	
	(bu/acre)				(%)
Bengal	24	113	72	88	79
Cocodrie	7	120	27	37	94
Cypress	68	124	131	125	45
Drew	80	137	105	128	42
Jefferson	113	136	132	120	17
Madison	69	122	90	99	43
Priscilla	111	149	146	108	26
Wells	113	157	124	148	28
LSD(0.05)	(within variety or among water management) = 58				--
LSD(0.05)	(within water management or among varieties) = 33				--

[z] Yield loss for each variety calculated by the following equation: [(Drain and Dry Yield - Continuous Flood Yield) / Drain and Dry Yield] × 100.

Table 2. Numerical straighthead ratings of eight rice varieties as affected by water management regime for a straighthead evaluation study conducted at the Rice Research and Extension Center during 1999.

Variety	Numerical Rating[z]			
	Continuous Flood	Drain & Dry	10 d Delay Flood	20 d Delay Flood
Bengal	7.5	4.0	5.8	5.5
Cocodrie	7.8	2.8	7.0	7.0
Cypress	4.5	1.3	1.8	1.8
Drew	4.5	1.0	2.0	1.5
Jefferson	2.8	1.3	1.5	2.0
Madison	5.5	1.8	2.8	2.5
Priscilla	3.8	1..5	3.0	3.3
Wells	4.5	1.8	3.0	3.3
LSD(0.05)	(within variety or among water management) = 2.7			--
LSD(0.05)	(within water management or among varieties) = 1.3			--

[z] Numerical rating: 1.0 = no visible straighthead; 9 = severe straighthead.

Table 3. Influence of water management on internode length of Cocodrie and Wells from straighthead evaluation studies conducted at the Rice Research and Extension Center during 1999.

Variety	Internode Length[z]			
	Continuous Flood	Drain & Dry	10 d Delay Flood	20 d Delay Flood
Cocodrie	34.0	32.5	15.2	8.4
Wells	11.7	9.2	3.8	3.3

[z] Internode length is the total distance of all internodes that had moved.

CHARACTERIZATION OF INDIVIDUAL RICE KERNEL MOISTURE CONTENT AND SIZE DISTRIBUTIONS AT HARVEST AND DURING DRYING

R.C. Bautista, T.J. Siebenmorgen, and P.A. Counce

ABSTRACT

Moisture content (MC) and size distributions of individual kernels in a panicle were measured from three rice varieties ('Bengal', 'Cypress', and 'Drew') harvested at two locations (Rice Research and Extension Center, Stuttgart, and Northeast Research and Extension Center, Keiser) during the fall of 1999 to obtain fundamental information for optimizing postharvest processes, specifically for drying and milling. Individual kernel MC distributions in a panicle were multi-modal, especially at high harvest MC (HMC), and were skewed at lower HMC. The standard deviation of kernels from a panicle decreased with decreasing MC. Individual kernel size for rough and brown rice were normally distributed and different for the three varieties tested. Kernel size distributions at various harvest MCs and during drying are discussed, as is the corresponding shrinkage in kernel size caused by drying.

INTRODUCTION

This study reports the continuation of 1998 studies on individual kernel MC and dimensional size characteristics of three U.S.-grown rice varieties. Data were gathered for the same cultivars of rice during the fall of 1999 in augmenting the results of the previous year's studies.

Physicochemical properties inherent to a rice kernel should be understood to obtain the maximum potential yield in milling. Variability in physicochemical properties, however, presents difficulties in enhancing and preserving the inherent quality of rice. Moisture content and size distribution of individual kernels from a panicle of rice vary greatly and influence processing and handling operations. Some of the inherent properties are indirectly affected by climate and cultural practices during growth. For example, fissure formation or occurrence in rice kernels affects milling quality. Studies have shown that fissure variation is affected by rice kernel size and moisture transfer during drying. To minimize or prevent losses due to fissures, application of proper air conditioning during drying or storage should be optimized. A fundamental description of the material changes during moisture transfer is needed to accurately predict stress development. Individual kernel MC and size distribution studies of different rice varieties are needed to generate this information, useful in understanding which kernels fissure and break during drying and milling.

PROCEDURES

Panicles of three rice cultivars, Bengal, Cypress, and Drew, were collected from foundation seed fields at the research and extension centers at Keiser and Stuttgart at different HMCs that ranged from about 12 to 26% during the fall of 1999. Samples representing every two percentage points in MC were collected by hand. For each harvest, 10 panicles were picked for individual kernel MC and dimensional size measurements. Immediately after harvest, the panicles were stripped by hand and kernels cleaned to remove chaff. Individual kernel MC distributions were measured using a single-kernel MC meter, Shizuoka Seiki CTR 800A. For kernel dimensional measurements, sets of rough and brown rice samples were prepared consisting of five panicles each. Brown rice samples were prepared by manually removing the hulls with a tweezer. Individual kernel sizes were measured using a Satake Image Analysis System that measures the length, width, and thickness of individual kernels. Subsequent dimensional measurements at approximately every two percentage points drop in MC were also done for each sample while the kernels were drying inside the laboratory until the moisture content reached about 12%.

RESULTS AND DISCUSSION

Individual Kernel MC Distributions From Panicles at Harvest

Fig. 1 shows the individual kernel MC distributions at various HMCs for Cypress, which were also typical for Bengal and Drew. At harvest, the individual kernel MC distributions in a panicle were multi-modal, especially at high HMCs. As the average MC decreased, the distributions became single-modal but were skewed to the high MC end of the scale. These results agree with the results of Kocher *et al.* (1990). According to Holloway *et al.* (1995), the multi-modal distributions were caused by the individual kernel MC plateaus observed during peak development of the kernel endosperm. At a given time, a greater number of kernels would exist at plateau MCs than at other MC levels. The individual kernel MC distributions also indicated that the average MC does not reflect the MC of the majority of the kernels. The gradual decrease in average MC does not necessarily indicate the rapidly increasing proportion of kernels with low MCs. The standard deviation (STD) in individual kernel distributions between replications was not significantly different but the average STDs between mean HMCs were significantly different. This finding can be explained by the increasing variation in kernel MC from a panicle at higher HMC versus samples harvested at lower HMC. Between panicles at a given harvest MC, the MC distribution resembles a similar pattern.

Kernels Above 22% and Below 14% and Fissured Kernels

Critical moisture content (CMC) is the MC level below which a kernel is susceptible to fissure damage from moisture absorption. Mixing of wet (>22%) and dry (<14%) kernels could cause fissuring damage on dry kernels (Bautista and Siebenmorgen, 1999; Siebenmorgen *et al.*, 1990). The percentage of kernels with MCs above 22% and lower than 14% for the three rice cultivars at various HMC are shown in Fig. 2. For rice (var. Cypress) harvested at Keiser and Stuttgart, a significant number of kernels were below 14% and higher than 22%. A similar trend was obtained for Bengal and Drew. As expected, there was an increase in number of kernels from a panicle below 14% with a decrease in HMC. The percentage of kernels above 22% also increased with an increase in HMC. Presence of low- and high-MC kernels in a bulk of rice in a bin is important to processors because mixing of high- and low-MC kernels during harvest would create a condition that would permit intrakernel moisture migration. Low-moisture kernels (14% or below) are critical because rewetting (in this case, absorption of moisture from high-moisture kernels, ≥ 22%MC) would result in fissuring of kernels.

Kernel Dimensional Size Distributions

Individual kernel size distributions—length, thickness and width—for brown rice (var. Cypress) are shown in Fig. 3. They were not normally distributed, and they varied according to different HMC levels. The standard deviation was significantly different between HMCs and decreased as HMC declined. This can be due to kernel shrinkage as the kernel matures and approaches an equilibrium MC. The average kernel thickness for Cypress and Drew were similar and lower than for Bengal. Bengal was also thicker than Cypress and Drew. Drew was longer than Cypress, and Cypress was longer than Bengal. Table 1 shows the mean dimensional sizes of the three varieties tested for brown rice.

Size fractions of individual kernels in a panicle varied according to HMC. The difference in size was very evident between 26.3 and 17.5% HMC for Bengal. There was minimal change in size fractions between 17.5 and 15.1%HMC. The change in size fractions can be exponential in form as the kernel approaches its equilibrium MC. A similar pattern was observed for Cypress and Drew. Individual kernel size distributions showed similar change patterns as observed in kernels drying in the shade. Samples harvested at different HMCs exhibited similar size at the end of drying (Fig. 4).

SIGNIFICANCE OF FINDINGS

This study provides fundamental information on the physical properties of individual rice kernels at harvest and during drying, which is important in our program's effort to maximize head rice quality. The MC distributions at harvest were not statistically normal but rather multi-modal, especially at high HMCs, and were skewed to the right at lower HMCs. The STDs for all varieties studied decreased with a decrease in HMC. Kernel size dimensional distributions were different for all varieties studied and were not statistically normal. Size variation was higher at high HMCs. At the end of drying, samples harvested at different HMC levels approached similar size distributions. The results present a significant impact in rice processing, particularly in increasing drying efficiency and maintaining or improving the quality of milled rice. These results are being utilized as basic information in predicting kernel MC and temperature distributions in our program's simulation studies to minimize fissure occurrence using mathematical modeling during drying. Consequently, drying operations can then be optimized and dryer designs improved for more efficient operations. Grading and milling equipment will also need such information in processing different kernel types as to medium- or long-grain.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the University of Arkansas Rice Processing Program Industry Alliance Sponsors, The Rice Dryer and Warehousemen Association of Arkansas, and the Institute of Food Science and Engineering.

LITERATURE CITED

Bautista, R.C., and T.J. Siebenmorgen. 1999. Characterization of rice individual kernel moisture content and size distributions at harvest and during drying. ASAE Paper No. 996053. ASAE International Mtg., Toronto, Canada.

Holloway, G.E., T.J. Siebenmorgen, P.A. Counce, and R. Lu. 1995. Causes of multi modal moisture content frequency distributions among rice kernels. Applied Eng. Ag. 11:561-565.

Kocher, M.F., T.J. Siebenmorgen, R.J. Norman, and B.R. Wells. 1990. Rice kernel moisture content variation at harvest. Transactions of the ASAE 33:541-548.

Siebenmorgen, T.J., M.M. Banaszek, and M.F. Kocher. 1990. Kernel moisture content variation in equilibrated rice samples. Trans. of ASAE 33(6):1979-1983.

Table 1. Individual brown rice kernel dimensional size mean, minimum, maximum, and corresponding standard deviations (STDs) at different harvest moisture contents (HMCs).

	Length				Width				Thickness			
Cultivar/HMC	Mean	Min	Max	STD	Mean	Min	Max	STD	Mean	Min	Max	Std
(%)	(mm)											
Bengal												
24.3	6.8	6.1	7.5	0.24	2.7	2.4	3.1	0.12	2.1	1.8	2.7	0.11
22.9	6.6	5.9	7.1	0.21	2.7	2.4	2.9	0.10	2.0	1.7	2.4	0.10
17.5	6.4	5.7	6.8	0.23	2.6	2.3	2.8	0.10	1.9	1.6	2.1	0.09
14.7	6.2	5.2	6.7	0.24	2.5	2.2	2.9	0.12	1.8	1.5	2.0	0.09
Cypress												
24.3	7.3	6.4	8.7	0.35	2.2	1.8	2.6	0.11	1.8	1.6	2.3	0.11
22.6	7.4	6.1	8.2	0.49	2.2	1.8	3.5	0.19	1.8	1.5	2.3	0.11
20.5	7.3	6.3	8.8	0.37	2.2	1.7	3.1	0.19	1.8	1.6	2.0	0.08
18.9	7.3	6.1	8.2	0.38	2.1	1.8	2.4	0.09	1.8	1.5	2.3	0.12
14.2	7.2	6.2	8.9	0.35	2.1	1.8	3.2	0.14	1.7	1.5	2.0	0.09
Drew												
22.6	7.6	6.6	8.3	0.31	2.2	1.8	4.2	0.26	1.7	1.4	2.0	0.10
20.0	7.6	6.7	8.4	0.30	2.1	1.7	3.3	0.19	1.8	1.5	2.2	0.09
17.3	7.5	6.5	8.2	0.31	2.1	1.7	2.3	0.10	1.7	1.5	2.2	0.09
14.8	7.4	6.3	8.0	0.32	2.1	1.7	2.3	0.11	1.6	1.4	1.9	0.08

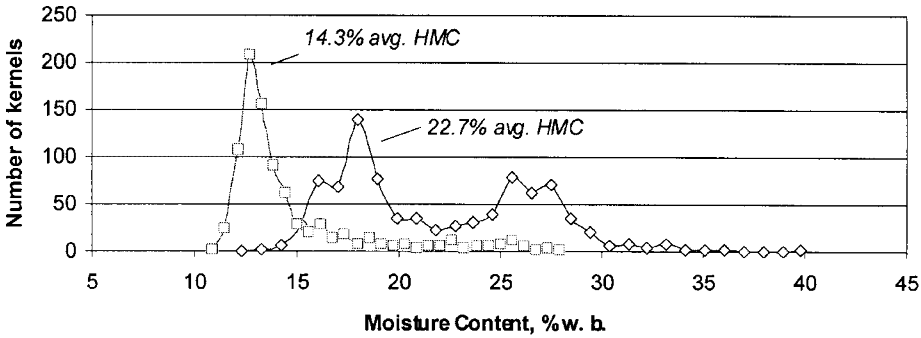


Fig. 1. Individual kernel MC distributions in a panicle of rice harvested at various HMCs (Stuttgart, 1999).

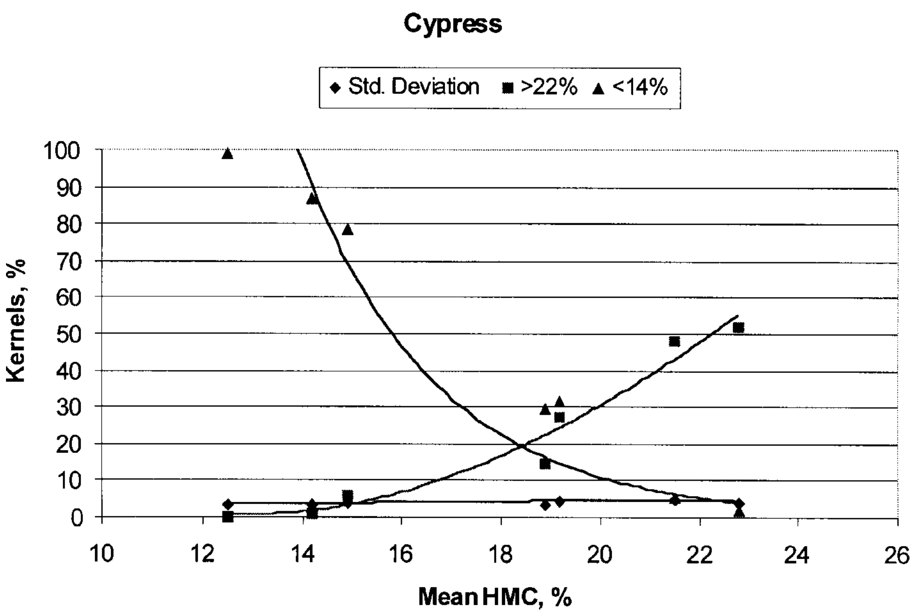


Fig. 2. Percentage of individual kernels with MC >22% and individual kernels with MC <14% in a panicle and standard deviation at various HMCs.

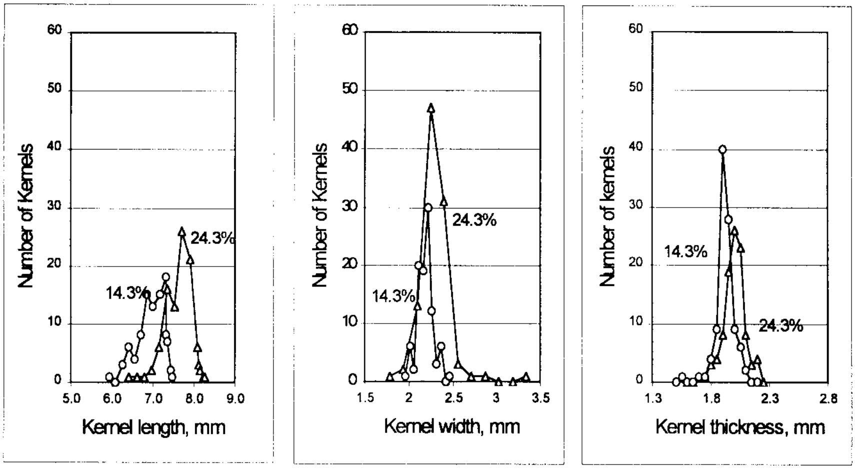


Fig. 3. Dimensional size distributions of individual kernels of rice (var. Cypress) from a panicle at various HMC levels (brown rice, Stuttgart).

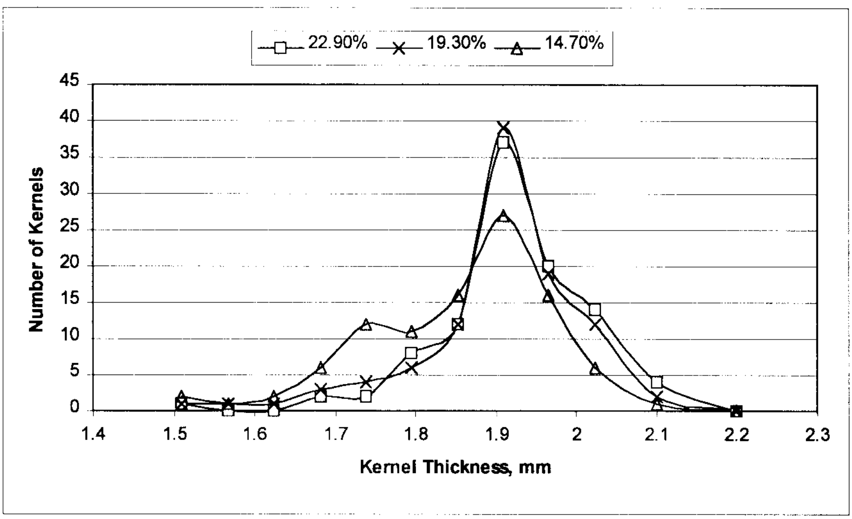


Fig. 4. Individual kernel thickness distributions at 12% MC from panicles of rice harvested at various HMC levels (var. Bengal, Stuttgart).

FISSURE FORMATION CHARACTERIZATION IN RICE KERNELS DURING DRYING USING VIDEO MICROSCOPY

R.C. Bautista, T.J. Siebenmorgen, and J.W. Fendley

ABSTRACT

Fissure formation in rice kernels was characterized for three rice varieties, 'Bengal', 'Cypress', and 'Drew', using a video microscopy system. Rice kernels were exposed to various air drying treatments to simulate drying with and without tempering. Fissures originated from the internal part of the kernel and increased in magnitude with time. Most fissures formed and appeared as a fine line perpendicular to the long axis of the kernel. Kernels sustained multiple fissures at air temperatures greater than 45°C. They occurred after drying and in succession with more than an hour of interval between occurrences. It was speculated that moisture gradient in various sections of the kernel undergoes state transition from rubbery to glassy after drying has stopped. According to variety, Drew was most susceptible to air drying temperature, followed by Bengal; Cypress was most resistant. Tempering at 45°C in 2 hr after drying reduced fissure occurrence by 34 to 62%.

INTRODUCTION

Fissure formation in a rice kernel affects milling, cooking, and puffing performance. Fissuring in a rice kernel during drying is a complex process influenced interactively by heat and moisture transfer, kernel properties, and drying treatments (Liu *et al.*, 1997). The more popular theory in fissure formation is the one caused by moisture gradient during drying. This theory explains that moisture gradient is created by the difference in moisture loss between the inner and outer layer of the kernel (Sarker *et al.*, 1996). Moisture loss is affected by the ability of drying air to transfer moisture from the kernel to the atmosphere. The faster the removal of moisture, the greater is the moisture gradient created, because the moisture removal rate is higher at the kernel surface (Bautista, 1998). Moisture gradient differences within the rice kernel produce stress that can cause the kernel to fissure when it exceeds the tensile strength of the rice. Our recent research, involving measurements of polymer state transitions in rice kernels and studies of quality changes during rice drying, has led us to a hypothesis explaining the occurrence of fissure development. The hypothesis (termed as the glass transition or T_g hypothesis) attributes the formation of fissures to differential stress inside a kernel produced when the kernel, or various sections of the kernel undergo state transition from a rubbery to glassy state. The presence of a moisture content gradient, such as would be created during drying, would cause different sections of the kernel to undergo state transition when subjected to a rapid temperature change (Perdon and Siebenmorgen, 1999). Certainly, fissuring according to this hypothesis can occur during drying and tempering. In light of this hypothesis, there is a need to understand fissure initiation in a rice kernel during drying. The objectives of this study were to characterize the dynamic behavior of fissure formation and validate the T_g hypothesis using a video microscopy system in drying. The video microscopy system magnifies the kernel image 50 times and allows visual monitoring of the kernel under investigation continuously at prolonged periods using a time-lapse video recorder. Development of fissures and changes in size dimensions can be tracked during investigation.

PROCEDURES

A video microscopy system was procured and assembled in the rice-processing laboratory in October 1999. Fig. 1 shows the schematic diagram of the system. The system consists of a 0.5-in. CCD camera with a 50X magnification lens, luminance controller, image processor, a high resolution monitor, and a video recorder and photo printer. A drying chamber was fabricated, and an air duct was coupled to an air refrigerating system by means of an air duct. Samples of medium-grain rice (var. Bengal) and long-grain rice (vars. Cypress and Drew) were collected at about 18% moisture content (MC) from the research and extension centers at Keiser and Stuttgart during the fall of 1999. Samples were cleaned and sealed in containers and stored in a walk-in cooler. From the lot samples, selected kernels free of fissures were dehulled to produce brown rice. Single kernels of brown rice with about 18% MC were mounted under the microscope lens inside the drying chamber and exposed to different drying treatments. Images of each kernel under investigation were captured continuously and recorded in video cassette tapes for 24 hr. The timing and magnitude as well as intensity of fissure propagation were determined later by reviewing the tapes. Simultaneous with the monitoring of a single kernel under the microscope, control samples consisting of 100 brown rice kernels were arranged in a single kernel layer on a mesh wire tray. Fissured kernels were counted immediately after exposure to heated air and 24 hr after exposure. Two drying treatments were performed, with tempering and without tempering. Drying air conditions were set at 20% RH and temperatures at 40, 45, 50, 55, and 60°C. The kernels were exposed to these conditions until the MC reached about 12%. When the kernels reached this MC, the drying chamber was opened and ambient air allowed to enter the chamber; this situation simulated a nontempering treatment. With tempering, the drying air condition of the dryer was reset to 45°C for 2 hr, and the chamber was opened afterwards.

RESULTS AND DISCUSSION

Fissure Initiation

Fissures originated from the inner portion of the kernels. The occurrence was rapid and formed a fine line perpendicular to the long axis of the kernel. Fissures occurred hours after exposure to heated air, when the kernel had cooled and equilibrated with the ambient air. Most fissures started to develop at about 2 hr or longer after the heated air was shut off. Multiple fissures occurred in succession, not simultaneous, with more than a 1-hr interval between fissure occurrence. Some fissures appeared 9 hr after the dryer was shut off. There were some fissures that formed along the long axis of the kernel usually connecting two parallel fissures along the dorsoventral section. In a rapid drying treatment (60°C and 20%RH), multiple fissures formed that appeared crooked, resembling a tortoise-shell formation.

Fissures did not occur during drying, primarily because the kernel endosperm was still in the rubbery or elastic state that would tolerate stresses. Fig. 2 shows the progression of fissure formation. Substantial time after the kernels had equilibrated or cooled down to ambient condition was required for fissures to initiate. It is speculated that the endosperm or sections of the kernel had undergone transition from rubbery to a glassy state at different sections of the kernel. Stresses inside the kernel will lead to fissuring since the structure is no longer elastic. However, there is a need to determine the glass transition temperature curves for specific varieties of rice to correlate fissure formation using the data obtained in this study.

Fissuring Characteristics of Bengal, Cypress, and Drew

The effect of drying air temperature on fissure formation is shown in Fig. 3 for Bengal, Cypress, and Drew. Fissures were observed at air temperature of 45°C and higher. The magnitude of fissures was greater for Drew followed by Bengal and Cypress. It is interesting that Drew and Cypress have similar kernel shapes (both are slender), while Bengal, which has a different kernel shape, showed susceptibility similar to Drew. It appears that kernel shape is not a factor in fissuring characteristics among the three samples. The results also indicate that the critical drying air temperature for Bengal and Drew is about 45°C and for Cypress is about 48°C, if 10% fissure occurrence is used as a critical limit. Chemical properties and starch cellular structure of the kernel could have some effects on the variability in fissure formation.

Effect of Tempering

Tempering rice after drying reduced fissuring incidence by 34 to 62%, depending on drying treatment conditions as shown in Table 1. The reduction in fissures can be attributed to the reduction in moisture gradient during tempering that could lead to stress and fissure formation. Application of tempering immediately after drying provides time for moisture to migrate toward the outer part of the kernel as it approaches equilibrium while it is still in a rubbery state. It is imperative that tempering conditions be optimized to obtain highest reduction in fissure formation.

SIGNIFICANCE OF FINDINGS

This study was able to visually locate the initiation of fissure formation in rice kernels during drying. It has determined the actual time of fissure occurrence and how multiple fissures are formed. The results have also provided insights on the relationship of glass transition theory on fissure formation, though additional tests are being conducted to confirm earlier findings. Additional information such as determination of T_g curves for specific rice varieties as well as chemical properties of the endosperm are needed.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the University of Arkansas Rice Processing Program Industry Alliance Sponsors, The Rice Dryer and Warehousemen Association of Arkansas, and the Institute of Food Science and Engineering.

LITERATURE CITED

Bautista, R.C. 1998. Experimental studies on fissure occurrence in rice by desorption and adsorption of moisture. Ph.D. dissertation, Iwate University, Japan.

Liu, H., Zhou, L., and K. Hayakawa. 1997. Sensitivity analysis for hygrostress crack formation in cylindrical food during drying. Journal of Food Science. 62(3):447-450.

Perdon, A., and T. J. Siebenmorgen. 1999. Development of brown rice state diagrams for mapping of drying processes. Cereal Chemistry (in press).

Sarker, O. R. Kunze, and T. Strouboulis. 1996. Transient moisture gradient in rough rice mapped with finite element model and related to fissures after heated air drying. Transactions of the ASAE. 39(2):625-631.

Table 1. Fissure occurrence in rice kernels with and without tempering.

Air temperature	Kernel MC	No tempering	With tempering
(°C)	(%)		
50	18.5	41	27
55	18.6	89	34
60	18.5	96	51

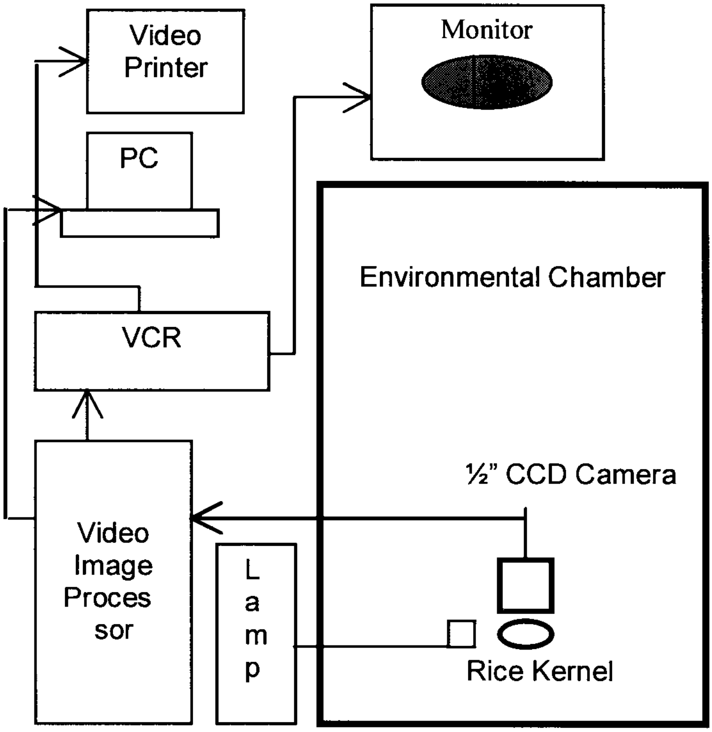


Fig. 1. Schematic drawing of the video microscopy system.

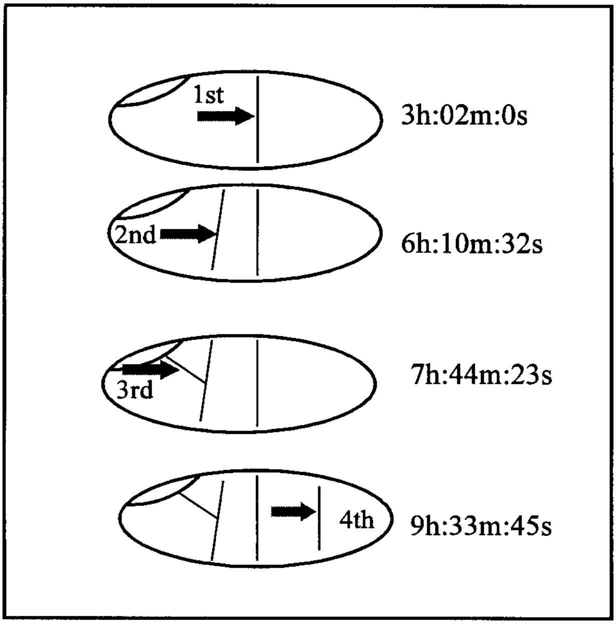


Fig. 2. Progression of fissure formation in a rice kernel after exposure to drying air temperature of 60°C and 20% RH.

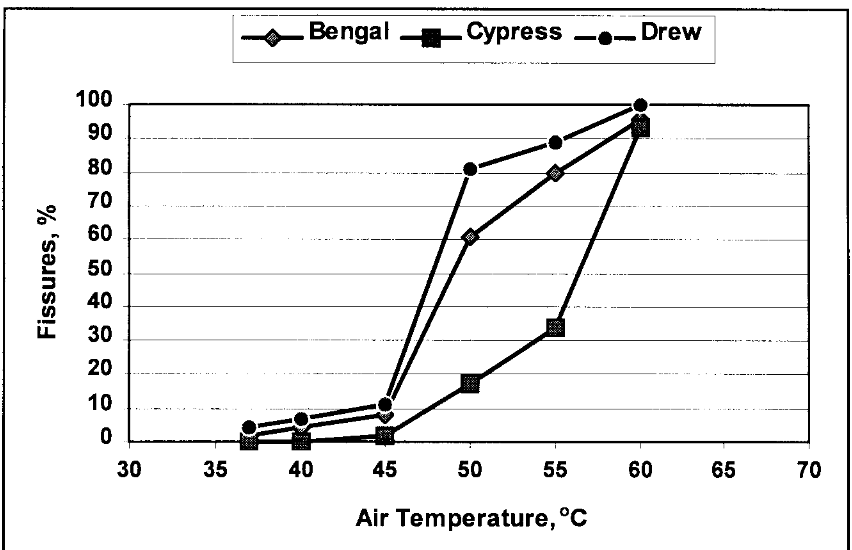


Fig. 3. Fissuring characteristics of rice varieties Bengal, Cypress, and Drew (brown rice) in drying without tempering.

DETERMINING MINIMUM TEMPERING DURATIONS WHILE MAINTAINING HEAD RICE YIELD

A.G. Cnossen and T.J. Siebenmorgen

ABSTRACT

Drying and tempering tests were conducted during the 1998 and 1999 harvest seasons using 'Bengal' and 'Cypress' rice from two locations in Arkansas harvested over a range of moisture contents (MCs) (22 to 17%). The rice was dried under three air conditions, two with a drying air temperature above the glass transition temperature (T_g) of the rice, and one below T_g, in order to test the T_g-hypothesis of fissuring proposed by Perdon and Siebenmorgen (1999), which relates milling quality reduction to T_g. Four drying durations were used, resulting in 1.5, 3, 4.5, and 6 percentage points MC (PPMC) loss. After drying, the samples were tempered for varying time periods ranging from 0 to 4 hr at the same temperature as the dryer. Results indicate that tempering duration after a drying pass has a significant influence on head rice yield (HRY). Results for both Bengal and Cypress show that 5 to 6 PPMC can be removed per drying pass without damaging the rice kernel, as long as sufficient tempering is allowed. Required tempering durations were shorter for Cypress than for Bengal.

INTRODUCTION

Commercial rice dryers use multi-pass procedures to remove moisture from grain. A tempering period is typically used between drying passes. Tempering allows moisture to migrate from the core to the outer layers of the kernel. Moisture gradients in the rice kernel will thus decrease during tempering. Moisture gradients cause stress inside the kernel, which if sufficiently great, causes the kernel to fissure. In commercial rice drying, tempering durations vary widely, ranging from 6 to 24 hr in the United States

(Mossman, 1986). By determining the minimum tempering duration required to reduce kernel moisture gradients, the drying process can be optimized.

Tempering Research

High tempering temperatures have been shown to be effective in maintaining high HRYs and reducing the tempering duration necessary for moisture gradients to subside. Cnossen *et al.* (1998) showed increasing HRYs for tempering durations up to 150 min. In this study, medium-grain rice was dried with air at a temperature of 60°C, and the rice was tempered at this same temperature. Wasserman *et al.* (1964) showed increasing HRY and decreasing tempering duration with increasing tempering temperature for a short-grain rice variety dried using 43.3°C air. HRY was 2 percentage points higher for rice tempered warm (40.6°C) compared to rice tempered cold (23.8°C). Samples tempered at 40.6° C required 4 hr of tempering, while samples tempered at 23.8°C required 6 hr.

Material Property Considerations

Perdon and Siebenmorgen (1999) suggested that a complete and fundamental understanding of the response of kernels to various drying and tempering environments must include considerations of material properties at the temperature and MC of various sections of the kernels. The change of state of starch, as it goes through a T_g, is hypothesized to be of importance. Physical properties of a starch material change dramatically as it goes through T_g. At temperatures below T_g, starch exists as a glassy material, while it exists as a rubbery material at temperatures above T_g. Figure 1 shows a T_g relationship for rice.

During drying, temperature and MC gradients are created inside the kernel. These gradients may result in one region of the kernel being at a temperature and MC so as to exist in one state, while other regions of the kernel may exist in another state, resulting in different regions having different material properties. This is illustrated in Fig. 2, which shows a hypothetical moisture gradient inside a rice kernel. During the tempering stage, following a drying pass, the temperature and MC gradients from the surface to the center of the kernel will equalize. However, it is hypothesized that if the tempering environment is one that produces a change of state of the starch, differential stresses within the kernel, resulting from the temperature and MC gradients, could cause kernel fissuring. This scenario is depicted by situation *B* in Fig. 3, in which the tempering temperature is less than the T_g of the rice and the surface, middle, and center of the kernel cross the T_g line at different MCs. Our hypothesis would indicate that this scenario would create kernel fissuring, with resultant HRY reduction, if there were a sufficient MC gradient inside the kernel at the initiation of the tempering process. This theory is explained in more detail by Perdon and Siebenmorgen (1999) and Cnossen *et al.* (1999).

The objectives formulated for this study were to (1) minimize overall drying duration by determining the minimum tempering duration required between drying passes, while maintaining high HRYs and (2) investigate the effects of glass transition on HRY reduction during tempering.

PROCEDURES

Both Bengal (medium-grain) and Cypress (long-grain) rice at two harvest MCs, high (21 to 22%) and low (17 to 18%), were harvested from research and extension centers at Stuttgart and Keiser in 1998 and 1999. Fig. 4 illustrates the experimental design for the drying and tempering experiments. The samples were dried at three air conditions, two with drying air temperatures above (condition HI: 60°C, 16.9% RH; 5.5% EMC; and HII: 60°C, 50% RH; 9.2% EMC) the T_g line and one with drying air temperature below (condition LI: 40°C, 12.5% RH; 5.8% EMC) the T_g line (Fig. 1). Samples were dried for four durations to create varying magnitudes of moisture gradient, resulting in 1.5, 3, 4.5, and 6 PPMC loss. After these drying durations, the samples were tempered for varying durations ranging from 0 to 4 hr in 40-min increments in an oven set at the temperature of the dryer. These varying tempering durations created varying levels of MC equilibration in the kernels, i.e., a tempering duration of 0-min resulted in maximum MC gradient, while extended tempering resulted in minimal gradients. After tempering, the samples were placed into a chamber set at 21°C and 55% RH to gently dry to 12.5% MC. This 21°C temperature is well below T_g. Thus, the kernels were forced to undergo a state transition with varying levels of MC gradients due to the varying tempering durations. Our hypothesis would indicate that this state transition would create HRY reduction if there is a sufficient MC gradient inside the kernel.

The samples were held in storage for 3 months. Samples were subsequently milled for 30 sec in a McGill no.2 mill. The mass of head rice was determined using a FOSS Graincheck 310 image analyzer and the HRY calculated.

RESULTS AND DISCUSSION

Drying Above T_g: HRY Results

According to our hypothesis, if rice is tempered above the T_g line long enough to reduce MC gradients, a state transition will not cause HRY reduction. Insufficient MC gradient reduction before a state transition will produce fissures and consequent HRY reduction.

Fig. 5 shows the HRYs of Bengal samples for different tempering durations, after various percentage points MC were removed using the 60°C, 16.9% RH drying condition (HI). From Fig. 5, removing 1.5 PPMC caused little damage to the rice and tempering had no effect. This indicates that for this drying duration, sufficient MC gradients were not produced during drying to create fissures when the rice was placed in the 21°C environment and forced to undergo a state transition. However, when removing up to 4.8 PPMC without tempering (zero tempering duration), a dramatically lower HRY was observed; furthermore, the samples that were tempered for 40 min showed a significant increase in HRY, and the samples tempered for 120 min did not show any HRY reduction compared to the control sample. When up to 5.6 PPMC was removed, 160 min tempering was necessary to achieve a HRY equivalent to that of the control. This indicates that after these tempering durations, the MC gradients were sufficiently reduced and did not lead to fissuring.

Up to 6.5 PPMC was removed for a different harvest lot, dried with the 60°C, 50% RH air condition (HII), as shown in Fig. 6. These samples showed significant irreversible structural damage; even after 240 min tempering, the HRY was lower than the HRY of the control sample. The samples dried under this high RH air condition had higher HRYs for shorter tempering durations compared to Fig. 5, indicating that these samples tempered faster than samples dried under the 60°C, 16.9% RH drying condition.

Fig. 7 represents the HRY results for Cypress when dried at the 60°C and 16.9% RH condition. Required tempering durations to maintain a high HRY were significantly lower for the long-grain Cypress rice than for the medium-grain Bengal rice. Tempering times of approximately 40 min were sufficient when up to 4.5 PPMC was removed and 80 min of tempering was needed to reduce the MC gradients when removing up to 6% MC. Because of a thinner kernel, the magnitude of the MC gradient in a long-grain rice kernel could be smaller than that of a medium-grain, resulting in a faster equilibration time. The differences in tempering response between rice dried using the low RH drying condition and rice dried under the high RH drying condition that were observed with the medium-grain variety were not observed with the long-grain variety.

Harvest MC (HMC) had a significant influence on tempering duration: the lower the HMC, the longer the required tempering duration. Cypress harvested at 23% MC required 40 min of tempering when 6 PPMC was removed, while Cypress harvested at 20.6% MC required 80 min of tempering, when dried under the 60°C, 16.9% RH drying air condition. Similar trends were observed for the Bengal rice.

Drying Below T_g: HRY Results

Because of a slower drying process, resulting in less severe MC gradients, and the fact that a state transition did not occur when cooling, tempering had little effect on the HRY for both cultivars when rice was dried using a drying air temperature below the T_g. The slower drying process did not cause a sufficient MC gradient inside the kernel to cause significant fissuring and subsequent breakage. Fig. 8 shows the HRY versus tempering duration for rice dried with air below theT_g. The Bengal rice showed a small decrease in HRY with increasing amounts of MC removal. Cypress showed little HRY reduction for prolonged drying durations. Harvest MC did not have a significant effect on HRY results when drying air temperatures less than T_g were used.

The following conclusions were drawn from this study. Drying air temperatures as high as 60°C can be used without reducing the HRY as long as sufficient tempering at a temperature above the T_g of the rice is allowed. Tempering rice immediately after drying has a significant effect on HRY when the drying air conditions produces sufficient MC gradients inside the kernel and produces a state transition that places the kernel, or parts of the kernel, into the rubbery region. For both Bengal and Cypress and for both drying conditions HI and HII, 5 to 6 PPMC could be removed in a single drying pass without damaging the kernel, if the rice is tempered at 60°C before cooling to 21°C. For Bengal, 160 min of tempering is sufficient and for Cypress a tempering time of 80 min is sufficient, based on achieving HRYs equivalent to that of the control samples.

SIGNIFICANCE OF FINDINGS

Determining an optimum drying and tempering strategy for rough rice will improve dryer performance and increase rice quality. Additional understanding of the effects of glass transition during drying and tempering on kernel quality could provide fundamental understanding of why and when kernels fissure during the drying process.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board and the University of Arkansas Rice Processing Program Industry Alliance Group for the financial support of this project.

LITERATURE CITED

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and A.A. Perdon. 1998. Characteristics of rough rice during tempering. ASAE Paper No. 98-6033. ASAE, St. Joseph, MI.

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and W. Yang. 1999. Incorporating the glass transition temperature concept in rice drying and tempering to optimize moisture removal and milling quality. ASAE Paper No. 99-6022. ASAE, St. Joseph, MI.

Mossman, A.P. 1986. A review of basic concepts in rice-drying research. CRC Critical Reviews in Food Science and Nutrition 25:49-71.

Perdon, A.A. 1999. Development of brown rice state diagrams for mapping of drying processes. Ph.D. dissertation, University of Arkansas, Fayetteville.

Perdon, A.A. and T.J. Siebenmorgen. 1999. Development of brown rice state diagrams for mapping of drying processes. Cereal Chem. (submitted).

Wasserman, T., R.E. Ferrel, D.F. Houston, E. Breitweiser, and G.S. Smith. 1964. Tempering western rice. Rice Journal 67(2):16-17, 20-22.

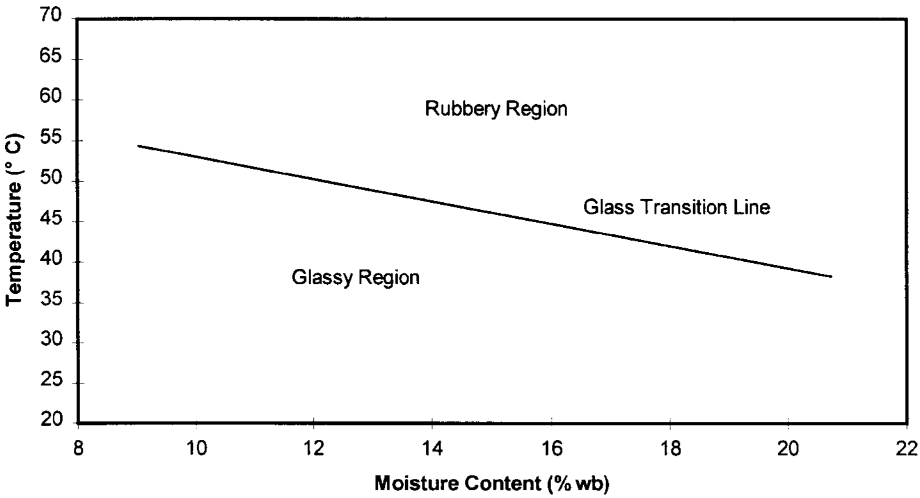


Fig. 1. Glass transition relationship for Bengal brown rice (Perdon, 1999).

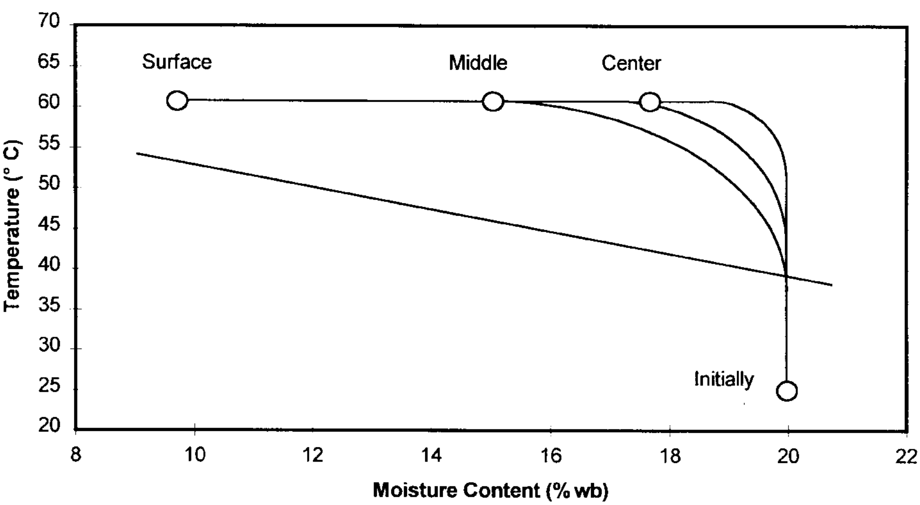


Fig. 2. Hypothetical temperatures and MCs within a brown rice kernel after removing a large amount of moisture (4 to 5% overall MC reduction) using a drier temperature of 60°C.

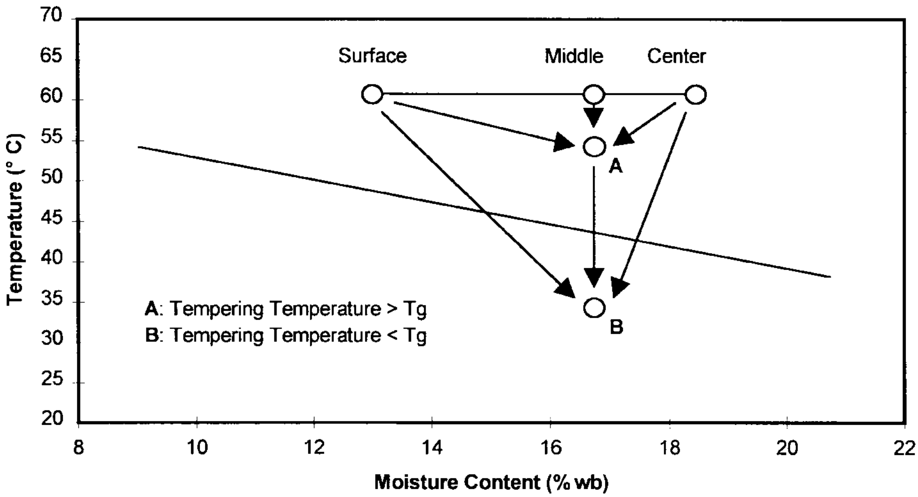


Fig. 3. Alternative hypothetical responses of the various sections of a brown rice kernel during tempering at temperatures above or below the kernel glass transition temperature (T_g).

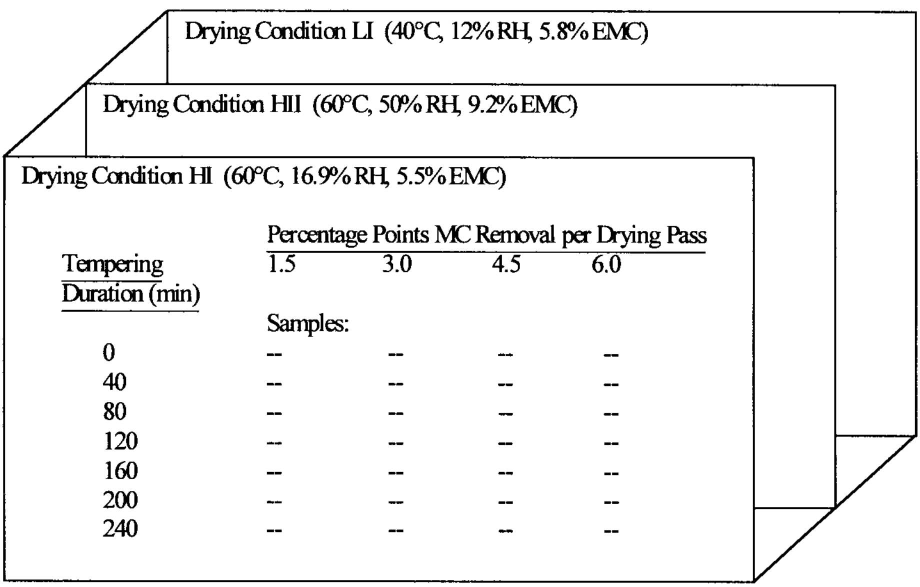


Fig. 4. Experimental design for the drying and tempering experiments. Layout represents the sampling routine for each harvest location/cultivar/harvest MC lot.

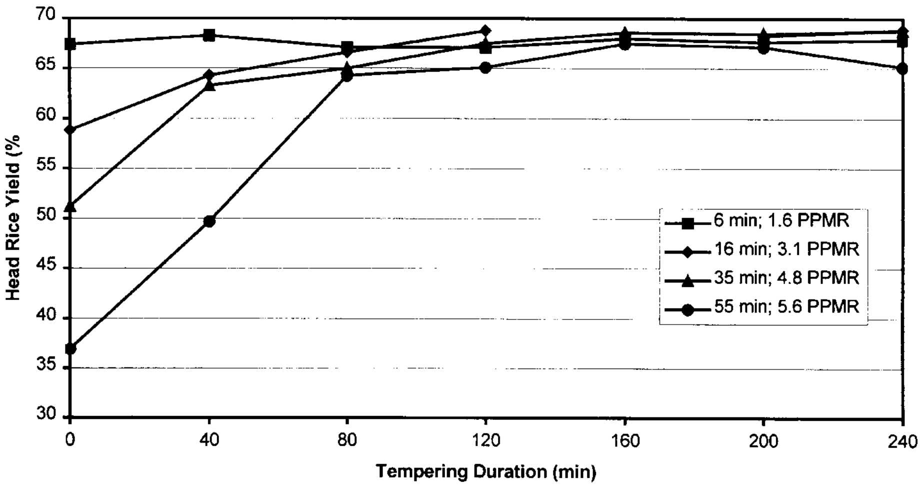


Fig. 5. Head rice yield (HRY) versus tempering duration for Bengal rice dried for four durations (PPMR is percentage points MC removed) with 60°C and 16.9% RH drying air (condition HI). The HRY of the control sample was 67.9% and the harvest MC was 21.3%.

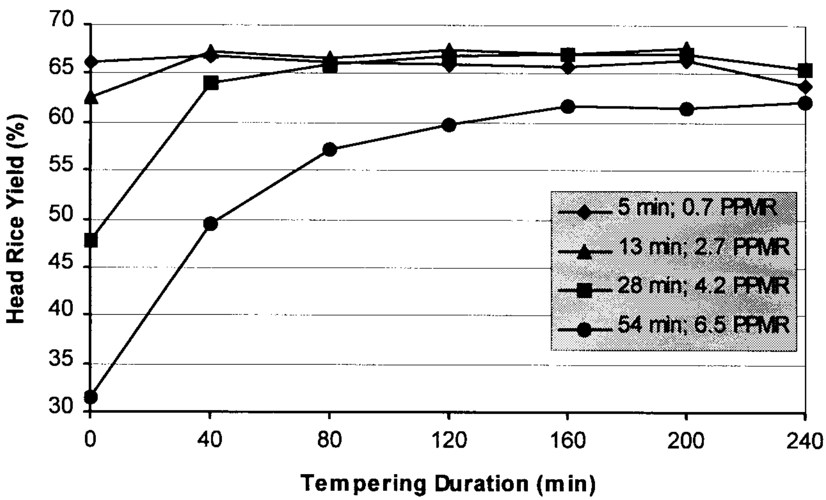


Fig. 6. Head rice yield (HRY) versus tempering duration for Bengal rice dried for four durations (PPMR is percentage points MC removed) with 60°C and 50% RH drying air (condition HII). The HRY of the control sample was 65.7% and the harvest MC was 21.3%.

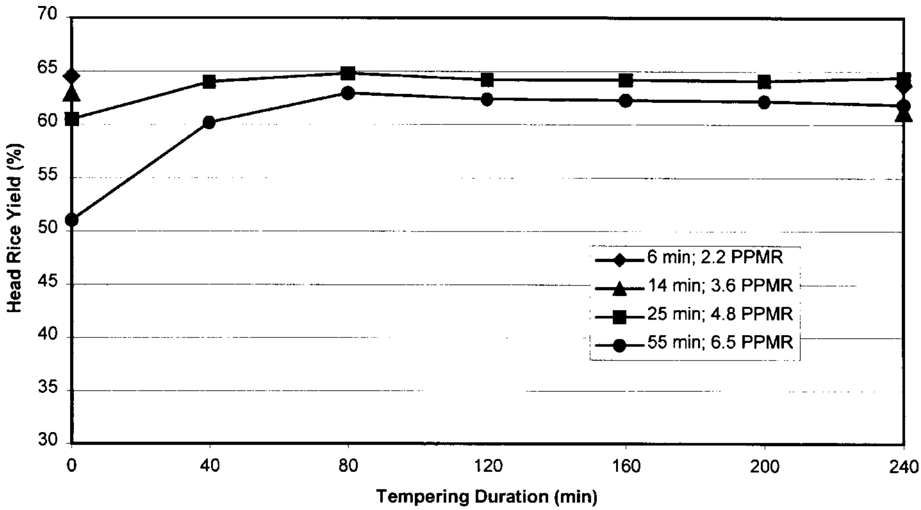


Fig. 7. Head rice yield (HRY) versus tempering duration for Cypress rice dried for four durations (PPMR is percentage points MC removed) with 60°C and 16.9% RH drying air (condition HI). For the 2.2 and 3.6 PPMR durations only the 0- and 240-min tempering durations are depicted. The HRY of the control sample was 64.5% and the harvest MC was 20.6%.

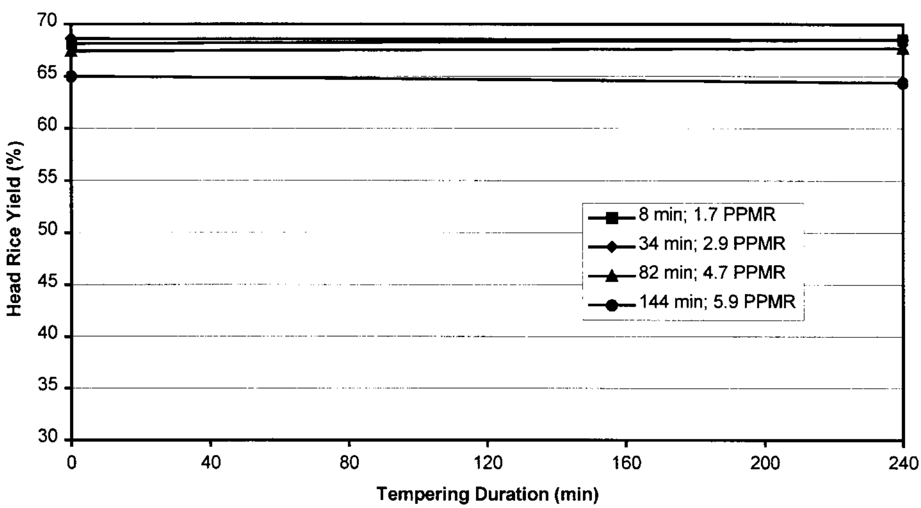


Fig. 8. Head rice yield (HRY) versus tempering duration for Bengal rice dried for four different durations (PPMR is percentage points MC removed) with 40°C and 12% RH drying air (condition LI). The HRY of the control sample was 67.9% and the harvest MC was 20.6%.

EFFECT OF GLASS TRANSITION TEMPERATURE ON DRYING RATES AND TEMPERING DURATION OF ROUGH RICE

A.G. Cnossen, T.J. Siebenmorgen, and W. Yang

ABSTRACT

Previous research on rice drying and tempering has shown that high drying temperatures and high moisture removal rates can be used without reducing milling quality as long as sufficient tempering at a temperature above the glass transition temperature (T_g) is allowed between drying passes. Temperatures above the T_g of the rice significantly reduce both drying and tempering duration, since the moisture diffusivity is much higher above T_g. The following objective was formulated for this study: Apply the T_g concept during the rice-drying process to determine drying and tempering rates above and below T_g to optimize drying strategies. Medium-grain and long-grain rice were harvested during 1998 and 1999. The rice was dried under various drying and tempering conditions above and below the T_g. During drying, moisture content (MC) loss was monitored to determine drying rates for the various conditions. Results showed that rice dried above T_g dried significantly faster than rice dried below T_g and that rice dried with high relative humidity (RH) drying air tempered significantly faster than rice dried with low RH air.

INTRODUCTION

High tempering temperatures have been shown to decrease tempering duration while maintaining high HRYs. Wasserman *et al.* (1964) showed increasing HRY and decreasing tempering duration with increasing tempering temperature for a short-grain rice cultivar dried using 43.3°C air. HRY was two percentage points higher for rice tempered warm (40.6°C) than rice tempered cold (23.8°C). Samples tempered at 40.6°C required 4 hr of tempering, while samples tempered at 23.8°C required 6 h. Steffe and Singh (1980) found similar trends of decreasing tempering duration with increasing temperature. Cnossen *et al.* (1999) showed increasing HRYs for tempering durations up to 160 min. In this study, both medium- and long-grain rice were dried with 60°C air, and tempered at the drying temperature. Their study showed that high drying temperatures and high moisture removal rates can be used without reducing milling quality as long as sufficient tempering at a high temperature is allowed before cooling (See: "Determining Minimum Tempering Durations While Maintaining Head Rice Yield" found in this edition of the *Rice Research Studies*).

Previous research within the University of Arkansas Rice Processing Program has shown that T_g plays an important role in rice drying and tempering. At a temperature and MC below the T_g, starch exists as a "glassy" material, with low expansion coefficients, specific volume, and diffusivity. Above T_g, starch exists as a "rubbery" material with higher expansion coefficients, specific volume, and diffusivity (Slade and Levine, 1995). Perdon and Siebenmorgen (1999) concluded that the change in state of starch, as it goes through a glass transition, plays an important role in rice drying and tempering in terms of kernel fissuring potential. They concluded that this state transition occurs in the temperature range typically encountered during drying, and would affect the material properties of a rice kernel.

Fig. 1 shows a T_g relationship for 'Bengal' rice measured by Perdon and Siebenmorgen (1999), indicating that the T_g is inversely related to MC, i.e., as MC increases, T_g decreases. Perdon and Siebenmorgen showed that the physical properties of a rice kernel chang dramatically as the kernel temperature passes through T_g.

Previous work in thin-layer drying has focused on quantifying the changes in the drying rate as a function of drying air conditions (Kunze, 1979; Chen *et al.*, 1997). With the knowledge of a state transition, the question arises whether or not the state transition has an effect on the drying rate. In particular, would drying at higher temperatures and higher RHs provide higher drying rates. The premise of this research is that the moisture diffusivity is much higher above T_g. There are several consequences of the change in diffusivity from the glassy (below T_g) to the rubbery (above T_g) state. When the kernel is above the T_g, the kernel dries faster. Also, because of the higher diffusivity above the T_g, the tempering time will be reduced. If extremely low equilibrium MCs (achieved when using high temperatures and low RHs) are used, the surface of the kernel dries quickly and equilibrates with the drying air, and we speculate that the starch of the kernel surface could transition back to the glassy state. This situation is illustrated in Fig. 2. Under this scenario, the kernel would dry more slowly than if the surface were maintained above T_g. The lower diffusion, if the surface were in the glassy state, would limit diffusion from the rubbery center.

Understanding the effects of drying air temperature and RH on the drying rate of rough rice could help improve drying strategies. The objective of this study is to apply the T_g concept in rice drying and tempering and determine drying rates above and below T_g to optimize drying.

PROCEDURES

Cultivars Bengal (medium-grain) and 'Cypress' (long-grain) at two harvest MCs, high (21 to 22%) and low (17 to 18%), were harvested from the research and extension centers at Stuttgart and Keiser in 1998 and 1999. The samples were dried at three air conditions, two with drying air temperatures above (condition HI: 60°C, 16.9% RH; 5.5% EMC; and HII: 60°C, 50% RH; 9.2% EMC) and one with drying air below (condition LI: 40°C, 12.5% RH; 5.8% EMC) the T_g line (Fig. 1). Samples were dried for four durations to create different magnitudes of moisture gradient, resulting in 1.5, 3, 4.5, and 6 percentage points MC (PPMC) loss. During the drying runs, moisture loss was monitored and drying was terminated as soon as the desired percentage point of moisture loss was achieved.

After these drying durations, the samples were tempered for varying durations ranging from 0 to 4 hr in 40-min increments in an oven set at the temperature of the dryer. These varying tempering durations created varying levels of MC equilibration in the kernels, i.e., a tempering duration of 0 min resulted in maximum MC gradient, while extended tempering resulted in minimizing gradients. After tempering, the samples were placed into a chamber set at 21°C and 55% RH to gently dry to 12.5% MC.

Additional drying tests were performed to measure the RH response of the interkernel air during tempering. The RH response of the interkernel air can be used as an indicator of moisture gradient relaxation. When the RH reaches a steady state, it is assumed that there is no additional moisture transfer from the kernel to the surrounding air, indicating that the moisture gradient inside the rice kernel had disappeared. For these tests, Bengal and Cypress were dried for three durations (3, 4.5, and 6 percentage points MC reduction) under the two drying air conditions above T_g. and was tempered for 150 min in a sealed flask with a temperature and RH probe.

RESULTS AND DISCUSSION

Results of the 1998 drying runs showed a slightly faster drying process for the samples dried with the 50% RH drying air, as compared to the samples dried with 16.9% RH drying air when drying at 60°C, as can be seen in Fig. 3. This trend was observed for all drying durations, both cultivars, and all harvest MCs. However, during the 1999 season, a faster drying process was observed for the low RH drying condition (Fig. 4). As can be seen from Figs. 3 and 4, the rice dried at 60°C dried more than twice as fast as the rice dried at 40°C.

Fig. 5 shows the RH response of the interkernel air during tempering of samples after they had been dried with low RH and with high RH drying air. The sample dried with high RH air tempered much faster than the sample dried with low RH air. This is explained by reasoning that under the high temperature, low RH air condition, the outer layer of the rice kernel would be expected to be in the glassy state and the diffusivity at the kernel surface would be lower, thus the RH of the interkernel air would increase more slowly during tempering. This observation supports the need for further research on the surface phenomenon during drying. This trend was consistent among variety, harvest MC, and drying duration.

The minimum tempering duration can be determined from the interkernel RH response curves of Fig. 5 as the timespan required for the RH to reach steady state. This method was used by previous researchers in determining minimum tempering duration (Steffe and Singh 1982). The minimum tempering durations found from the RH response were much less than the minimum tempering duration required to maintain a high HRY. Cnossen *et al.* (1999) (See also: "Determining Minimum Tempering Durations While Maintaining Head Rice Yield") showed that 120 to 160 min of tempering was necessary for Bengal to maintain a HRY equal to the that of a control sample when removing 6 PPMC; for Cypress, only 40 to 80 min of tempering was necessary. The RH response indicated that for Bengal only 40 to 60 min of tempering was sufficient to reduce the MC gradient and for Cypress only 30 to 50 min was sufficient. Thus, this comparison indicates that tempering duration determined by interkernel RH response might not be sufficient to relax MC gradients that could cause HRY reduction upon subsequent cooling of the rice.

SIGNIFICANCE OF FINDINGS

Understanding the effects of glass transition during rice drying and tempering is important in optimizing the drying and tempering processes in terms of rice milling quality and dryer efficiency. This will ultimately lead to the development of new drier controls and drier designs.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board and the University of Arkansas Rice Processing Program Industry Alliance Group for the financial support of this project.

LITERATURE CITED

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and W. Yang. 1999. Incorporating the glass transition temperature concept in rice drying and tempering to optimize moisture removal and milling quality. ASAE Paper No. 99-6022. St. Joseph, MI: ASAE.

Chen, H., T.J. Siebenmorgen, and B.P. Marks. 1997. Relating drying rate constant to head rice yield reduction of long-grain rice. Transactions of the ASAE 40(4):1133.

Kunze, O.R. 1979. Fissuring of the rice grain after heated air drying. Transactions of the ASAE 22:1197-1202, 1207.

Perdon, A.A. and T.J. Siebenmorgen. 1999. Development of brown rice state diagrams for mapping of drying processes. Cereal Chem. (submitted).
Slade, L. and H. Levine. 1995. Glass transitions and water – Food structure interactions. Advanced Food Nutrition Research 38:103-269.
Steffe, J.F. and R.P. Singh. 1980. Theoretical and practical aspects of rough rice tempering. Transactions of the ASAE 23:775-784.
Wasserman, T., R.E. Ferrel, D.F. Houston, E. Breitweiser, and G.S. Smith. 1964. Tempering western rice. Rice Journal 67(2):16-17, 20-22.

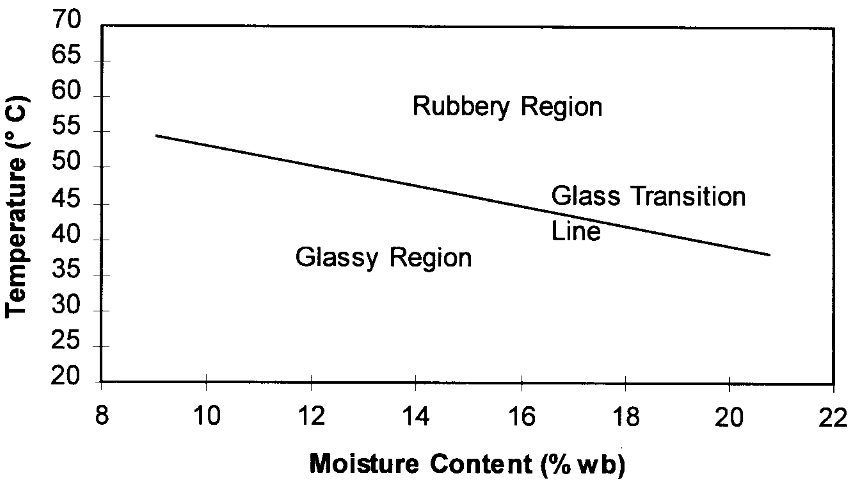


Fig. 1. Glass transition relationship for cultivar Bengal brown rice (Perdon, 1999).

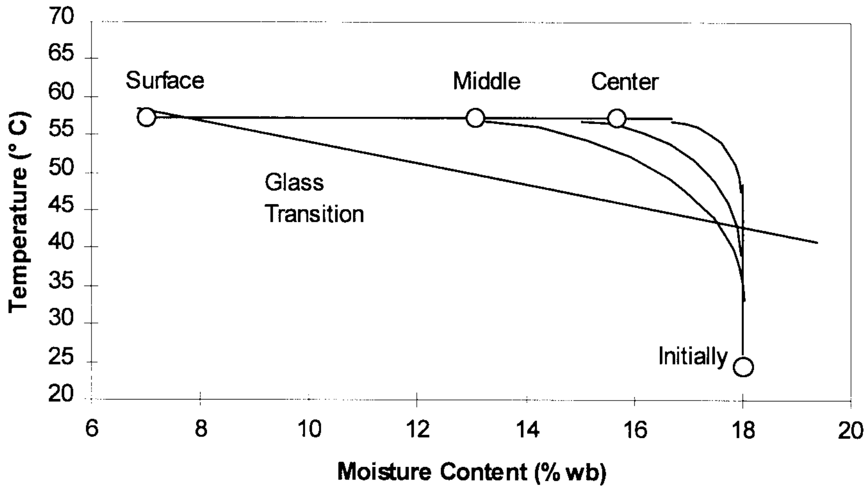


Fig. 2. Hypothetical moisture content gradient inside a rice kernel after extended drying when using drying air conditions that result in low equilibrium moisture contents. Surface, middle, and center refer to the surface, middle, and center of the rice kernel.

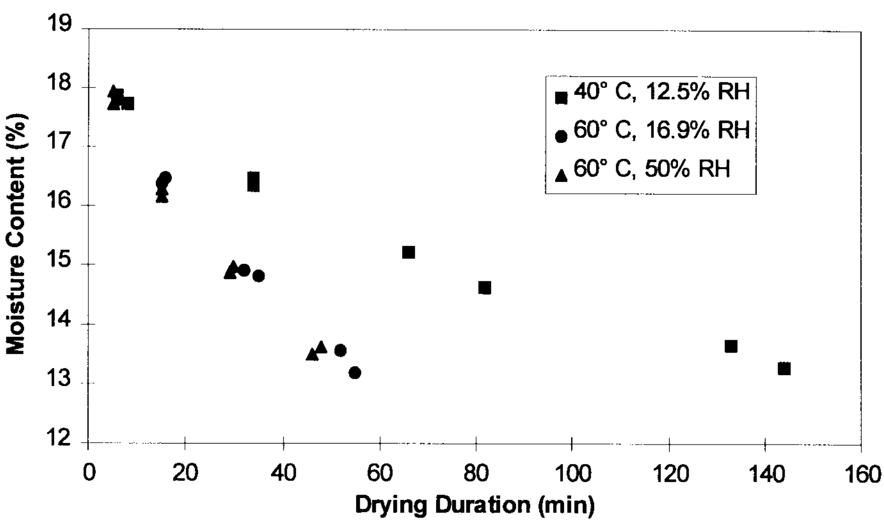


Fig. 3. Drying duration versus moisture content (MC) for Bengal rice dried in 1998. The harvest MC was 19.6%. The plot shows the MC after one drying run of two replications of the drying durations resulting in 1.5, 3, 4.5, and 6 percentage points moisture removal.

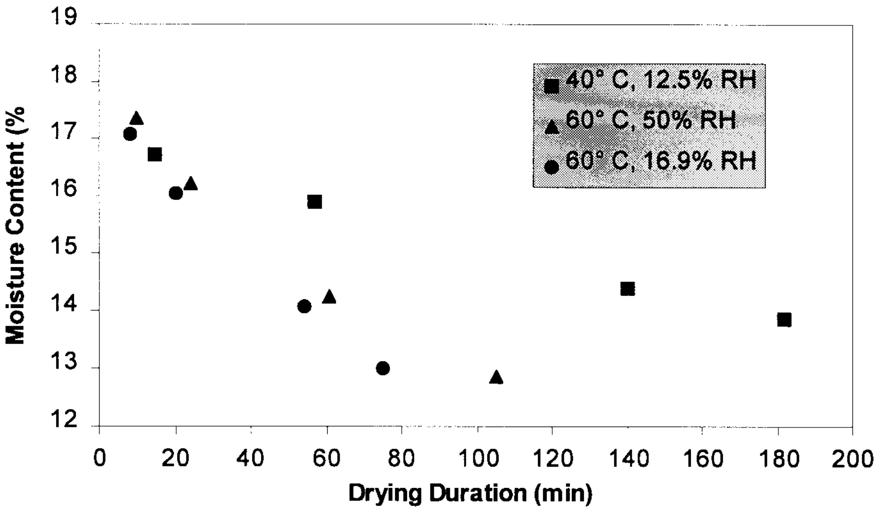


Fig. 4. Drying duration versus moisture content (MC) for Bengal rice dried in 1999. The harvest MC was 19%. The plot shows the MC after one drying run of one replication of the drying durations resulting in 1.5, 3, 4.5, and 6 percentage points moisture removal.

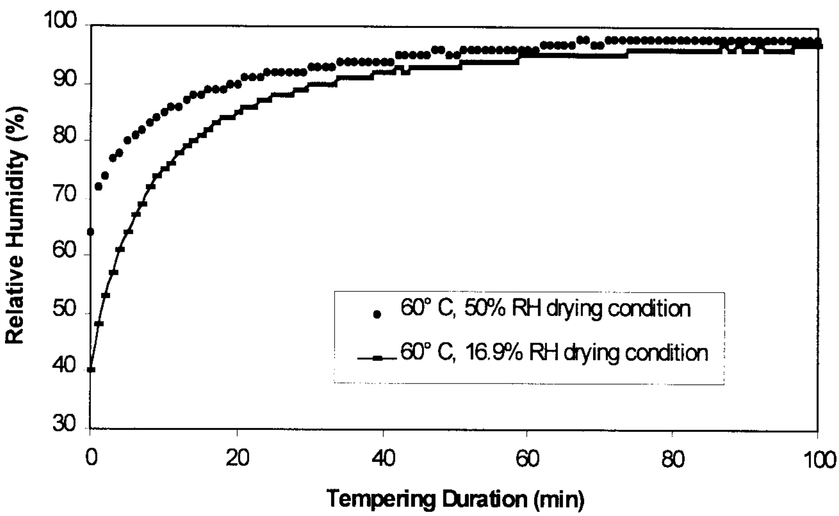


Fig. 5. Relative humidity (RH) response during tempering of Bengal rice after removing 6 PPMC) with high and low RH drying air at 60°C in one drying pass. The harvest MC was 21.4%.

EFFECT OF DRYING AND TEMPERING TREATMENT ON MOISTURE ABSORPTION KINETICS OF RICE

J. Diederen, A.G. Cnossen, T.J. Siebenmorgen, and Y.-J. Wang

ABSTRACT

Previous research in rice drying and tempering has shown that high drying temperatures and high moisture removal rates can be used without reducing the head rice yield (HRY), as long as proper tempering techniques are used. The objective of this research was to determine whether rice that had been dried using these high drying and tempering temperatures would have altered end-use processing properties, including water absorption kinetics during cooking and structural/chemical changes. Rice cultivars 'Bengal' and 'Cypress' were dried for varying durations under three conditions, two with a drying air temperature above the glass transition temperature (T_g) of the rice and one below the T_g. Immediately after drying, the samples were tempered for various durations. Results showed that both drying duration and tempering duration did not significantly influence the water absorption. However, the total water absorption was significantly different for samples dried below T_g compared to samples dried above T_g. The same trend was observed for the gelatinization temperature (GT) and the gelatinization enthalpy (GE).

INTRODUCTION

During rice drying, moisture gradients are created inside the kernel. These gradients cause stress inside the kernel, which if sufficiently great, causes the kernel to fissure. Fissured kernels can break, causing HRY reduction. Cnossen *et al.* (1999) showed that high drying temperatures can be used without incurring HRY reduction, as long as proper tempering techniques are used. Tempering temperatures up to 60°C showed to be effective in maintaining high HRYs.

Perdon (1999) showed that T_g plays an important role in the rice drying and tempering processes. The T_g is the temperature at which a polymer changes from a glassy state (below T_g) into a rubbery state (above T_g), or vice versa. In the glassy state, material properties such as diffusivity, specific heat, specific volume, and expansion coefficients are much lower than in the rubbery state. Perdon (1999) showed that this transition occurs in the temperature range typically encountered during rice drying. When rice is dried at 60°C, the rice starch is above T_g, while rice dried at 40°C is still in the glassy state.

The effect of drying rice with drying air temperatures above and below Tg, as well as the duration it was dried and tempered, on end-use processing properties is unknown. Understanding these effects is important in controlling and optimizing end-use processing operations.

Water-Absorption Kinetics

During cooking, the starch granules in a rice kernel absorb water. The rate at which water is absorbed is influenced by several factors. The total water absorption for rice with a high amylose content is greater than for rice with a lower amylose content (Burns, 1972). Slender and smaller/lighter kernels, because of a larger surface area, absorb more water than more spherical and heavy kernels. A more crystalline structure in rice (i.e., a higher GT) is more resistant to water penetration and swelling, thus reducing the water absorption rate. Other factors influencing water absorption include kernel age, and kernel defects (i.e., fissures).

Gelatinization Temperature

During cooking, the starch will first undergo a glass transition, and after this transition, the rubbery structure will gelatinize at the GT (Whistler and Bemiller, 1997). The GT can be measured using a differential scanning calorimeter (DSC). Above the GT, the water uptake rate increases (Okechukwu and Rao, 1996), and in starches with a lower GT, this water absorption increase starts at a lower temperature (Juliano, 1967). A sample with a high GT will absorb less water than a sample with a low GT.

The goal of this research was to determine the effect of various drying and tempering treatments on the moisture absorption kinetics of rice during cooking. The change in molecular structure caused by the drying or tempering treatments was also investigated.

PROCEDURES

Cultivars Bengal (medium-grain) and Cypress (long-grain) were harvested from research and extension centers at Stuttgart and Keiser in 1998 and 1999. The rice was dried using three air conditions for different durations (See: “Determining Minimum

Tempering Durations While Maintaining Head Rice Yield", found in this edition of the *Rice Research Studies*). The samples dried for durations causing 1.5, 4.5, and 6 percentage points MC (PPMC) loss and the 0- and 240-min tempering durations for each of these drying durations were used for this study. The 1998 samples were stored for 12 months at 21°C prior to analysis, and the 1999 samples were stored for 2 months.

In order to measure the moisture absorption kinetics of the rice samples, subsamples of each sample were cooked for varying durations, and the amount of water taken up by 1 g of rice on a dry matter basis during a certain cooking time (1 to 30 min) was determined. As such, 1-g rice samples were placed in a cooking bag, and the mass of each bag was measured.

A Pyris 1 DSC was used to measure the GT and GE of flour from each of the rice samples. To prepare the flour, 15 to 20 whole kernels of each rice sample were ground in a mortar with a pestle. Subsequently, 4 mg of this powder was weighed into an aluminum calorimeter pan. The samples were heated from 25°C to 120°C, at a heating rate of 10°C/min. The GT and GE were then measured from the thermogram produced by the DSC.

RESULTS AND DISCUSSION

Bengal

The data for Bengal showed an inverse relationship between water absorption and GT: as water absorption increased, the GT decreased (Table 1). Both drying duration and tempering duration did not have a significant effect on the water absorption rate and on the total water absorption, nor on the GT and GE.

Water absorption for Bengal dried at 40°C was significantly lower than for the Bengal dried at 60°C (Figure 1). This trend was consistent for both the samples stored for 2 months and the samples stored for 12 months. This can be explained by a higher GT and a higher GE found for the samples dried at 40°C.

Cypress

The water absorption results and the GT and GE results for Cypress are summarized in Table 2. Cypress dried at 40°C had, in contrast to Bengal, a higher water absorption than Cypress dried at 60°C when samples had been stored for 12 months. This result can also be explained by the GT; the Cypress dried at 40°C had a lower GT than the Cypress dried at 60°C, which follows the inverse relationship observed with Bengal. The GE was not significantly different for these samples. Cypress stored for 2 months did not show a significant difference in water absorption among the three drying conditions.

The GT for the Cypress dried at 40°C (for the 2 months' storage duration) was found to be the highest of all the Cypress samples measured. The GE for the 40°C sample, however, was the lowest, which would result in a greater water absorption—

the opposite effect that the high GT would have. These results indicate that GT and GE both influence the water absorption and that their influences are independent (one has no priority above the other one).

Most of the rice samples dried at 40°C differed significantly from the undried control samples for both GT and GE compared with samples dried at 60°C (Tables 1 and 2). This suggests that drying at 40°C influences the rice structure more than at 60°C. A possible explanation is that at 40°C, the rice starch is probably still in the glassy state (below T_g), where the molecules are less mobile, whereas at 60°C the rice is in the more flexible, rubbery state. Therefore, the structure at 40°C is presumably more affected by the movement of the water molecules during drying, which could result in a greater change in GT and/or GE than those dried at 60°C.

Cypress absorbed significantly more water during cooking than Bengal for both the samples stored for 2 months and for 12 months (Figure 2). Both the GT and the GE can not explain this difference, since the GT for Bengal is lower instead of higher than for Cypress. A higher amylose content and a larger surface area, due to a smaller kernel, for Cypress could explain these results. Apparently, the amylose content or the surface area is influencing the water absorption more than the GT and GE.

SIGNIFICANCE OF FINDINGS

Understanding the effects of glass transition temperature and high drying and tempering temperatures during drying on the moisture absorption kinetics and on structural and chemical changes inside the rice kernel will provide end-use processors with valuable information to optimize their processing operations. This will help eliminate waste in end-use processing operations and could ultimately allow milled rice quality for end-use operation to be maximized in the drying operations.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board and the University of Arkansas Rice Processing Program Industry Alliance Group for their financial support of this project.

LITERATURE CITED

Burns, E.E. 1972. Canned rice foods. *In:* Rice: Chemistry and Technology, Houston, D.F. (ed.). American Association of Cereal Chemists, Inc., St. Paul, MN.

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and W. Yang. 1999. Incorporating the glass transition temperature concept in rice drying and tempering to optimize moisture removal and milling quality. ASAE Paper No. 996022. ASAE, St, Joseph, MI.

Juliano, B.O. 1967. Physicochemical studies of rice starch and protein. International Rice Communication Newsletter (special issue):93-105.
Okechukwu, P.E. and M.A.Rao. 1996. Kinitics of cowpea starch gelatinization based on granule swelling. Staerke 48:43-47.
Perdon, A.A. 1999. Amorphous State Transition in Rice During the Drying Process. Ph.D. dissertation. University of Arkansas, Fayetteville.
Whistler, R.L., and J.N. Bemiller. 1997. Carbohydrate Chemistry for Food Scientists. Publ: Eagan Press, St.Paul, MN.

Table 1. Water absorption after 30 minutes, gelatinization temperature, and gelatinization enthalpy measured for Bengal rice dried at three different drying conditions for three drying durations and two tempering durations.

			Bengal					
	Drying		2 months storage			12 months storage		
Drying condition	Duration PPMR[z]	Tempering	WA[y]	GT[x]	GE[w]	WA	GT	GE
40°C	1.5%	0	1.98	71.5	8.2	2.25	72.8	9.1
12% RH[v]	4.5%	0	1.88	69.9	9.0	2.30	72.1	9.6
	4.5%	240	1.92	70.0	8.4	2.36	72.5	9.3
	6%	0	-[u]	-	-	2.27	71.6	9.1
	6%	240	-	-	-	2.32	71.3	9.6
60°C	1.5%	0	2.04	70.6	8.2	2.36	71.3	8.6
50% RH	4.5%	0	2.21	70.2	7.0	2.38	71.4	7.6
	4.5%	80	1.97	70.3	7.9	2.32	71.8	7.9
	6%	0	2.07	70.1	7.3	2.39	70.7	7.8
	6%	240	2.19	70.3	8.6	2.37	71.7	9.8
60°C	1.5%	0	1.96	70.6	8.8	2.35	71.8	8.8
17% RH	4.5%	0	2.10	70.1	7.8	2.48	71.1	6.4
	4.5%	80	1.97	70.2	8.0	2.33	71.0	5.4
	6%	0	1.98	70.6	8.3	2.39	70.8	6.4
	6%	240	1.84	70.5	8.6	2.34	70.9	5.1
Undried			X[t]	69.8	4.6	X	69.8	6.2

[z] Percentage points moisture removed in one drying pass.
[y] Water absorption after cooking for 30 min (g water/g rice on a dry basis).
[x] Gelatinization temperature (°C).
[w] Gelatinization enthalpy (J/g rice on a dry basis).
[v] Relative humidity.
[u] - means no sample.
[t] X = not measured.

Table 2. Water absorption after 30 minutes, gelatinization temperature, and gelatinization enthalpy measured for Cypress rice dried at three different drying conditions for three drying durations and two tempering durations.

			Cypress					
			2 months storage			12 months storage		
Drying condition	Drying Duration PPMR[z]	Tempering	WA[y]	GT[x]	GE[w]	WA	GT	GE
40°C	1.5%	0	2.35	76.3	9.0	2.98	74.7	7.5
12% RH[v]	4.5%	0	2.44	78.6	-[u]	2.90	x[t]	x
	4.5%	240	2.32	77.6	7.3	2.94	x	x
	6%	0	2.61	77.4	7.2	2.88	74.7	7.2
	6%	240	2.34	77.8	7.4	2.94	75.1	7.4
60°C	1.5%	0	2.37	76.2	9.5	2.90	76.0	7.4
50% RH	4.5%	0	2.45	75.7	9.2	2.85	x	x
	4.5%	80	2.33	76.0	9.7	2.85	x	x
	6%	0	2.47	75.7	8.5	2.77	75.3	7.2
	6%	240	2.42	75.9	8.5	2.92	75.1	6.5
60°C	1.5%	0	2.33	75.8	8.1	2.90	75.1	7.4
17% RH	4.5%	0	2.30	75.7	8.5	2.88	x	x
	4.5%	80	2.46	76.4	7.8	2.85	x	x
	6%	0	2.40	77.0	8.4	2.84	75.2	7.1
	6%	240	2.36	76.7	8.7	2.91	75.4	7.9
Undried			x	75.7	8.4	x	75.5	6.1

z Percentage points moisture removed in one drying pass.
y Water absorption after cooking for 30 min (g water/g rice on a dry basis).
x Gelatinization temperature (°C).
w Gelatinization enthalpy (J/g rice on a dry basis).
v Relative humidity.
u - means no sample.
t X = not measured.

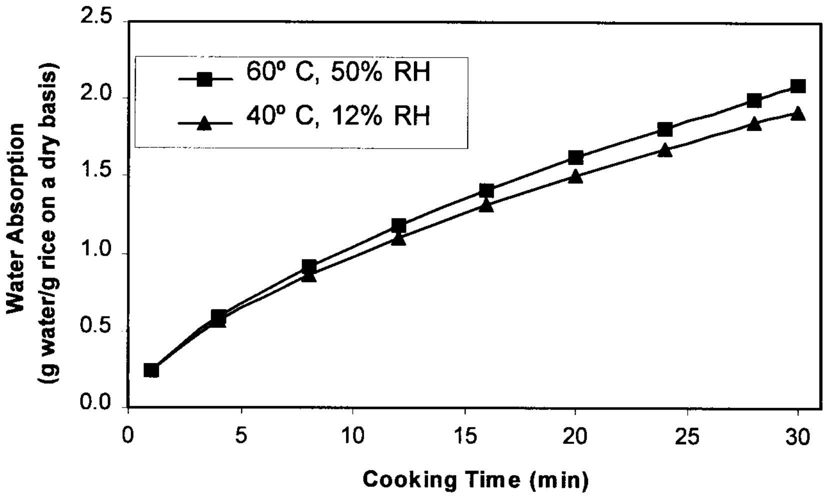


Fig. 1. Water absorption for Bengal rice dried at two drying air conditions after the rice was stored for 12 months.

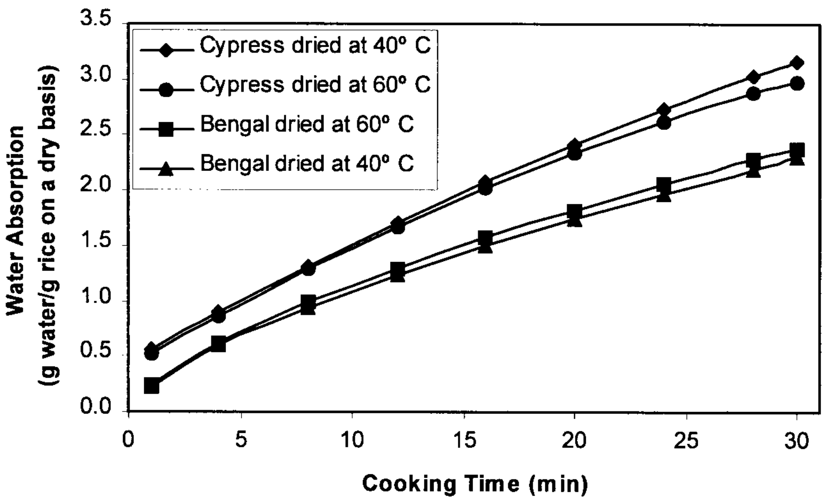


Fig. 2. Water absorption for Cypress and Bengal rice dried at 40°C and at 60°C. The rice was stored for 12 months.

EFFECT OF TEMPERATURE, EXPOSURE DURATION, AND MOISTURE CONTENT ON THE YELLOWING OF RICE

A.L. Dillahunty, T.J. Siebenmorgen, and A. Mauromoustakos

ABSTRACT

Rice yellowing is a problem for the rice industry, but there is no conclusive explanation for the occurrence. The objective of this research was to determine the effect of various temperatures and exposure durations at certain moisture contents (MCs) on yellowing of rice. Preliminary experiments were performed on stored grain of 'Cypress'. These experiments showed that exposure temperature and duration affected yellowing, but the effect of MC did not ($p > 0.15$). With this information, similar experiments were performed on freshly harvested Cypress and 'Bengal' grain. Color degradation, as measured by hue angle and chroma, was observed when temperatures exceeded 50°C for exposure longer than 12 hr. Temperatures above 55°C with exposure longer than 12 hr also resulted in lowered peak viscosity, but not all samples that showed yellowing had lowered viscosity. Head rice yield was not affected by treatment conditions. For the conditions of these experiments, temperature and exposure duration were the most important factors affecting color and viscosity.

INTRODUCTION

Postharvest yellowing of rice, often referred to as stack-burn, can be a significant problem to the rice industry. Other crops, such as barley, wheat, rye, speltz, cornmeal, cotton, and hay are affected by a similar phenomenon (Gilman and Barron, 1930). Rice is typically harvested between 16 and 24% MC, and dried to 12 to 14% MC for safe storage (Schroeder, 1963). Delayed or improper drying can cause "heat burns or heat discoloration," yielding yellow rice kernels (Sahay and Gangopadhyay, 1985). Aibara *et al.* (1984) also cited that improper handling of fresh rice, either after harvest or during storage, could cause increased respiration and, therefore, increased loss of quality.

While yellowing generally occurs in the paddy state, it is the endosperm that is affected, and thus yellowing is not apparent until the rice is milled. Yellowing is a form of deterioration that affects quality, appearance, flavor, and yield (Misra and Vir, 1991; Phillips *et al.*, 1988; Singaravadivel and Raj, 1983). There are tolerance levels for yellowing, but the rice is often downgraded or rejected. This research was conducted to determine the effects of temperature, exposure duration, and MC on yellowing of rough rice.

PROCEDURES

After performing two preliminary experiments using stored grain, additional experiments were performed on freshly harvested Cypress and Bengal grain from Stuttgart and Keiser in the fall of 1998. Immediately upon arrival at the University of Arkansas Rice Processing Laboratory, the rice was cleaned with a dockage tester (Model XT4, Carter Day Company, Minneapolis, Minnesota), rebagged, and placed in storage at 4°C until experiments were conducted approximately 2 months later.

Two replications of 400-g samples of grain from a high harvest MC lot (MC ~ 21%) and a lower harvest MC lot (MC ~ 18%) from each variety/harvest location combination were placed in aluminum containers and covered with aluminum foil. The grain was then exposed to one of seven temperatures (35, 40, 45, 50, 55, 60, and 70°C) for one of three durations (12, 36, or 72 hr). After exposure, the grain was left covered in the aluminum containers and cooled for about 12 hr at 21°C. The grain was poured onto screens and dried in an equilibration chamber (21°C, 53% RH) until a MC of 12.5% was reached. Following drying, the grain was sealed in ziploc bags and stored at 4°C for 6 wk. After storage, 150-g samples of rough rice, in duplicate, were dehulled (Satake Rice Machine, type THU, Satake Engineering Co., Ltd., Tokyo, Japan), and the resulting brown rice was milled with a laboratory mill (McGill #2, RAPSCO, Brookshire, Texas). Head rice (kernels three-fourths or more of the original kernel length) was separated from brokens using a sizing device (Seedburo, Chicago, Illinois). Head rice yield (HRY) was calculated using the equation: HRY = (Head rice/150 g) x 100.

A Rapid ViscoAnalyzer (RVA) (Model 4, Newport Scientific, Warriewood, NSW, Australia) was used to determine the peak and final viscosity of the rice flour. A 20-g sample of head rice was ground into flour with a UDY Cyclo-tec mill with a 0.5 mm sieve (Model 2511, UDY Corporation, Fort Collins, Colorado). Viscosity was determined by mixing 3 ± 0.01 g of flour at approximately 12% MC with 25 ± 0.05 ml of deionized water. The MC of the rice flour was determined according to the methods described by Juliano *et al.* (1985). The RVA was set for a 12.5-min run time with the temperature program: 1.5 min at 50°C, heating to 95°C at 12°C/min, 2.5 min at 95°C, and cooling to 50°C at 12°C/min (Anonymous, 1995). Two subsamples of each treatment combination were measured in the RVA. The peak and final viscosity in Rapid Visco units (RVU, 1 RVU=10 centi-Poise) were recorded and analyzed.

A Colorgard Color Meter (System 05, BYK Gardner, Silver Springs, Maryland) was used to measure the color of a 50-g sample of the head rice, in duplicate, using the L*a*b* scale. These values were then converted to hue angle ($\tan^{-1}$ b/a) and chroma $(a^2 + b^2)^{1/2}$ as described by McLellan *et al.* (1995). In addition, the surface lipid content of the head rice was measured. For this measurement, a Soxtec lipid extractor (System HT 1043, Tecator, Sweden) with petroleum ether as the solvent (b.p. 35 to 600C) was utilized according to the method described by Chen *et al.* (1997).

RESULTS AND DISCUSSION

The treatments tested in this experiment included a temperature level of 70°C; however, analysis only included temperatures up to and including 60°C. This was due to the excessive crumbling during milling of the rice treated at 70°C.

Fig. 1 shows that as temperature increased above 45°C, chroma increased, indicating a more intense color. Discoloration, as measured by chroma, could be controlled if temperatures were kept below 50°C for exposure durations less than 36 hr. To determine which treatments significantly affected yellowing as measured by hue angle and chroma, a model that included all main effects and two factor interactions was fit. Statistical analysis found cultivar, location, and MC interactions to be significant (p = 0.001) for chroma, with the temperature by exposure duration interaction having a highly significant effect ($p < 0.0001$). With this information, a final model was developed to describe chroma using linear and quadratic effects of temperature, a linear effect of exposure duration, and the temperature by duration interaction for each cultivar/location combination. Results showed that the model fit all combinations of cultivar and location for these factors, as shown by their highly significant p values ($p <$ 0.0001 to 0.03).

For hue angle, a model that included the main effects and two-way interactions showed the main effects of cultivar and location (p = 0.001) and MC (p = 0.04) as significant, but none of the interactions between these factors were significant. Temperature and exposure duration, as well as their interaction, were highly significant ($p < 0.0001$). A reduced model fitting the main effects of cultivar and location, linear effects of MC and duration, quadratic effects of temperature, and the interaction of temperature by duration was then tested. This model showed all of these factors to be significant ($p < 0.0001$) except for MC, which was marginally significant (p = 0.05). Although the cultivar and location effects were statistically significant, there was not a large range, so samples over all cultivars and locations were averaged and plotted. Fig. 2 shows that holding rough rice for 72 hr above 45°C caused hue angle to decrease after longer exposure durations, indicating that the rice became more reddish. This discoloration could again be controlled if temperatures were kept below 55°C for exposure durations less than 36 hr.

Viscosity of Cypress grain was affected by exposure duration and temperature (Fig. 3). The separation of the 60°C/72 hr viscosity profile shown in Fig. 3 did not appear at the 12-hr or 36-hr exposure durations (data not shown), nor did it appear in any of the Bengal samples. This suggested that a certain level of exposure temperature and exposure duration was necessary to affect viscosity. This also showed that the appearance of yellowing did not necessarily mean that there were changes in functional properties. Chroma and hue angle values of the rice showed yellowing at 55°C for 36 hr and 72 hr exposure durations, as well as at 60°C for 12-hr and 36-hr exposure durations, yet there was not a decrease in the viscosity of those samples (data not shown).

Surface lipid content and head rice yield for both Bengal and Cypress did not change with the different MCs, temperatures (in the range of 35 to 60°C), or exposure durations. Both cultivars showed tendencies of increasing in HRY at higher temperatures (Fig. 4), although there was not a dramatic change. Surface lipid content, measured to determine if the treatments affected the degree of milling of rice, was not significantly affected by treatment conditions.

SIGNIFICANCE OF FINDINGS

These experiments showed that the combined effects of temperature and exposure duration are the most important factors influencing yellowing as measured by hue angle and chroma. Overall, all experiments showed that by minimizing the time rice was exposed above 50°C to durations less than 12 hr, yellowing, as determined by hue angle and chroma measurements of bulk samples, was minimized.

While this research showed that the temperature and exposure duration of rice affected color and viscosity, additional research is needed. In the current study, color measurements were made on “bulk” samples. However, observations indicated that some kernels within the bulk samples incurred much greater color change than others; thus, research on the effects of treatment variables on individual kernels should now be conducted in an attempt to determine which kernels in a bulk are discolored by the treatments.

LITERATURE CITED

Aibara, S., H. Yamashita, I.A. Ismall, F. Sekiyama, and Y. Morita. 1984. Post-harvest changes in the respiratory activity of and ethanol accumulation in fresh rice grains. Agric. Biol. Chem. 48:1293-1301.

Anonymous. 1995. Assessing rice quality in the rapid visco analyser. RVA-4 Series Operation Manual, Newport Scientific Pty., Ltd., NSW Australia. p. 48.

Chen, H., B.P. Marks, and T.J. Siebenmorgen. 1997. Quantifying surface lipid content of milled rice via visible/near-infrared spectroscopy. Cereal Chem. 74:826-831.

Gilman, J.C., and D.H. Barron. 1930. Effects of molds on temperature of stored grain. Plant Physiol. 5:565-573.

Juliano, B.O., C.M. Perez, E.P. Alyoshin, V.B. Romanov, M.M. Bean, K.D. Nishita, A.B. Blakeney, L.A. Welsh, L.L. Delgado, A.W. ElBaya, G. Fossati, N. Kkongseree, F.B. Mendes, S. Brillante, H. Suzuki, M. Tada, and B.D. Webb. 1985. Cooperation test on amylography of milled rice flour for pasting viscosity and starch gelatinization temperature. Starch/Staerke 37:40-50.

McLellan, M.R., L.R. Lind, and R.W. Kime. 1995. Hue angle determinations and statistical analysis for multiquadrant hunter L,a,b data. J. Food Quality 18:235-240.

Misra, A.K. and D. Vir. 1991. Assessment of losses due to discoloration of paddy grains. Indian J. Mycol. and Plant Pathol. 21:277-278.

Phillips, S., S. Widjaja, A. Wallbridge, and R. Cooke. 1988. Rice yellowing during post-harvest drying by aeration and during storage. J. Stored Prod. Res. 24:173-181.

Sahay, M.N. and S. Gangopadhyay. 1985. Effect of wet harvesting on biodeterioration of rice. Cereal Chem. 62:80-83.

Schroeder, H.W. 1963. The relationship between storage molds and damage in high-moisture rice in aerated storage. Phytopathol. 53:804-808.

Singaravadivel, K. and S.A. Raj. 1983. Changes in parboiled rough rice caused by improper drying and microbial infection. J. Food Biochem. 7:15-21.

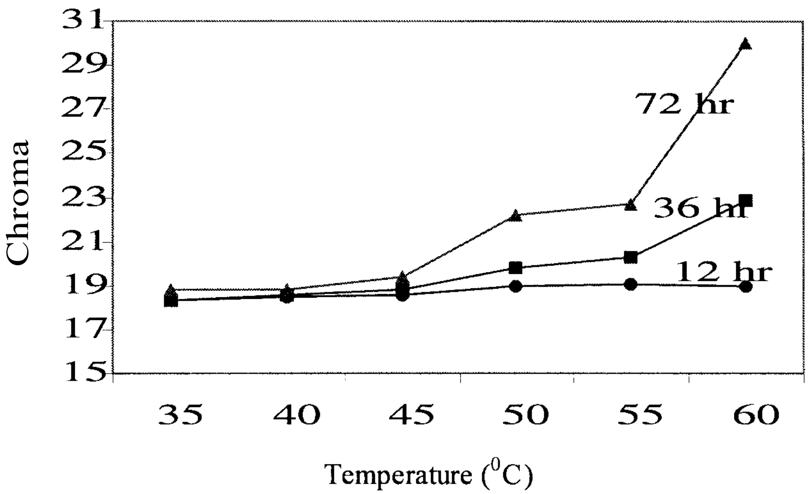


Fig. 1. Chroma values in which rough rice from each cultivar/location combination was exposed to a range of temperatures for the indicated durations. Each point represents the combined data from both high and low harvest MC samples from each cultivar (mean value of 16 color measurements).

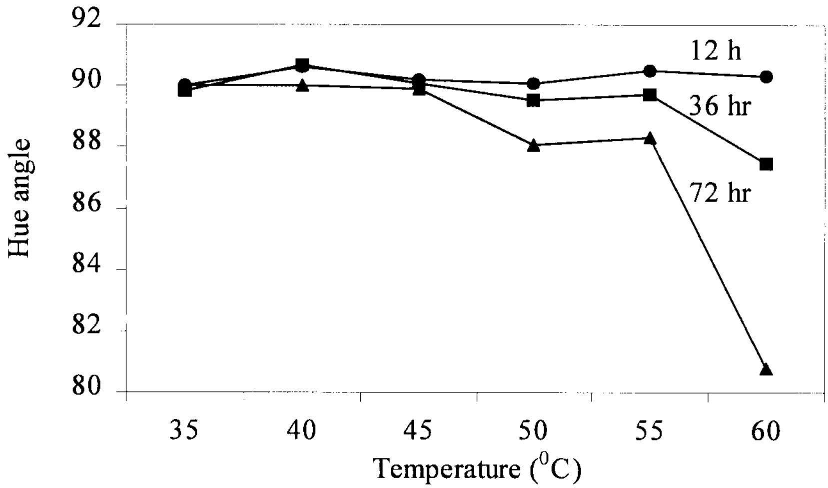


Fig. 2. Hue angle values in which rough rice was exposed to a range of temperatures for the indicated durations. Lower values indicate darker colored rice. Each point represents the combined data of Bengal and Cypress samples (mean value of 32 color measurements).

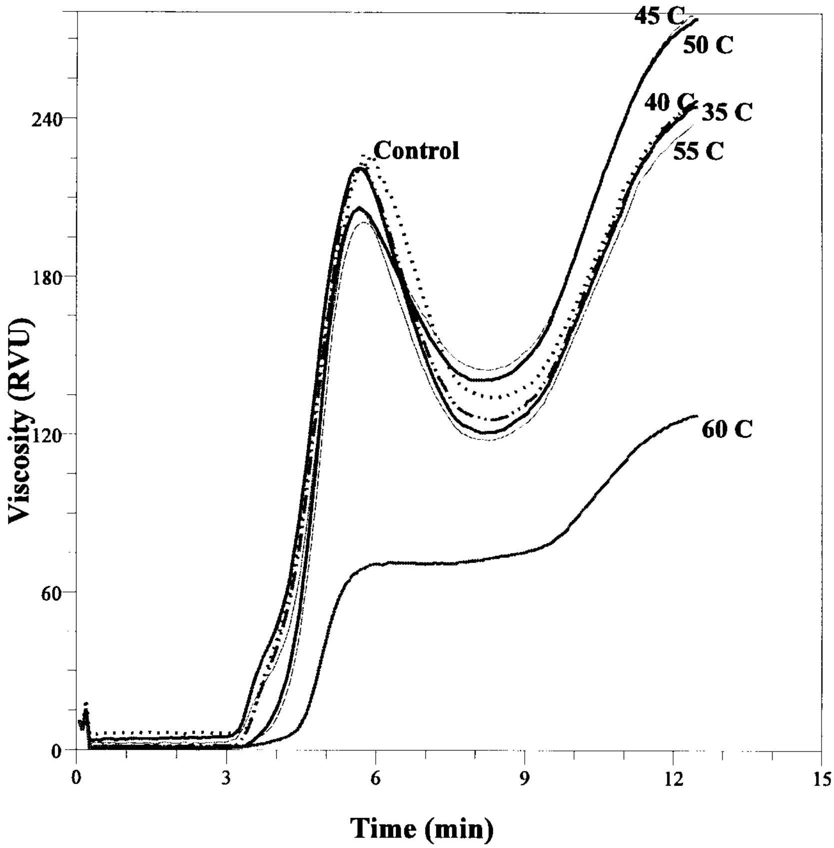
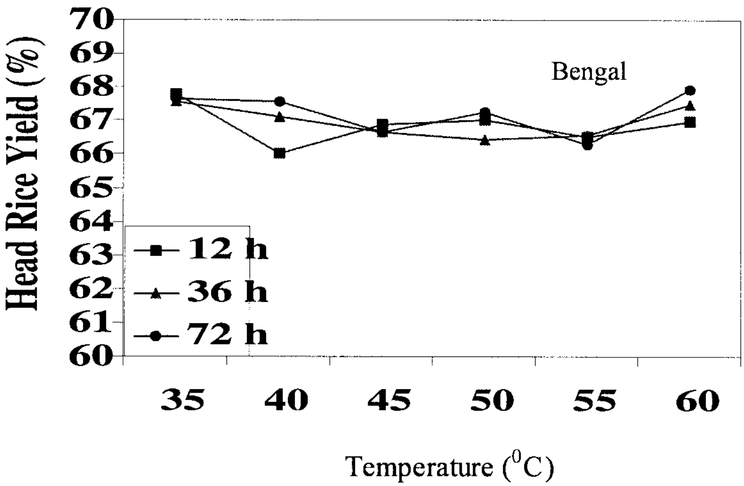


Fig. 3. Viscosity profiles for the indicated temperature treatments of Cypress rough rice for the 72-hr exposure duration.



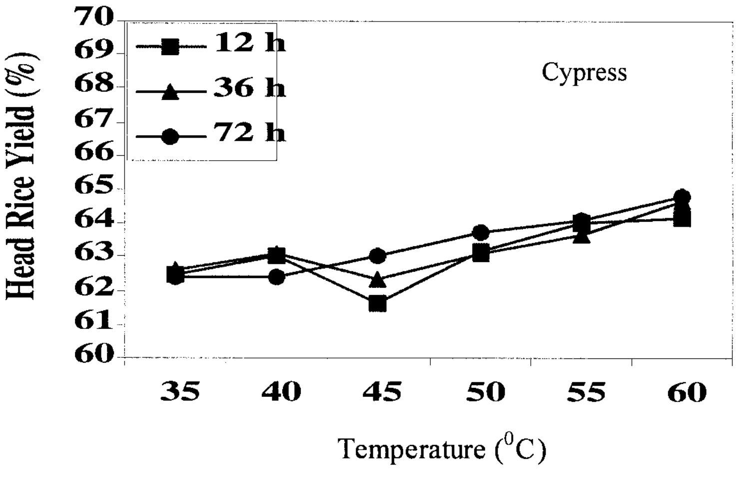


Fig. 4. Head rice yield for Bengal and Cypress rice. Each point represents the average of 16 separate measurements of head rice yield. Data for samples collected at Stuttgart and Keiser were combined.

EFFECTS OF STORAGE DURATION AND LOCATION (WITHIN BIN) ON RICE QUALITY FACTORS

T.A. Howell, Jr., M.S. Slape, and J-F.C. Meullenet

ABSTRACT

Rough rice (cv. 'Bengal') was dried slowly with ambient air and stored. Samples were removed from 15 locations within a bin [depths of 3, 6, and 9 ft at north (N), south (S), east (E), west (W), and center (C) positions] at monthly intervals for 4 months. Rice quality parameters were studied for each sample to determine the effect of storage location (within a bin) and duration on the traditional quality markers in rice. The head rice yield (HRY) peaked after 3 months of storage in every case. Cooking parameters (water absorption) did not appear to be affected by storage duration, location in bin, or depth. Peak viscosity of rice flour slurries increased during the storage interval studied but did not appear to be affected by location in bin or depth. Moisture content (MC) of the grain dropped slightly over time and was highly dependent on location in the bin (center had highest MC, followed by the N and E, then the S and W). The grain at the top of the bin had higher MCs than that in the middle.

INTRODUCTION

Throughout the storage process for rice, grain quality attributes change. These changes have been documented for a variety of storage conditions (Villareal *et al.*, 1976; Chrastil, 1990; Hamaker *et al.*, 1993). Findings from these studies have aided in the understanding of storage effects on rice quality. The optimization of storage conditions for rice is crucial to the continued economic success of farmers.

Head rice yield has been shown to increase initially upon storage (approximately over the first 2 to 3 months) and then decrease (Marks *et al.*, 1999). Villareal *et al.*

(1976) showed that water absorption during cooking increases with storage time. Little information is available on the effects of rice location within the bin. Each area of the bin receives different amounts of radiant heat from the sun, producing pockets of rice within a bin with distinctly different properties. The overall goal of this project is to further the understanding of the physicochemical changes in rice as a function of storage duration and location within a bin. These findings will then be related to laboratory data and used to construct computer models of the storage process.

PROCEDURES

Medium-grain rice (cv. Bengal) was collected from the farm of Mr. Scott Meins near Stuttgart. Samples (approximately 1 lb) were collected within a bin at five locations [N, S, E, W and C] and at three depths (3, 6, and 9 ft measured from the rice surface at the top of the bin) using a deep-bin grain probe, for a total of 15 samples. Subsequent samples were collected every month from each location and depth. Samples were returned to the University of Arkansas, Fayetteville, and stored overnight at 40°F. Moisture content was determined using two methods: a Shizouka-Seiki CTR-800 individual kernel moisture content meter (300 rough rice kernels) and an oven moisture content method. For the oven drying method, approximately 20-g samples were dried for 24 hr at 266°F (130°C) in a convection oven.

Rough rice (150 g) was hulled using a Satake Huller (Satake Engineering Co., Tokyo). The brown rice was milled for 40 sec using a McGill No. 2 mill. Degree of milling (DOM) was measured using a Satake MM1-B meter. Only whole kernels were used for the brown and milled rice testing. The whole kernels were separated from the brokens using a Grainman Shaker Table with 10/64 trays. Head rice yield was calculated by dividing the milled rice weight by 150 g and multiplying by 100 to get a percentage.

Cooking tests were performed to determine the water absorption (WA) of the head rice. A wire basket was weighed and 20 g of head rice was added to the basket and weighed. The basket was placed in a 250-mL beaker, and 150 mL of deionized water was added. The beaker was placed into a boiling kettle of deionized water at 400°F. The rice was cooked at 400°F for 10 min and then reduced to 300°F and cooked for 10 more minutes. The beaker was removed from the kettle, and the baskets were drained and cooled for 10 min. The wire baskets were weighed with the cooked rice, and the absorption ratio was calculated.

Amylographic properties of rice were determined by grinding the head rice to flour using a Udy Cyclone Sample Mill with a 40-mesh screen. Moisture content of the rice flour was determined using oven testing. Two grams of rice flour was heated in a convection oven for 1 hr at 266°F (130°C). After MC determination, samples were prepared on a 12% moisture basis by adding a given mass of rice flour, depending on MC, to a given volume of deionized water. The water and flour were mixed in a container and placed into the analyzer. Samples were analyzed using the Newport Scientific Rapid Visco Analyzer (RVA) Series-4 rice analysis procedure. Peak and final viscosity samples were collected.

RESULTS AND DISCUSSION

Head Rice Yield

The HRY data vs. storage duration showing the effect of location within a bin are shown in Fig. 1. The HRY at the N location was consistently higher than at the other locations. Values of HRY increased at each location through the week-12 sampling and dropped by the next sampling. This follows trends seen in previous years. The effect of storage depth on HRY is shown in Fig. 2. Although there is not a consistent pattern to show how depth affects HRY, it appears that the rice nearer the top of the bin may have reduced HRY compared to the 9-ft depth.

Water Absorption

Water absorption data record the ability of rice to absorb water while being cooked. The WA corresponds to the weight of the cooked rice to the weight of the raw, white rice. The ratio fluctuated between 1.5 and 1.9 for most samples but did not appear to have a definable pattern with respect to sampling depth (Fig. 3). The ratio drops from its initial values to a low between 8 and 12 wk of storage and then begins to rise again. Rice stored closer to the top of the storage bin may have lower WA, but the trend cannot be determined without more analysis.

Peak Viscosity

The peak viscosity (PV) is obtained from the RVA during heating of a rice flour-water slurry. The PV is related to the thickness of slurry during gelatinization and uses an applied rheological unit. Fig. 4 contains the PV data as a function of storage duration and location. The data show an increase in PV to around 250 RVA units as duration increased. The location in the bin did not appear to affect PV values based on these data. Overall, the peak viscosity does probably increase with storage time to a maximum point at which it either remains stable or begins to drop. We were not able to reach that point in this study.

Moisture Content

Moisture content decreased during the storage experiments. Moisture content of rice at the C location was consistently higher than at the other four locations. The MC of rice at the N and E locations typically were very similar, as was the MC of rice at the

S and W locations (Fig. 5). This is based on the amount of heat received solar radiation. As the depth increased, the MC decreased (Fig. 6). This trend continued throughout the study. The rice at the top of the bin did not reach the same MC as the rice in the middle of the bin (9-ft depth). In fact, the rice at the 3-ft depth did not drop below 13% during the study.

SIGNIFICANCE OF FINDINGS

The results from this study confirm previous research showing that HRY and other functional properties of rice improve or remain constant with storage duration to a point, and then begin declining. Also, in unaerated and/or unstirred bins, location and depth play an important role in rice quality attributes. Producers and processors should seek to create conditions in which their rice is as uniform as possible.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board as well as supporters of the University of Arkansas Rice Processing Program for their support of this project.

LITERATURE CITED

Chrastil, J. 1990. Chemical and physicochemical properties of rice during storage at different temperatures. J. Cereal Sci. 11:71-85.

Hamaker, B.R., T.J. Siebenmorgen, and R.H. Dilday. 1993. Aging of rice in the first six months after harvest. Arkansas Farm Research 42:8-9.

Marks, B.P., J. Cui, N.B. Reid, and M.J. Daniels. 1999. Predictive modeling of quality changes during rough rice storage. Presented at the 1999 International Meeting of the American Society of Agricultural Engineers, Paper No. 996045. ASAE, 2950 Niles Rd., St. Joseph, Mississippi.

Villareal, R.M., A.P. Resureccion, L.B. Suzuki, and B.O. Juliano. 1976. Changes in the physicochemical properties of rice during storage. Starch/Staerke 28:88-94.

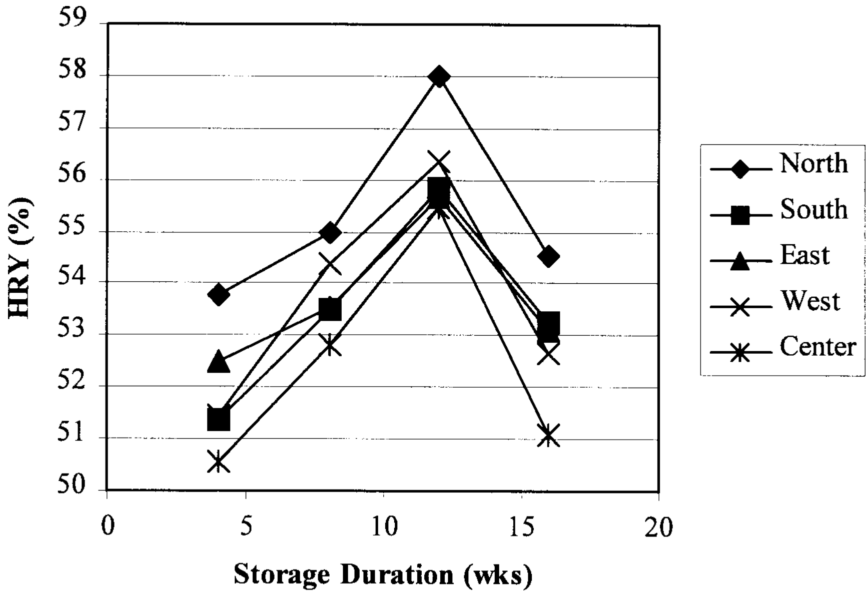


Fig. 1. Head rice yield (HRY) versus storage duration and location in rice bin.

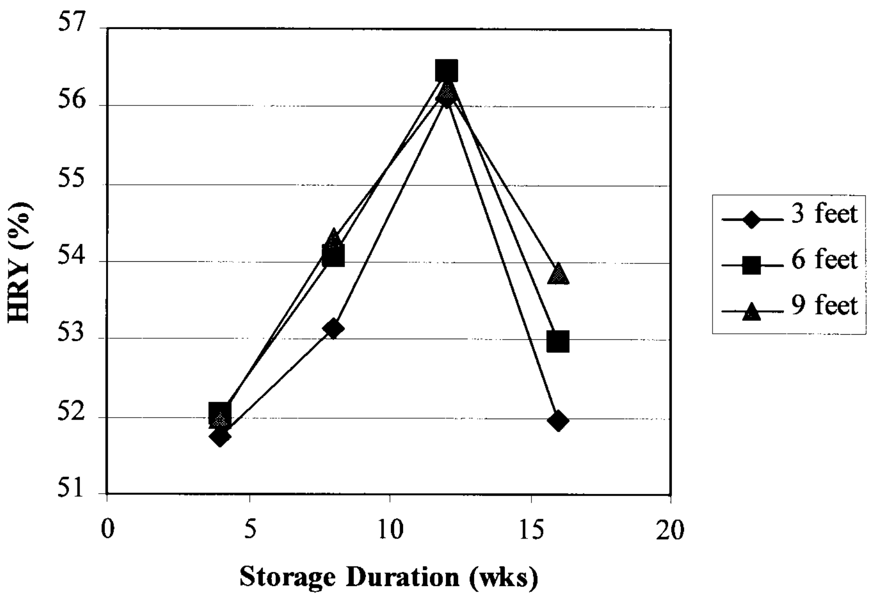


Fig. 2. Head rice yield (HRY) versus storage duration and depth.

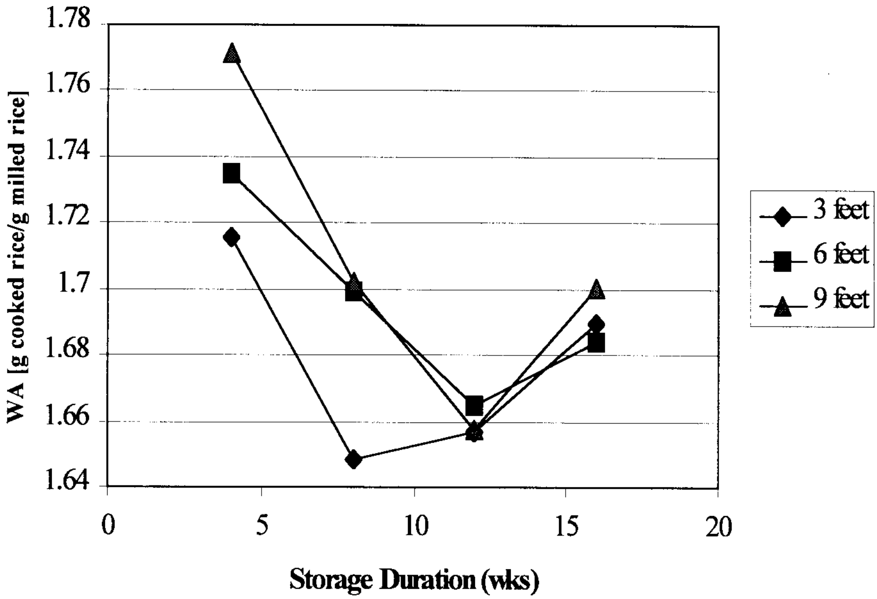


Fig. 3. Water absorption (WA) versus storage duration and depth.

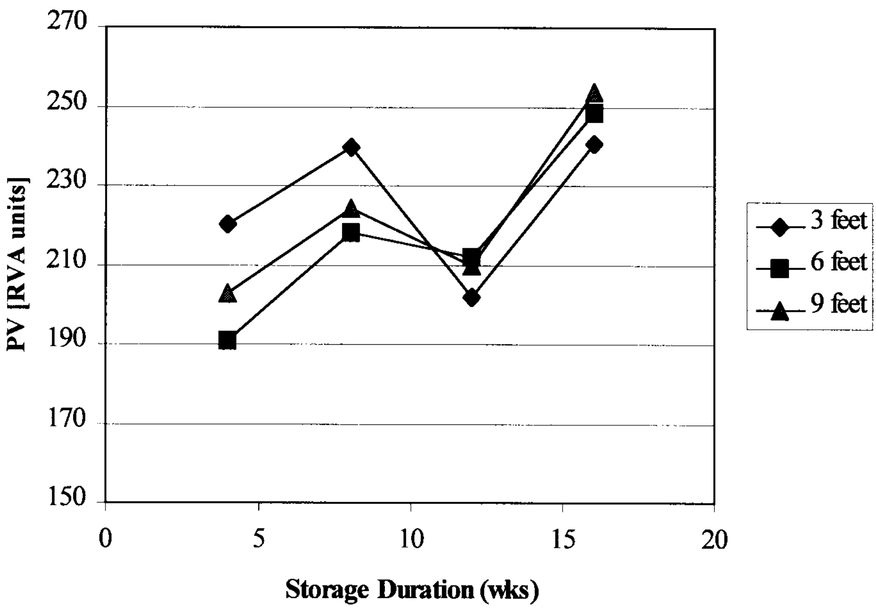


Fig. 4. Peak Viscosity (PV in RVA Units) versus storage duration and depth.

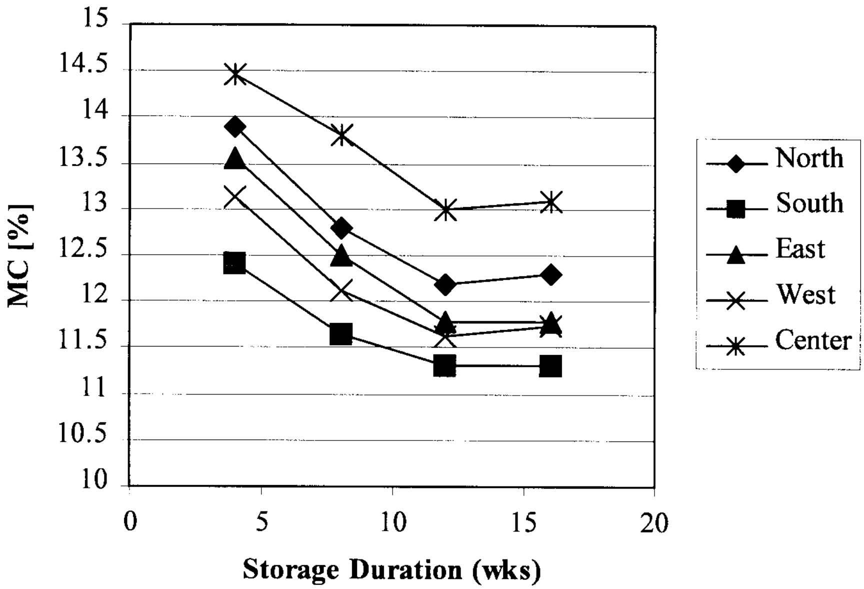


Fig. 5. Moisture content (MC) versus storage duration and location (in bin).

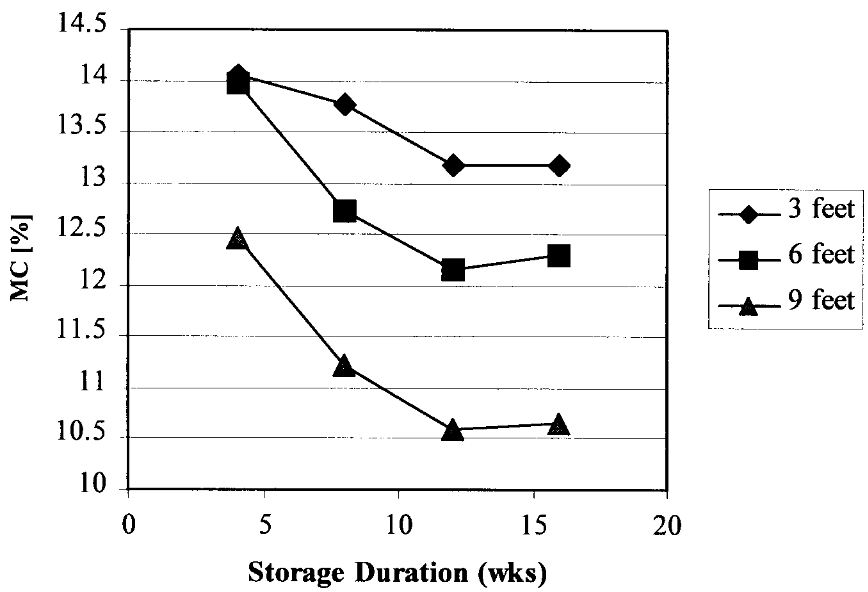


Fig. 6. Moisture content (MC) versus storage duration and depth.

EFFECTS OF COMMERCIAL PROCESSING ON ANTIOXIDANTS FOUND IN RICE BRAN

B.J. Lloyd, T.J. Siebenmorgen, and K.W. Beers

ABSTRACT

Rice bran is known to contain high amounts of beneficial antioxidants, including tocopherols, tocotrienols, and oryzanols. Current rice milling technology produces rice bran from various layers of the kernel caryopsis. Under current practices, these layers are combined and then often steam-extruded to form a stabilized rice bran pellet, which is storage-safe prior to oil extraction. Each of these rice bran "intermediates" is speculated to vary in antioxidant content. The objective of this study was to investigate the changes in selected antioxidants in rice bran from both long- and medium-grain rice during commercial milling and bran processing. Rice bran collected from the various milling breaks of a commercial system had varying antioxidant levels. Bran collected after the initial milling operations had the highest levels of tocopherol and tocotrienol. Results also indicate that the long-grain rice bran contained approximately 30% more antioxidants than bran from the medium-grain rice at selected processing locations.

INTRODUCTION

Rice bran has long been considered an excellent source of vitamins and other nutrients but has been an underutilized co-product from rice milling. Rice bran contains roughly 20% lipids, which is similar to other oilseeds, but rice bran oil (RBO) contains more unsaponifiable lipids than other common vegetable oil sources (Orthoeffer, 1996). RBO contains approximately 3 to 5% unsaponifiables (Sayre, 1988) depending on the type of rice (Gaydou *et al.*, 1980) and the method used to extract and refine the lipids. The unsaponifiable fraction in RBO contains a unique complex of naturally occurring antioxidant compounds of which the tocopherols (vitamin E), tocotrienols, and oryzanol compound groups have received the most interest.

These antioxidant compounds have purported health benefits as well as antioxidant characteristics for improving the storage stability of foods utilizing rice bran or RBO. Several studies have reported the effects of RBO on metabolic activities, including reduced plasma cholesterol reduction in humans (Hegsted *et al.*, 1990; Yoshino *et al.*, 1989). Oryzanol has been studied for its ability to reduce cholesterol absorption (Rong *et al.*, 1997). Komiyama *et al.* (1992) reported anti-cancer activity associated with tocotrienols. Thus, rice bran is being viewed as a potential source of these high-value antioxidants to be used as additives in foods, pharmaceuticals, and cosmetics. The overall goal of this study was to establish a better understanding of how commercial milling systems affect the levels of specific antioxidants in rice bran from long- and medium-grain varieties.

PROCEDURES

Long-grain and medium-grain classes of rice were used in this study. This rice was obtained from Riceland Foods (Jonesboro, Arkansas, Division) harvested from several commercial farms located in Craighead County in northeast Arkansas. The medium-grain rice was of a pure cultivar, 'Bengal'. The long-grain rice was denoted as an LG-1 class, which is a rice industry grain classification. This lot was not a pure cultivar, but a mixture of several cultivars of similar size.

Rice bran samples were procured from a commercial milling system (Riceland Foods in Jonesboro). The LG-1 samples were milled to retail packaged-rice specifications, and this rice underwent a three-break milling treatment. This milling treatment comprised three successive and separate Satake (Houston, Texas) commercial-sized milling machines (Fig. 1), which individually removed bran from the rice kernels. The medium-grain samples were milled to cereal customer specifications and were milled in only the first two of the three machines shown in Fig. 1.

Bran was collected after each separate milling machine, and then a sample from the composite bran stream was also collected. Finally, bran was collected at the outlet of a high-temperature steam-injection extruder. Fig. 1 shows a diagram of the locations where rice bran samples were collected in the commercial processing system.

The collected bran was stored –20°C (–4°F) to minimize enzymatic degradation of the lipids prior to lab analysis. Hexane was used as the solvent to extract the lipids and antioxidants from the bran sample. The extracted lipids were analyzed with high-performance liquid chromatography (HPLC) to quantify three primary antioxidants of interest: tocopherol, tocotrienol, and oryzanol. A detailed description of the HPLC analysis is given in Lloyd *et al.* (2000). The levels of these antioxidants were measured at each processing location.

RESULTS AND DISCUSSION

Processing Effects on Tocopherol Levels

Fig. 2 shows that there was a significant difference ($p < 0.05$) in tocopherol levels across most processing locations observed for long- and medium-grain rice bran. These results indicate that tocopherol levels varied according to the degree of polish of the rice kernel as well as location in the commercial processing stream. The bran from mill break #2 had the highest tocopherol concentration for long- and medium-grain rice of any sampling location. This might be attributed to removal of the concentrated aleurone layer during this milling step.

Long-grain bran that had been steam extruded into stabilized collets had minor changes in tocopherol content from the bran taken from mill break #1, mill break #2, and the composite sample. The steam extrusion process was anticipated to greatly reduce tocopherol levels because of the high temperature exposure (120°C), but no significant difference ($\alpha = 0.05$) was observed between the composite bran sample and the steam stabilized collet sample. Peterson (1994) noted no significant reduction in tocopherol levels in barley after a malting process, which included a final temperature of 85°C.

In a coomparison of tocopherol concentrations of long- and medium-grain rice bran, the bran collected from long-grain rice at mill break #1 had a significantly higher ($\alpha = 0.05$) tocopherol content than medium-grain bran at the same processing point. Long-grain rice bran collected after mill break #1 averaged 30% more tocopherol than bran from medium-grain rice.

Processing Effects on Oryzanol Levels

Fig. 3 shows the distribution of oryzanol levels among the different processing locations. Bran collected directly after mill break #1 had the highest oryzanol content at 6.42 g oryzanol/kg of bran for long-grain rice bran and 5.17 g of oryzanol/kg of bran for medium-grain rice bran. This indicates that the ferulate esters that comprise oryzanol predominantly resided in the outer pericarp, seedcoat, and nucellus layers, which are the outermost layers of a brown rice kernel (Mahadevappa and Desikachar, 1968).

A significant difference ($\alpha = 0.05$) in oryzanol content was noticed between the composite bran samples and the heat stabilized collets. A 26% decrease in oryzanol content of the composite rice bran occurred after the bran had been steam extruded.

In a comparison of long-grain and medium-grain bran, a significant difference ($\alpha = 0.05$) was found in oryzanol content of the bran from break #1 for long-grain rice bran and medium-grain rice bran. Long-grain rice bran averaged 19.5% more oryzanol for the bran collected from the outermost milling operation.

Processing Effects on Tocotrienol Levels

Fig. 4 illustrates the changes in tocotrienol levels in rice bran as affected by processing location. Like tocopherol, tocotrienol concentration was maximum in the bran taken from mill break #2 for both long- and medium-grain bran. The average concentration measured across processing locations was 150 ppm for this study. These levels across processing locations changed the least compared to the other antioxidants, indicating that tocotrienols are more stable throughout the processing system. A small decrease in tocotrienol occurred as a result of the steam extrusion process, but the effect was minimal. The overall difference in tocotrienol content among or across processing locations measured in this study was determined to be 1.56 mg tocotrienol/kg of bran, which was only a 10% difference. This relative change was much less than that of the other antioxidants. This would tend to indicate that tocotrienol was more uniformly distributed through the bran layer surrounding the kernel than tocopherol or oryzanol. This finding was similar to that of Peterson (1994), who reported that tocotrienol concentration in oat kernels was uniformly distributed throughout the endosperm. Like tocopherol and oryzanol, long-grain rice bran contained more tocotrienol than medium-grain rice bran.

SIGNIFICANCE OF FINDINGS

The origin of rice bran within the processing stream of a commercial rice bran processing system had a significant influence on antioxidant levels. Tocopherol and tocotrienol of long- and medium-grain rice bran from mill break #2 had the highest levels. Bran taken from mill break #1 had the highest oryzanol content. Also, there was not a pronounced decrease in tocopherol or tocotrienol levels after steam extrusion of rice bran, but oryzanol showed a 26% decrease prior to steam stabilization. These results show that bran from long-grain rice had an overall higher tocopherol, oryzanol, and tocotrienol content than bran from medium-grain rice.

LITERATURE CITED

Gaydou, E.M., R. Raonizafinimanana, and J.P. Bianchini. 1980. Quantitative analysis of fatty acids and sterols in malagasy rice bran oils. J. Am. Oil Chem. Soc. April 1980:141-142.

Hegsted, M., M. Windhauser, S. Lester, and S. Morris. 1990. Stabilized rice bran and germ product on hypercholersterolemia. Food Chemical News. November 13.

Komiyama, K., M. Hayashi, S. Cha, and M. Yamaoka. 1992. Antitumor and antioxidant activity of tocotrienols. *In:* Ong, A.S.H. and L. Packer (eds.). Lipid-Soluble Antioxidants: Biochemistry and Clinical Applications. Basel, Switzerland: Birkhauser Verlag, 152-159.

Lloyd, B.J., T.J. Siebenmorgen, and R.K. Beers. 2000. Effects of commercial processing on antioxidants found in rice bran. Cereal Chem. #6415 (in press).

Mahadevappa, M., and H.S.R. Desikachar. 1968. Some observations on the histology of raw and parboiled rice. J. Food Sci. Technol. 57(5):71-73.

Orthoefer, F.T. 1996. Rice bran oil: healthy lipid source. Food Technology 50(12):62-64.

Peterson, D.M. 1994. Barley tocols: effects of milling, malting, and mashing. Cereal Chem. 71(1):42-44.

Rong, N., L.M. Ausman, and R.J. Nicolosi. 1997. Oryzanol decreases cholesterol adsorption and aortic fatty streaks in hamsters. Lipids 32:303-309.

Sayre, R.N. 1988. Rice bran as a source of edible oil and higher value chemicals. *In:* Proceedings of the American Association of Cereal Chemists 73rd Annual Meeting. San Diego, California, 12 October.

Yoshino, G., T. Kazumi, and M. Amano. 1989. Effects of gamma-oryzanol and probucol on hyperlipidemia. Current Therapeutic Res. 45:975-982.

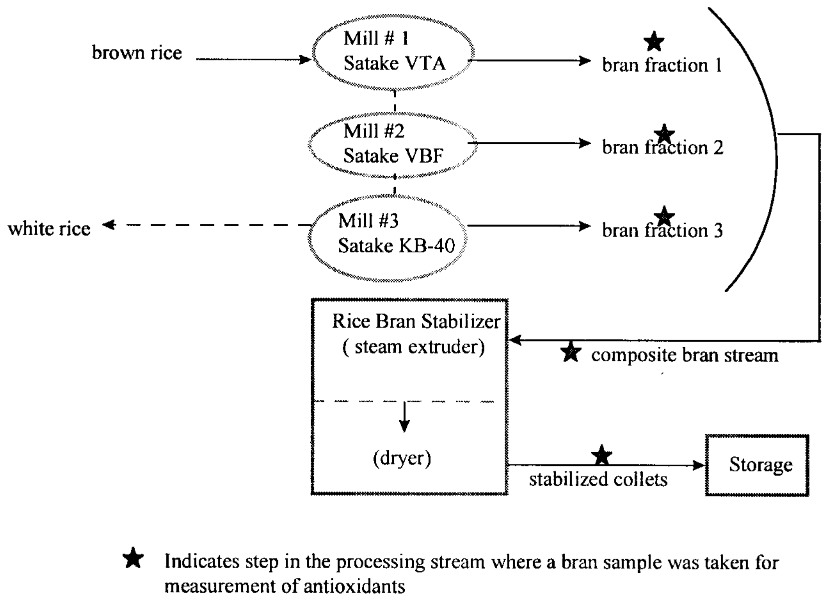


Fig. 1. Simplified schematic of the three-break, commercial rice mill and bran processing system used in this study.

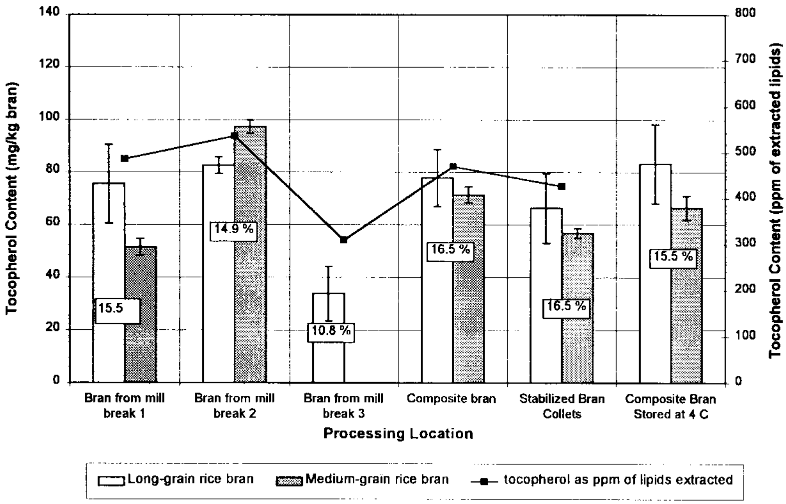


Fig. 2. Tocopherol concentrations for rice bran taken at various locations from a commercial rice-processing facility. Data points for a given location represent the mean of six subsamples collected on two dates. Error bars present the standard error of each mean value. Percentages are the amount of lipids extracted from the respective long-grain rice bran sample.

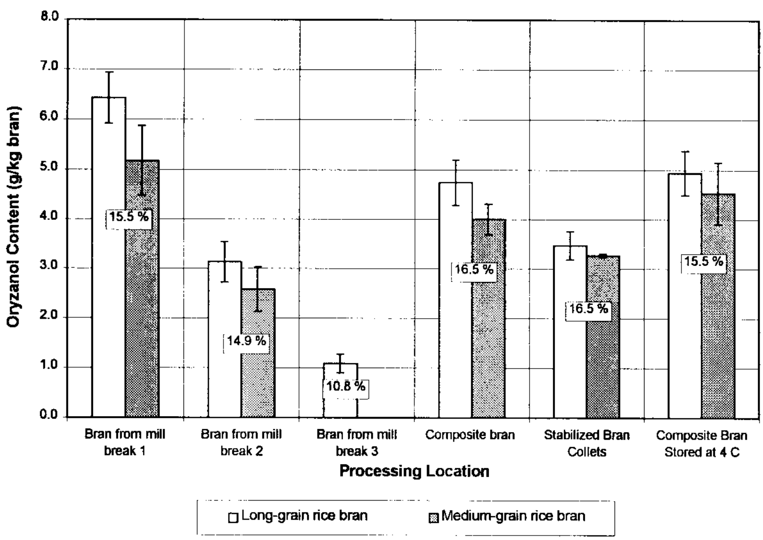


Fig. 3. Oryzanol concentrations for rice bran taken at different locations from a commercial rice-processing facility. Data points for a given location represent the mean of six subsamples collected on two dates. Error bars present the standard error of each mean value. Percentages are the amount of lipids extracted from the respective long-grain rice bran sample.

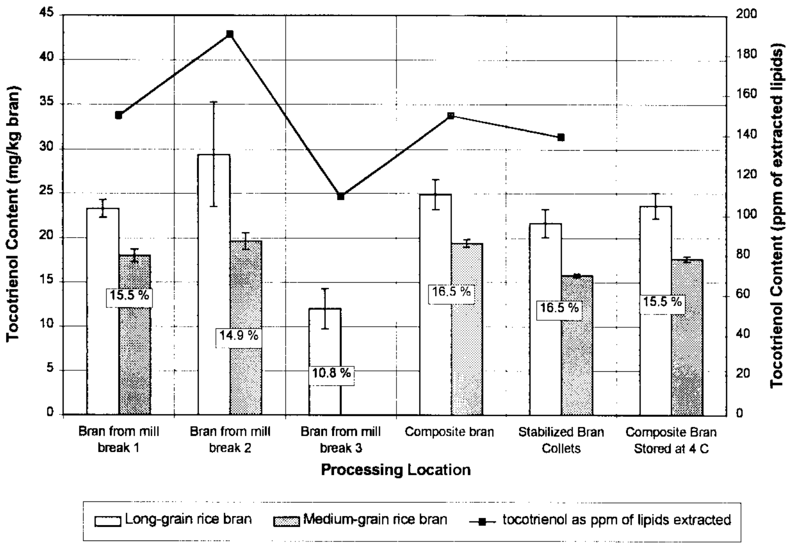


Fig. 4. Tocotrienol concentrations for rice bran taken at different locations from a commercial rice-processing facility. Data points for a given location represent the mean of six subsamples collected on two dates. Error bars present the standard error of each mean value. Percentages are the amount of lipids extracted from the respective long-grain rice bran sample.

CORRELATING FISSURE OCCURRENCE TO HEAD RICE YIELD FOR VARIOUS DRYING AND TEMPERING TREATMENTS

M.J. Jiménez, A.G. Cnossen, T.J. Siebenmorgen, and R.C. Bautista

ABSTRACT

Fissure occurrence was correlated to head rice yield (HRY) to determine optimum drying conditions and minimum tempering durations to maximize not only milling quality, but kernel physical integrity as well. Three drying conditions were used, two above the glass transition temperature (T_g) of the rice and one below. Immediately after drying, the samples were separated into four subsamples and tempered for 0, 80, 160, or 240 min at a temperature equal to that of the drying air. Brown rice kernels (200) were randomly selected and visually observed by one person using a light box and the percentage of fissured kernels determined. The results showed that the percentage of kernels having heavy fissures decreased with increasing tempering time. However, some samples still showed many fissures after extended tempering, yet these samples had a high HRY. This indicates that the tempering duration required for preventing kernel fissuring might be longer than the tempering duration required for maintaining HRY.

INTRODUCTION

Rice kernel fissuring and breakage is a major problem in the rice industry. Fissured kernels cause HRY reduction and thus decrease the value of the rice crop, since broken kernels are typically worth approximately half the value of whole kernels. Kunze and Hall (1965) stated that a rice kernel with two or three cross-sectional fissures has lost its commercial value.

A number of researchers have found that kernels do not fissure until after the drying process has ceased (Kunze, 1979; Nguyen and Kunze, 1984). Previous research (Cnossen *et al.*, 1999) on drying and tempering of rice, conducted by the University of Arkansas Rice Processing Program, has concluded that high drying air temperatures can be used without incurring HRY reduction, as long as proper tempering techniques are used (See "Determining Minimum Tempering Durations While Maintaining Head Rice Yield" found in this edition of the *Rice Research Studies*). High tempering temperatures seemed to be very effective in maintaining high HRYs. However, Siebenmorgen *et al.* (1998), Henderson (1954), and Matthews (1970) concluded that some fissured kernels would not break during the milling process and remain as head rice. During further processing (i.e., cooking, puffing, etc.) these kernels may break and thus reduce the quality of the final product and/or produce significant waste.

An understanding of the effect of various drying and tempering treatments on fissure occurrence, and the relation between fissure occurrence and breakage/HRY reduction will provide end-users, such as cereal and cooked-rice product manufacturers, with information to optimize their processing operations. Because of this paramount importance of milling quality and kernel physical quality, understanding this relationship would greatly improve the value, and thus the sustained profitability of rice. The following objectives were formulated for this study: (1) determine the effect of various drying and tempering treatments on fissure occurrence and (2) correlate fissure occurrence data and HRY data to determine optimum drying conditions and minimum tempering durations to maximize milling quality.

PROCEDURES

Drying and Tempering Treatments

Rice cultivars 'Bengal' (medium-grain) and 'Cypress' (long-grain) at two harvest moisture contents (MCs), high (around 19 to 20%) and low (around 17 to 18%), were harvested from research and extension centers at Stuttgart and Keiser during the 1999 harvest season. The samples were dried at three conditions, two with drying air conditions above the T_g of the rice [60°C, 16.9% RH; 5.4% equilibrium MC (EMC); and 60°C, 50% RH; 9.2% EMC] and one below T_g (40°C, 12% RH; 5.8% EMC), for two durations resulting in 4.5 and 6 percentage points MC (PPMC) loss. Immediately after a drying run, the rice batch was split up into four subsamples. One sample was immediately cooled by placing it in an EMC chamber set at 21°C and 55% RH; the sample was left in the chamber to gently dry to 12.5% MC. The other samples were tempered in a sealed bag for 80, 160, or 240 min at the temperature of the drying air before being taken out of the sealed bag to cool and then dry in the EMC chamber. The different drying durations created different magnitudes of moisture gradients inside the kernel; subsequently, the different tempering durations allowed different magnitudes of moisture gradient relaxation. This resulted in various levels of fissuring when the kernel was cooled and forced to undergo a transition from the rubbery to the glassy state.

Fissure Determination

After storage, the rice was hulled with a laboratory huller. The immature and chalky kernels were separated, and 400 brown rice kernels were randomly picked from each sample for the determination of the percentage of fissured kernels. Various methods have been used to determine the extent of fissuring in rice kernels. Stermer (1968) used two sheets of polarized light to make the fissures more visible and then photographed the rice kernels to visually observe and determine the amount of fissured kernels. Siebenmorgen *et al.* (1998) developed a roller mechanism that applied compressive pressure to each individual kernel, which resulted in breakage of the weaker, fissured kernels. The percentage of broken kernels was then determined.

In this project, one person using a light box visually observed the kernels. The light box was constructed as a rectangular box of blackened walls and bottom and glass top. The glass top was also blackened except for a 3-mm wide band across the middle, which allowed light to pass out of the box. The kernels were then put on top of this band and the fissures observed by moving the kernels across this line and into the shadowy region. This made it easier for the fissures to be identified as an obscured fraction of the kernel. Kernels were characterized as having light or heavy fissures, as illustrated in Fig. 1. Light fissures were defined as fissures that appear on the surface of the kernel, and heavy fissures were defined as internal fissures. After fissure counting, the 400 kernels were returned to the dried sample to be milled, and HRY was measured using a Graincheck 310-image analyzer (Foss North America, Minneapolis, Minnesota).

RESULTS AND DISCUSSION

Cnossen *et al.* (1999) hypothesized that if rice is tempered above the T_g line long enough to reduce MC gradients, a state transition will not cause HRY reduction; insufficient MC gradient reduction before a state transition will produce fissures and consequent HRY reduction. As can be seen in Fig. 2, when 6.0 PPMC are removed without tempering, a dramatically lower HRY was observed compared to a gently dried control sample. However, the samples that were tempered for 80 and 160 min showed a significant increase in HRY. The samples tempered for 240 min showed only a small HRY reduction compared to the control sample.

Table 1 shows the percentage of heavy and light fissured kernels, and the HRY results for Bengal. The results indicate that the number of fissured kernels having heavy fissures decreased with increasing tempering duration. In Fig. 2, both the percentage of heavy fissured kernels and the HRY were plotted against tempering duration. From Fig. 2, we can see that the sample tempered for 240 min still had a lot of fissured kernels while having a high HRY close to the HRY of the control sample. These kernels did fissure but apparently did not break in the milling process.

Table 2 shows the results for Cypress. The results show that the number of fissured kernels having heavy fissures was a good deal lower than for Bengal; because of a thinner kernel, Cypress is more resistant to fissuring. From Fig. 3, we can see that the HRY did not further improve after 80 min of tempering and that the number of fissured kernels did not further decease either.

The number of kernels having light fissures increased slightly with increasing tempering duration. For Bengal, the samples dried with the high RH drying air showed a higher number of kernels having light fissures.

We can conclude that kernels that fissure during drying and tempering do not necessarily break in the milling process. Consequently, the tempering durations required for preventing kernel fissuring might be longer than the tempering durations required for maintaining HRY.

SIGNIFICANCE OF FINDINGS

Fissuring is an important economic issue in the rice industry. The value of the rice is decreased by this factor, and therefore ways to minimize breakage must be found. Optimal drying conditions and minimum tempering time allowance will decrease the fissuring in rice. Although some fissured kernels will not break even after milling, there is a potential that they may in other processes such as cooking or puffing. An understanding of the relationship between fissuring and HRY will help end-use processors optimize their processing operations.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board and the University of Arkansas Rice Processing Program Industry Alliance Group for the financial support of this project.

LITERATURE CITED

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and W. Yang. 1999. Incorporating the glass transition temperature concept in rice drying and tempering to optimize moisture removal and milling quality. ASAE Paper No.996022. ASAE, Toronto, Ontario.

Henderson, S.M. 1954. The causes and characteristics of rice checking. Rice J. 57(5):16,18.

Kunze, O.R. 1979. Fissuring of the rice grain after heated air-drying. Transactions of the ASAE 22:1197-1202,1207.

Kunze, O. R. and C.W. Hall. 1965. Relative humidity changes that cause brown rice to crack. Transactions of the ASAE 8(3):396-399,405.

Matthews, J., T. Abadie, H.J. Deobald, and C.C. Freeman. 1970. Relation between head rice yields and defective kernels in rough rice. Rice J. 73:6-12.

Nguyen, C.N. and O.R. Kunze. 1984. Fissures related to post-drying treatments in rough rice. Cereal Chem. 61(1):63-68.
Siebenmorgen, T.J., Z.T. Nehus, and T.R. Archer. 1998. Milled rice breakage due to environmental conditions. Cereal Chem. 75(1):149-152.
Stermer, R. A. 1968. Environmental conditions and stress cracks in milled rice. Cereal Chem. 45:365-373.

Table 1. Percent heavy and light fissured kernels, and head rice yield (HRY) for cultivar Bengal dried under two conditions, each for two durations, and tempered for four durations. The harvest moisture content was 17.5% and the HRY of the control sample was 64%.

Drying Condition	Tempering	Heavy fissures	Light fissures	HRY
	(min)	-------	(%)	-------
4.5 PPMR[z]	0	64	6	52
	80	43	6	60
60°C,	160	47	4	64
50% RH[y]	240	43	12	65
6.0 PPMR	0	69	3	32
	80	55	3	53
60°C,	160	53	6	57
50% RH	240	49	6	60
4.5 PPMR	0	68	2	37
	80	47	6	60
60°C,	160	49	2	63
16.9% RH	240	40	8	64
6.0 PPMR	0	81	2	32
	80	65	0	47
60°C,	160	49	3	59
16.9% RH	240	57	5	59

[z] PPMR is percentage points moisture reduction in one drying pass.
[y] RH = relative humidity.

Table 2. Percent heavy and light fissured kernels, and head rice yield (HRY) for cultivar Cypress dried under two conditions, each for two durations, and tempered for four durations. The harvest moisture content was 18.6% and the HRY of the control sample was 63%.

Drying Condition	Tempering	Heavy fissures	Light fissures	HRY
	(min)		(%)	
4.5 PPMR[z]	0	12	6	61
	80	9	11	64
60°C,	160	7	10	63
50% RH[y]	240	7	10	63
6.0 PPMR	0	12	7	58
	80	9	7	62
60°C,	160	10	6	63
50% RH	240	9	9	62
4.5 PPMR	0	12	6	58
	80	6	11	62
60°C,	160	9	15	63
16.9% RH	240	10	11	63
6.0 PPMR	0	16	8	56
	80	9	13	62
60°C,	160	10	6	62
16.9% RH	240	8	10	63

[z] PPMR is percentage points moisture reduction in one drying pass.
[y] RH = relative humidity.

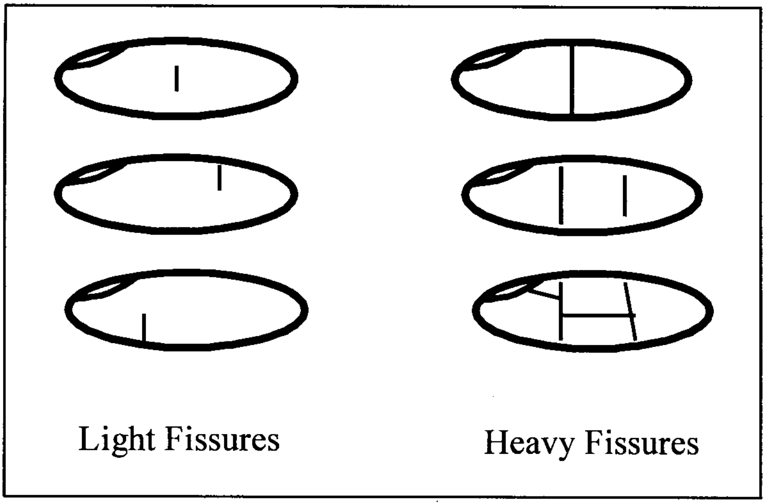


Fig. 1. Characterization of the various types of fissures.

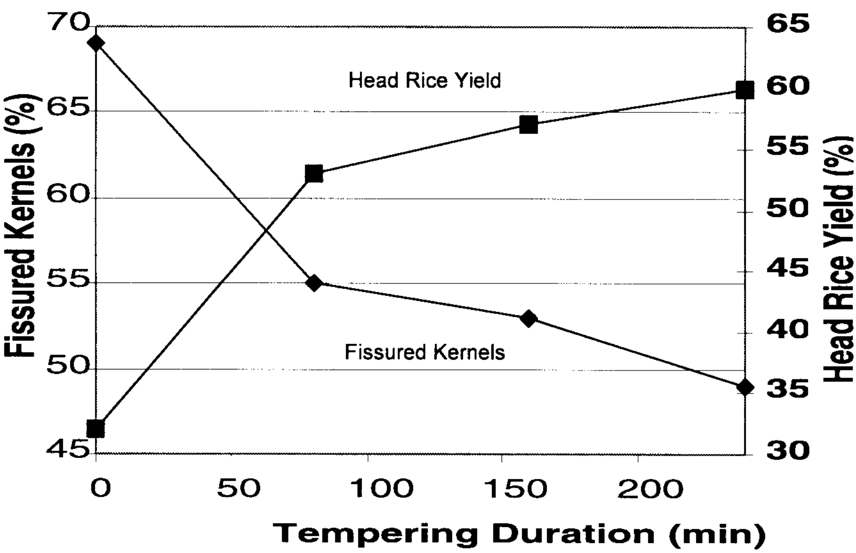


Fig. 2. The percentage of heavily fissured kernels and head rice yield versus tempering duration for cultivar Bengal after 6.0 PPMC were removed in one drying pass. The head rice yield of the control sample was 64%. The harvest MC was 17.5%.

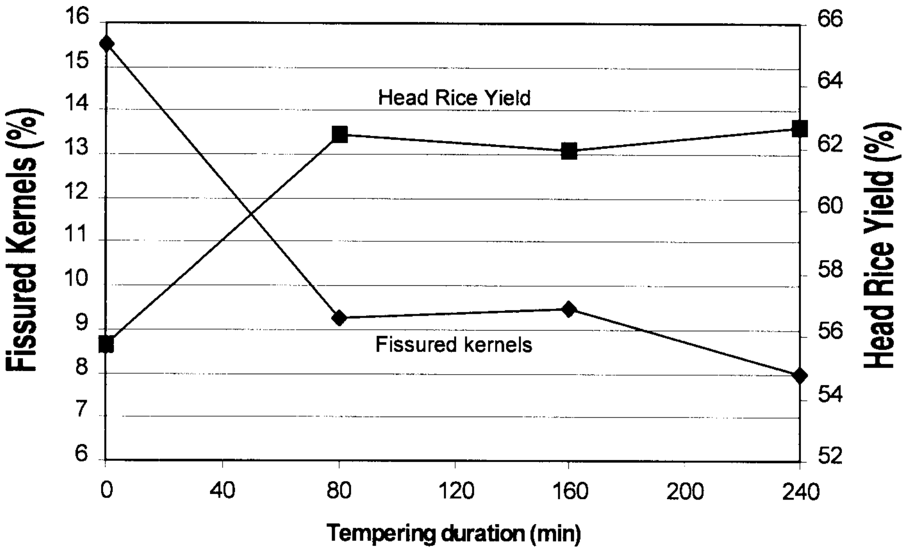


Fig. 3. The percentage of heavily fissured kernels and head rice yield versus tempering duration for cultivar Cypress after 6.0 PPMC were removed in one drying pass. The head rice yield of the control sample was 63%. The harvest MC was 18.6%.

RICE PROTEIN PREPARATION, THERMAL PROPERTIES, AND DENATURATION

Z.Y. Ju, N. Hettiarachchy, and T.J. Siebenmorgen

ABSTRACT

A simple procedure has been developed to extract rice proteins (albumin, globulin, glutelin, and prolamin) and to efficiently recover proteins from the extracts. The three proteins—albumin, globulin, and glutelin—were precipitated at their isoelectric pH (4.1, 4.3, and 4.8, respectively). Prolamin was precipitated by acetone. The four proteins were heterogeneous, and each contained >10 protein fractions as analyzed by reverse-phase high-performance liquid chromatography (RP-HPLC). The denaturation temperatures of albumin, globulin, and glutelin were 73.3, 78.9, and 82.2°C, respectively, and prolamin did not show a denaturation peak. The surface hydrophobicities of two main proteins, globulin and glutelin (representing 13% and 80% of total protein, respectively), progressively increased with increase in temperature and denaturation. The measurement of surface hydrophobicity may be as an effective tool to evaluate protein denaturation in rice.

INTRODUCTION

Good rice nutritional quality is of primary interest to consumers. Consumer recognition of rice as a healthy food has resulted in greater consumption. Environmental conditions during drying, milling, and storage affect rice quality by influencing functionality of rice components (Marshall and Wordsworth, 1994). Moisture interaction with protein and starch can affect rice biochemical and quality properties. However, the definitive roles of these components have not been established.

Protein and starch content in rice are approximately 9 and 80%, respectively.

Rice proteins contain albumin (5%), globulin (12%), glutelin (80%), and prolamin (3%) (Juliano, 1994). Rice drying, storage, and milling can change protein structure, denature proteins, and influence rice quality (Juliano, 1994). It is important to correlate rice quality with varying drying and storage conditions and develop methods to detect protein denaturation, functionality, characteristics, and interaction with other rice components (Chrastil, 1990). The objectives of this research are to develop effective methods to extract the four types of rice proteins—albumin, globulin, glutelin, and prolamin—from rice flour and to determine protein denaturation.

PROCEDURES

Materials

Rice flour from broken rice (long-grain, RL 100) was provided by Riceland Foods, Stuttgart. Analytical reagents were purchased from Fisher Scientific (Pittsburgh, Pennsylvania) and Sigma Chemical Co. (St. Louis, Missouri).

Protein Extraction From Rice Flour

A flow diagram for extraction of rice proteins is given in Fig. 1.

Separation of Proteins from Extracts

Albumin, globulin, and glutelin were precipitated from their supernatants by adjusting pH to their isoelectric points (Ips). The Ips were determined by subjecting portions of each supernatant to pH values ranging from 3.0 to 10.0 and determining the turbidity (OD 320 nm) with a spectrophotometer (Varian Series-634, Varian Techtron PTY. LTD, Australia). The pH that gave the maximum turbidity was taken as the Ip. Prolamin was precipitated by addition of acetone to the supernatant according to procedure of Tecson *et al.* (1971). The precipitated proteins (albumin, globulin, glutelin, and prolamin) were washed with distilled water twice, adjusted to pH 7.0, freeze-dried, and stored at 4°C.

Pure starch was prepared from the residue (crude starch) from protein extraction. The residue was sequentially washed with water (600 ml), ethanol (300 ml), acetone (300 ml), and diethyl ether (300 ml), centrifuged (1000 *g* for 10 min), and dried under a hood for 24 hr to remove residual solvents.

Quantification of Proteins

The Kjeldahl method was used to measure nitrogen content in freeze-dried protein products (AACC, 1983). The protein content was calculated from nitrogen contents.

Protein Characterization

The fractions of rice proteins (albumin, globulin, glutelin, and prolamin) were detected by RP-HPLC using a Hewlett packard liquid chromatograph equipped with a diode array ultra-violet (UV) detector. Trifluoroacetic acid buffer system was used with a flow rate of 1.2 mL/min. Proteins in the extracts and freeze-dried products were detected at 254 nm according to Juliano (1994).

Thermal Properties of Proteins

Thermal analysis of protein can provide valuable information on heat-induced structural and functional changes in food processing systems. Thermal characteristics of the four proteins were evaluated by a Perkin-Elmer DSC-4 (Norwalk, Connecticut). The samples were scanned during temperature increase from 20 to 120°C at 10°C/min. Onset denaturation temperature, denaturation temperature, and enthalpy value of denaturation were computed from each thermogram (Ju *et al.*, 1999).

Hydrophobicity Determination

Hydrophobicity is a very important parameter to evaluate protein's functionality such as emulsification, foaming, fat, and flavor binding. Protein denaturation could deteriorate functionality of rice proteins and influences rice quality. Monitoring protein hydrophobicity will give information on native and denatured proteins.

Surface hydrophobicity of rice protein was determined using a Kontron Spectrofluorometer, at 390 nm (excitation) and 470 nm (emission). The 8-anilino-1-naphthalenesulfonate (ANS) was used as a fluorescent probe (Kalapathy *et al.*, 1997).

RESULTS AND DISCUSSION

Proteins in Rice Flour and Recovery

Turbidity measurement showed that Ip of albumin, globulin, and glutelin occurred at pH 4.1, 4.3, and 4.8, respectively. The maximum amounts of each protein were precipitated at their Ips.

The rice flour (long-grain –100) contained 8.8% of protein. This protein contained 4.5% water-soluble albumin, 13.1% salt-soluble globulin, 79.7% alkali-soluble glutelin, and 2.6% alcohol-soluble prolamin.

The method in Fig. 1 successfully extracted 97.4% of total proteins. Of the total protein, 82.3% albumin, 91.5% globulin, 93.2% glutelin, and 90.2% prolamin were recovered from the respective supernatants (Fig. 1).

Protein Components in Albumin, Globulin, Glutelin, and Prolamin by RP-HPLC

Reverse-phase HPLC of rice prolamin has been used to characterize rice varieties (Juliano, 1994). The RP-HPLC profiles of the four proteins showed more than 10 peaks. Each peak represents one protein component, and the peak area reflects the content of the protein fraction. This indicates that the rice proteins were heterogeneous and each protein contained more than 10 components.

Reverse-phase HPLC separated proteins based on their hydrophobicity (Otte *et al.*, 1996). Hydrophilic protein components were eluted out first and hydrophobic proteins later. The profiles from RP-HPLC showed that water-soluble albumin proteins were eluted at less than 5 min, indicating their hydrophilic properties. While alcohol- and alkali-soluble prolamin and glutelin proteins were eluted at a range of 16 to 21 min, indicating their hydrophobic properties. Salt-soluble globulin proteins had two groups of proteins eluted out at < 5 min (hydrophilic) and at range of 18-21 min (hydrophobic), respectively.

Thermal Properties of Rice Flour, Starch, and Proteins

Thermal analysis of rice flour, starch, and proteins provides information on their cooking quality properties and provides information on their physical and chemical energetic effects including denaturation, crystallization, melting, glass transition, or other reactions.

Thermal properties of rice proteins, flour, and starch subjected to heat treatment (20 to 120°C) are shown in Fig. 2. The denaturation temperatures of albumin, globulin, and glutelin were 73.3, 78.9, and 82.2°C, respectively, and melting temperature of rice starch was 84.7°C (Table 1). Rice flour mainly containing ~9% protein and ~80% starch had a melting temperature at 80.5°C. This finding indicates that temperatures of 73 to 85°C are important for textural properties in rice cooking. Prolamin did not show any denaturation peak. Albumin and globulin had lower denaturation temperatures (73.3 to 78.9°C) and enthalpy values (2.88-3.14 J/g) than glutelin (82.2°C, 3.79 J/g; Table 1), suggesting that these two proteins can easily be denatured.

Protein Denaturation and Surface Hydrophobicity

In general, protein denaturation results in an increase of hydrophobicity because of exposure of hydrophobic groups folded inside the intact native protein molecule. Fig. 3 shows the surface hydrophobicity of native and denatured rice proteins (globulin and glutelin). The surface hydrophobicity significantly increased as the extent of denaturation increased (Fig. 3). This indicates that surface hydrophobicity values could be used to evaluate the extent of denaturation of the proteins in rice. Rice protein functional properties such as emulsion, foam, gelation, and binding flavor could also be predicted by the measurement of the hydrophobicity.

SIGNIFICANCE OF FINDINGS

1. A protein extraction method was developed that can extract 97% of total protein from rice flour.

2. Recovery efficiencies of rice proteins were 82 to 93% from these extracts. The residue after protein extraction could be processed to obtain pure starch.

3. Denaturation temperature of rice proteins was first revealed to be from 73 to 82°C. Measurement of surface hydrophobicity is a simple way to monitor the extent of denaturation in rice.

4. Surface hydrophobicity may be used to monitor protein denaturation during rice maturation, harvesting, drying, storage, and processing.

ACKNOWLEDGMENT

The authors appreciate the Arkansas Rice Research and Promotion Board for providing fund for this research.

LITERATURE CITED

AACC. 1983. Approved methods of the AACC. Methods 22-60. Eighth edition, AACC, Inc. St. Paul, Minnesota.

Chrastil, J. 1990. Protein-starch interaction in rice grain. Influence of storage on oryzenin and starch. J. Agric. Food Chem. 38:1804-1809.

Ju, Z.Y., N.S. Hettiarachchy, and A. Kilara. 1999. Thermal properties of whey protein aggregates. J. Dairy Sci. 82:1882-1889.

Juliano, B.O. 1994. Rice: Chemistry and Technology. Juliano, B.O. (ed.). American Association of Cereal Chemists, St. Paul, Minnesota.

Kalapathy, U, N.S. Hettiarachchy, and K.C. Phee. 1997. Effect of drying methods on molecular properties and functionalities of disulfide bond-cleaved soy proteins. J. Am. Oil Chem. Soc., 74:195-199.

Marshall, W.G. and J.I. Wordsworth. 1994. Rice Science and Technology. Marcel Dekker, Inc., New York.

Otte, J., Z.Y. Ju, and K.B. Qvist. 1996. Protease-induced aggregation and gelation of whey proteins. J. Food Sci., 61:911-915, 923.

Tecson, E.M.S., B.V. Esmama, L.P. Lontok, and B.O. Juliano. 1971. Studies on the extraction and composition of rice endosperm glutelin and prolamin. Cereal Chem. 48:168-181.

Rice Flour (100g)
↓
Defat with hexane (400 ml)
↓
Air-dry (under hood for 24 h)
↓
Water Extract (400 ml, 20°C, shaking 4 h)
↓

Supernatant (Albumin) | Residue
↓
Salt Extract
(400-ml 5% NaCl, 20°C, shaking 4 h)

Supernatant (Globulin) | Residue
↓
Alkali Extract
(400-ml 0.02 M NaOH, pH to 11.0, 20°C, shaking 30 min)
↓

Supernatant (Glutelin | Residue
↓
Alcohol Extract
(300 ml 70% alcohol, 20°C, shaking 4 h)
↓

Supernatant (Prolamin) | Residue (Crude starch)

Fig. 1. Flow diagram for extraction of rice proteins.

MILLED RICE SURFACE LIPID AND DEGREE OF MILLING DETERMINATION BY DIFFUSE REFLECTANCE FOURIER TRANSFORM INFRARED SPECTROSCOPY

G. R. Reddy and A. Proctor

ABSTRACT

'Drew' rice was milled for 10, 20, 30, and 40 seconds and grain from each milling time separated into kernel thickness fractions. The milled rice surface lipid was measured by weighing the lipids obtained by solvent extraction. The diffuse reflectance Fourier Transform Infrared (FTIR) spectroscopy response of the triglyceride carbonyl groups and total carbonyl groups on the surface of the milled rice was measured. Solvent extracted lipids correlated highly with the triglyceride carbonyl response (R^2 = 0.92), while a weaker correlation was found with total carbonyls (R^2 = 0.77). Both extraction and FTIR data showed that lipid content was independent of kernel size and distinguished among rice with different degrees of milling (DOM). FTIR offers the opportunity for rapid measurement of rice surface lipids and the advantage of being able to monitor changes in specific lipids, that is not possible with Near-Infrared (NIR) spectroscopy.

INTRODUCTION

Milled rice total lipid content is commonly used to measure the DOM, which is an important quality factor because residual bran oil deposited on the kernel during milling can degrade to free fatty acids, aldehydes, and ketones that adversely affect flavor quality. The weight of the solvent extracted lipid is routinely used to measure surface lipid. However, there is interest in developing rapid methods to more quickly determine total lipid content. Near Infra Red spectroscopy techniques rapidly determine DOM by measuring total surface lipids (Chen *et al.*, 1997), but do not show changes in lipid chemistry that would impact quality. However, diffuse reflectance Fourier Transform Infrared spectroscopy would provide this additional information by distinguishing and measuring triglyceride oil, free fatty acids, and aldehyde/ketone off-flavors separately. These substances are vital in determining the end use quality for many commercial rice users.

The objectives of this initial study were to (1) investigate the effectiveness of triglyceride carbonyl stretch intensity (1737-1776cm-1) and combined triglyceride, free fatty acid, aldehyde, and ketone carbonyl stretch intensities (1702- 1780 cm-1), as measured by FTIR, to rapidly determine total lipids and DOM; and (2) observe the effect of kernel size on the FTIR spectral response and solvent extracted surface lipid.

PROCEDURES

Grain samples from the long-grain cultivar Drew were dried to 9 to 10% moisture, dehulled, and milled for either 10, 20, 30, or 40 sec with a McGill no. 2 mill. The milled rice was separated into thickness fractions of <1.59 mm, (fraction 1) 1.59-1.79 mm (fraction 2), and >1.79 mm (fraction 3). Duplicate samples from each milling time and size fraction were subject to lipid analysis by Soxtec HT solvent extraction system (Hogan and Deobald, 1961). Corresponding samples were subject to FTIR analysis using a Nicolet Impact 410 instrument to obtain 40 spectra from each sample each consisting of 100 scans (Proctor *et al.*, 1996). The response from triglyceride was obtained by measuring the carbonyl peak area in the range 1737 to 1776 cm^{-1}. The total response from triglyceride, free fatty acid, aldehydes, and ketones was also obtained by measuring the peak area in the range 1702 to 1780 cm^{-1}. Correlation curves of percent lipid extracted against FTIR peak areas were plotted. The data were also plotted as kernel size against lipid content obtained by extraction and FTIR. The FTIR peak areas were converted to lipid values using the correlation curve.

RESULTS AND DISCUSSION

Fig. 1 shows the correlation curve of FTIR triglyceride carbonyl peak against solvent extracted oil. The R2 value is 0.92 with a RMSE of 0.07. The data suggest a high degree of correlation between the triglyceride carbonyl stretch on the rice surface and solvent extracted lipid. However, when the solvent extracted lipid was correlated with the FTIR total carbonyl peak areas from combined triglyceride, free fatty acids, aldehydes, and ketone response (Fig. 2) a much lower R2 of 0.77 and greater RMSE of 0.13 was obtained. The weaker correlation with the combined lipid peak areas was probably because each lipid had a different molar response to the radiation and indicates that FTIR quantification of each lipid should be done separately.

Fig. 3 shows the lipid content of three rice kernel sizes for each milling time as measured by both lipid extraction and FTIR triglyceride response. The data conform to a previous report (Chen and Siebenmorgen, 1997) that showed lipid content is independent of kernel thickness, with a slight increase in lipid content in the smaller kernels (thickness 1). The results obtained by the extraction and FTIR methods were similar, with most differences between the techniques being most evident at longer millings times, when lipid content was small.

Fig. 4 shows the lipid content of various rice kernel sizes for each milling time as measured by both lipid extraction and the FTIR peak areas of combined triglyceride, free fatty acid, and aldehyde responses. Although the trend is similar to that in Fig. 3, FTIR values tend to differ more from the solvent extraction data, relative to the data obtained from triglyceride spectra alone.

SIGNIFICANCE OF FINDINGS

FTIR determination of surface lipid and DOM is best determined by triglyceride carbonyl measurement alone rather than total carbonyls. This is probably because triglyceride comprises the vast majority of surface lipids. Furthermore, the molar response to the infrared radiation may vary among carbonyl containing molecules, which would reduce the accuracy if the total lipid spectrum used. FTIR triglyceride determination appears to be a reliable method for DOM determination under normal milling conditions. However, solvent extraction data are needed for FTIR lipid calibration. The potential value of FTIR is the ability to measure separately triglycerides, and other lipids on the rice surface, that are rice quality indicators.

ACKNOWLEDGMENT

The authors wish to thank the Arkansas Rice Research and Promotion Board for support of this project.

LITERATURE CITED

Chen, H., B.P. Marks, and T.J. Siebenmorgen. 1997. Quantifying surface lipid content of milled rice by visible/near-infrared spectroscopy. Cereal Chem. 74:826-831.

Chen, H., and T.J. Siebenmorgen. 1997. Effect of rice kernel thickness on degree of milling and associated optical measurements. Cereal Chem. 74:821-825.

Hogan, J.T. and H.J. Deobald. 1961. Note on a method to determine degree of milling of whole milled rice. Cereal Chem. 73:257-263.

Proctor, A., C. Adhikari, and G.D. Blyholder. 1996. Lipid adsorption on commercial silica hydrogels from hexane and changes in triglyceride complexes with time. J. Am. Oil Chem. Soc. 73:693-698.

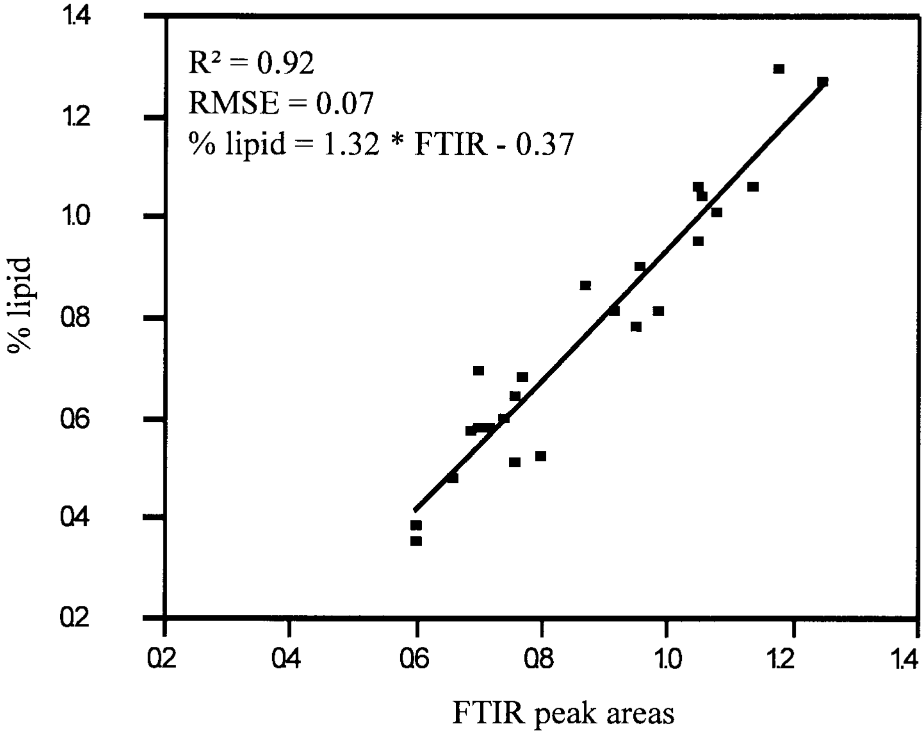


Fig. 1. Correlation of lipid content obtained by Soxtec solvent extraction with the FTIR peak area of triglyceride carbonyl stretch (1737 to 1776 cm^{-1}) obtained from long-grain rice (Drew). Rice samples were milled for 10, 20, 30, and 40 sec to obtain grain of various DOM and with a range of surface lipid content. Grain from each milling time was sorted into kernel thickness sizes (<1.59, 1.59-1.79, >1.79 mm) before analysis.

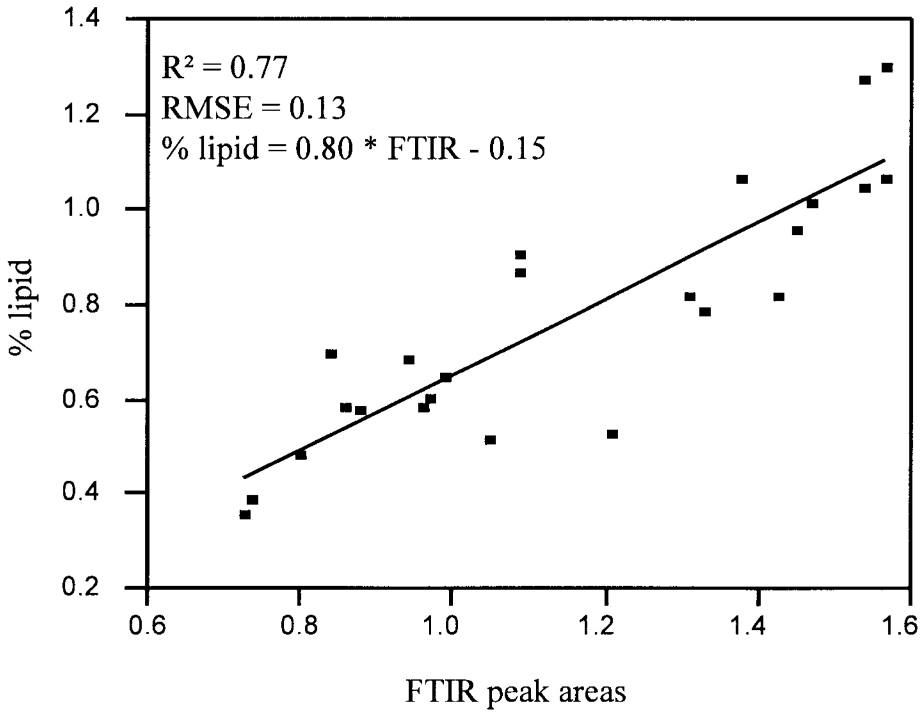


Fig. 2. Correlation of lipid content obtained by Soxtec solvent extraction with the FTIR peak area of total lipid carbonyl stretch (1702 to 1780 cm^{-1}) obtained from long-grain rice (Drew). Rice samples were milled for 10, 20, 30, and 40 sec to obtain grain of various DOM and with a range of surface lipid content. Grain from each milling time was sorted into kernel thickness sizes (<1.59, 1.59-1.79, >1.79 mm) before analysis.

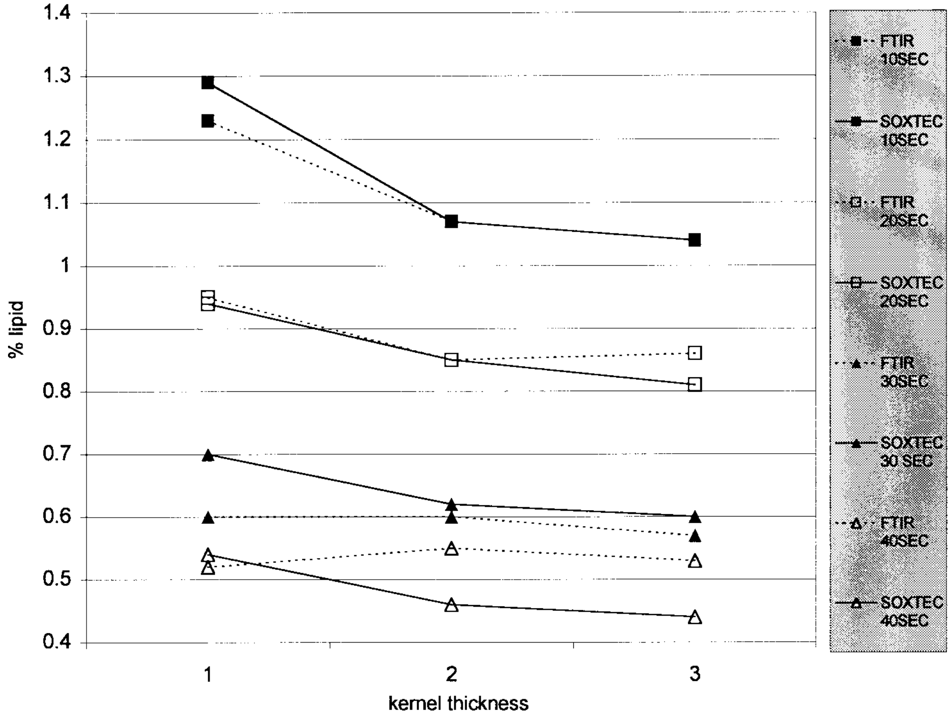


Fig. 3. Lipid content of long-grain rice (Drew) milled for 10, 20, 30, and 40 sec and sorted into kernel thickness sizes of <1.59 mm (thickness 1), 1.59-1.79 mm (thickness 2), and >1.79 mm (thickness 3). Lipid was determined by Soxtec solvent extraction and triglyceride FTIR peak area reaponse (1737-1776 cm^{-1}).

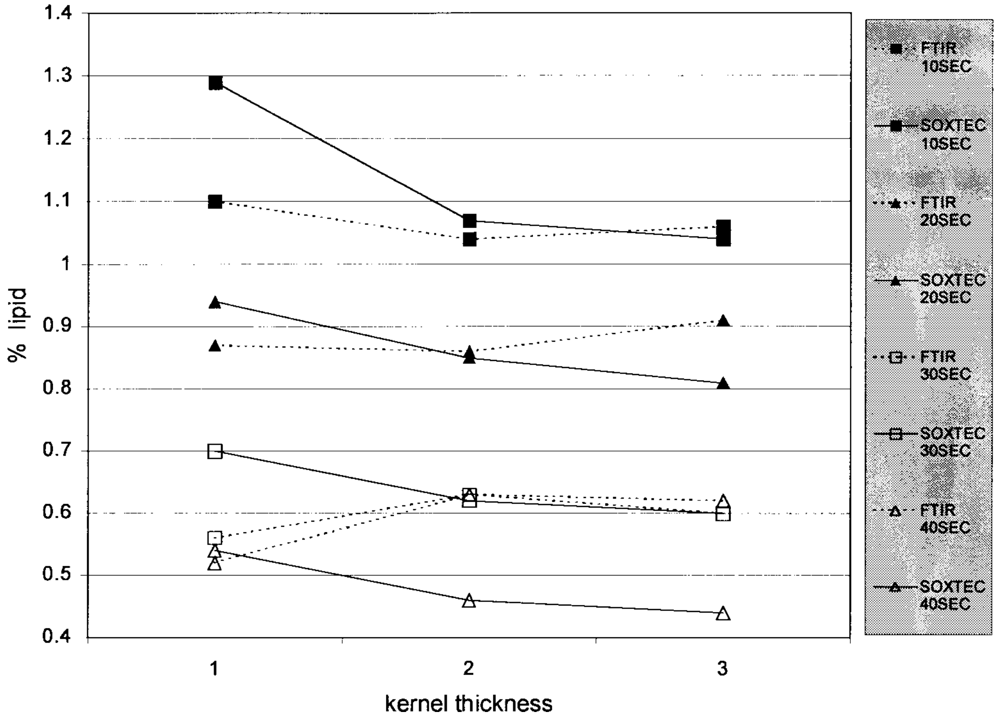


Fig. 4. Lipid content of long-grain rice (Drew) milled for 10, 20, 30, and 40 sec and sorted into kernel thickness sizes of <1.59 mm (thickness 1), 1.59-1.79 mm (thickness 2), and >1.79 mm (thickness 3). Lipid was determined by Soxtec solvent extraction and by total lipid carbonyl FTIR peak area reaponse (1702-1780 cm^{-1}).

PREDICTION OF RICE SENSORY TEXTURE ATTRIBUTES USING MULTIPLE INSTRUMENTAL PARAMETERS FROM A SINGLE COMPRESSION TEST, MULTIVARIATE REGRESSION AND A STEP-WISE MODEL OPTIMIZATION METHOD

A. Sesmat and J-F. Meullenet

ABSTRACT

Sensory texture characteristics of cooked rice (92 samples) were predicted using a compression test and a novel multivariate analysis method. Eleven sensory texture characteristics were evaluated via a trained descriptive panel, and 14 instrumental parameters from a compression test were used in combination with Partial Least Squares Regression to evaluate predictive models for each of the sensory attributes studied. Among the texture attributes evaluated by the panel, seven (cohesion of bollus, adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, and toothpack) were satisfactorily predicted after the optimization by the step-wise method (optimized Rcal > 0.6).

INTRODUCTION

Many researchers have studied the instrumental evaluation of cooked rice texture, and several instrumental methods have been examined. At present, one of the most popular and reliable instrumental methods involves the use of an Ottawa extrusion cell (Meullenet *et al.*, 1998; Juliano, 1984). The dimensions of the traditional Ottawa cell require rather large quantities (i.e., around 100 g of milled rice) of rice for evaluation. Compression tests, which require smaller sample sizes, performed between flat plates have been described by several researchers (Juliano *et al.*, 1984; Juliano *et al.*, 1981; Okabe, 1979; Szczesniak, 1975). Juliano *et al.* (1984) demonstrated that an instrumental method utilizing small sample sizes (i.e., a few kernels) was less reliable than tests performed on bulk samples. However, the successful development of a technique requiring a few kernels would be invaluable to rice-breeding programs to quickly and inexpensively assess texture characteristics of cooked rice. The objectives of this study were (1) to evaluate an instrumental compression method requiring small rice samples suitable for predicting cooked rice texture characteristics and (2) to evaluate the use of Partial Least Squares Regression for developing predictive models of specific texture attributes.

PROCEDURES

Rice Samples

All cultivars were harvested from the Rice Research and Extension Center from Stuttgart in 1998. Harvest moisture contents of the rice varieties were between 17 and 19% (wet base), respectively. The first sample set (75 samples) included only three rice cultivars [i.e., 'Drew' (D); 'Bengal' (B); and 'Kaybonnet' (K)] and constituted samples involved in drying and storage studies conducted by the University of Arkansas Rice Processing Program. In addition, 17 cultivars, obtained from the same location were used as an additional set of samples. Cultivars and varieties included in this sample set were: 89Y-235, 'Wells', RU9601096, RU961099, STG93M6-104, 'Arkrose', 'Baldo', Bengal, 'Dellrose', Drew, 'Irga 409', 'Koshihikari1', 'Koshihikari2', M202, 'Nato', S201, Toro2.

Sensory Evaluation

Eleven trained panelists evaluated and intensified 11 texture attributes of cooked rice. Attributes evaluated and definitions are described in Table 1. Complete sample preparation and sensory evaluation procedures are given in Meullenet *et al.* (1998, 1999).

Instrumental Texture Analysis

Because the sample availability did not allow for the instrumental test to be performed using the same protocol as for sensory testing, 10 g of milled rice was combined with 17 g of water in a 100-ml beaker and cooked in a rice cooker (National, model SR-W10FN) under steam conditions for 30 min. A texture analyzer (model TA-XT2i, Texture Technologies Corp., Scarsdale, New York) was used to perform the compression test. Five intact rice kernels were selected and placed in a single layer on a clean flat aluminum base. The compression plate traveled (0.5 mm/sec) for a distance defined to compress the kernels to 90% of their original height. Each of the 14 instrumental parameters calculated are defined in Fig. 1.

Statistical Analysis

Unscrambler (version 6.11b, CAMO, Throndheim, Norway, 1996), a multivariate analysis software was used to determine predictive models of sensory texture attributes using the 14 instrumental parameters as predictors. Partial Least Squares Regression was used for predicting sensory attributes from these parameters. The accuracy of the prediction was expressed using the Root Mean Square Error of Prediction (RMSEP). The lower the RMSEP calculated, the more accurate the prediction is. Stot/RMSEP was useful to estimate the relative error made by the prediction model compared with the difference reported by the panelists. The ratio of Root Square Error of Prediction and Root Square Error of Calibration (RMSEP/RMSEC) was also used as an indication of model robustness. The correlation coefficient for the calibration (RCal) and the validation (RVal) models were also used to evaluate the quality of both models.

Among the instrumental parameters used, many are probably not useful to the prediction of a given attribute and will create noise in the predictive model (i.e., it contains random variation that does not contain any information). As a result, a novel method (i.e., step-wise method) was used to optimize the original models.

RESULTS AND DISCUSSION

Prediction of Cooked Rice Texture

Cohesion of bollus was not well predicted by the full regression model (Rval = 0.57, Table 2). However, results were improved by the step-wise optimization method (Rval = 0.61, Table 3). Furthermore, the optimized model exhibited a RMSEP/RMSEC ratio close to 1 and the ratio of Stot/RMSEP was high (RMSEP/RMSEC=1.07 and Stot/RMSEP=3.75, Table 3). Hence, the model was robust, and its relative error was low compared to the standard deviation of the cohesion of bollus intensities across all samples. The RMSEP (–4.18%, Table 3) and Rval (+7.99%, Table 3) for the optimized model were found to be improved over values for the full regression model. Therefore, the method of optimization employed here allowed a significant improvement of the regression model. Adhesion to lips was the attribute for which the best predictive model was evaluated using the step-wise optimization method. The correlation coefficient for the validation model was the highest (Rval = 0.84, Table 3), RMSEP/RMSEC (1.05, Table 3) was close to 1, and Stot/RMSEP was relatively high (4.02, Table 3). The model was robust enough and the prediction was mainly influenced by three instrumental parameters (i.e., the product height (r_1=0.44, Table 3), the distance traveled by the plunger at the maximum negative force (r_9 = –0.25, Table 3), and the negative area under the curve (r_{14} = –0.84, Table 3). The influence of the sample height shows that the rice samples exhibiting higher adhesion to lips also featured a plumper kernel. This is not surprising, since stickier rice kernels such as medium-grain cultivars are also usually thicker. The two other instrumental parameters involved in the prediction of adhesion to lips were indicative of the adhesion stage of the compression test (Fig. 1, from B to C), a result expected for this sensory attribute. The optimized model was reduced to a total of 10 instrumental variables (Table 3). Hardness is the most commonly evaluated sensory attribute using instrumental tests. Hardness was also well predicted by the optimized model (Rval = 0.76, Table 3) using all the variables, except the maximum negative force value. The most important instrumental parameters were found to be the negative area under the curve (r_{14} = 0.21, Table 3) and the initial gradient (r_{10} = 0.14, Table 3). The later relationship was expected, since the force required to compress a hard sample increases faster than the force required to compress a less hard sample, resulting in a higher initial gradient. This result, which is in agreement with results reported by Meullenet *et al.* (1998), demonstrated that the hardness of the cooked rice was most highly correlated with initial slope. The RMSEP from the full regression model was improved by the step-wise method (–5.08%, Table 3) and the RMSEP/RMSEC ratio was the lowest of all the seven sensory attributes suitably evaluated (RMSEP/RMSEC = 1.04, Table 3). In addition, the Stot/RMSEP ratio (3.29, Table 3) was also high enough to conclude that the optimized predictive model of hardness has an acceptable prediction ability. Cohesiveness of mass was also one of the sensory attributes well predicted by the compression test data. Indeed, the performance indicators for the optimized model described a suitable predictive model. Rval (0.74, Table 3) was reasonably high. The RMSEP/RMSEC ratio (1.04, Table 3) was close to 1, and the Stot/RMSEP ratio (3.84, Table 3) was acceptable. The correlation coefficient for the validation of the optimized model for roughness of mass was adequate (Rval = 0.74, Table 3). This coefficient was improved by the step-wise optimization method (i.e., 8.83% improvement, Table 3). The RMSEP was also decreased by 8.44% (Table 3). Moreover, as for all the other models, the ratio RMSEP/RMSEC was close to 1 (0.99, Table 3) ,and the Stot/RMSEP was somewhat high (4.35, Table 3).

Toothpull showed slightly more disappointing results than for other sensory attributes (Rval = 0.63, RMSEP/RMSEC = 1.06 and Stot/RMSEP= 3.43, Table 3). However, the model was robust and its relative error of prediction was low. The regression coefficients for the 11 predictive variables were all lower than 0.09 and did not allow the identification of the most influential instrumental variables. From previous research conducted at the University of Arkansas (Meullenet *et al.*, 1998; Meullenet *et al.*, 1999), it was expected to find the prediction model for toothpack to be acceptable. Unfortunately, toothpack was predicted with moderate accuracy, even after the optimization process (Rval = 0.59, Table 3). However, the RMSEP/RMSEC ratio was close to 1 (1.07, Table 3), and the Stot/RMSEP ratio was the highest of all the optimized models (5.17, Table 3). The step-wise method was able to increase the correlation coefficient for the validation model by 3.97% (Table 3). No significant correlation (Rcal < 0.6) between sensory attributes and instrumental parameters was reported for particles size, cohesiveness, loose particles, and residual film.

SIGNIFICANCE OF FINDINGS

The use of a compression test in combination with multivariate analysis techniques and the step-wise optimization method allowed the satisfactory prediction of seven main attributes of cooked rice texture (cohesion of bollus, adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, and toothpack). However, the compression test has some limitations because it uses few kernels that may not be representative of the distribution of kernel properties.

Although this method might be less reproducible than extrusion tests and its error could be slightly higher, it is also less demanding on rice sample quantities necessary to perform the test. This feature may be of special interest to rice breeders.

LITERATURE CITED

Camo AS. 1996. The Unscrambler 6 User's Guide. Computer-Aided Modelling A/S, Trondheim, Norway.

Juliano, B.O., C. Perez, S. Barber, A.B. Blakeney, T. Iwasaki, N. Shibuya, K. Keneaster, S. Chung, B. Laignelet, B. Launay, A.M. Del Mundo, H. Suzuki, J. Shiki, S. Tsuji, J. Tokoyama, K. Tatsumi, and B.D. Webb. 1981. International cooperative comparison of instrumental methods for cooked rice. J. Texture Studies. 12:17-38.

Juliano, B.O., C.M. Perez, E.P. Alyoshin, V.B. Romanov, A.B. Blakeney, L.A. Welsh, N.H. Choudhury, L.L. Delgado, T. Iwasaki, N. Shibuya, A.P. Mossman, B. Siwi, D.S. Damardjati, H. Suzuki, and H. Kimura. 1984. International cooperative test on texture of cooked rice. J. Texture Studies 15:357-376.

Meullenet, J-F., J. Gross, B.P. Marks, and M. Daniels. 1998. Sensory descriptive texture analyses of cooked rice and its correlation to instrumental parameters using an extrusion cell. Cereal Chem. 75(5):714-720.

Meullenet, J-F., C. Sitakalin, and B.P. Marks. 1999. Prediction of rice texture by spectral stress strain analysis: a novel technique for treating instrumental extrusion data used for predicting sensory texture profiles. J. Texture Studies 30:435-450.

Okabe, M. 1979. Texture measurement of cooked rice and its relationship to the eating quality. J. Texture Studies 10:131-152.

Szczesniak, A.S. 1975. General foods texture profile revisited—Ten year perspective. J. Texture Studies 6:5-17.

Table 1. Vocabulary for sensory textural attributes of cooked rice.

Term	Definition	Technique
INITIAL STAGE:		
Cohesion of bollus	The degree to which the unchewed sample holds or sticks together.	Place ¼ teaspoon of sample in mouth and immediately evaluate how tightly the mass is sticking or holding together. Do not chew or manipulate!
Particle size	The amount of space the particle takes up in the mouth. (How big are the particles?)	Place sample in center of mouth and evaluate. Do not chew or manipulate!
PARTIAL COMPRESSION STAGE:		
Adhesiveness to lips	The degree to which the sample adheres to the lips.	Compress sample between lips, release, and evaluate the degree to which the product remains on the lips
FIRST BITE / CHEW:		
Hardness	The force required to compress the sample.	Compress or bite through sample with molars or incisors.
Cohesiveness	The amount the sample deforms rather than splits apart, cracks, or breaks.	Place sample between the molar teeth and compress fully. May also be done with incisors.
CHEWDOWN:		
Cohesivenss of mass	The amount that the chewed sample holds together.	Chew sample with molar teeth up to 15 times and evaluate. (Loose Mass -- Tight Mass)
Macro roughness of mass	The amount of roughness perceived on the surface of the chewed sample. Hint: You are looking for the large lumps, bumps, hills and valleys, etc.	Chew sample with molars and evaluate the irregularities on the surface of the sample mass.
Toothpull	The force required to separate the jaws during mastication.	Chew sample 2 to 3 times and evaluate.
RESIDUAL:		
Residual film	The amount and degree of residue felt by the tongue when moved over the surface of the mouth.	Swallow the sample and feel the surface of the mouth with the tongue to evaluate.
Toothpack	The amount of product packed into the crowns of your teeth after mastication.	Chew samples 10 to 15 times, expectorate, and feel the surface of the crowns of the teeth to evaluate.
Loose particles	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample with molars, swallow and evaluate.

Table 2. Full regression model statistics for predicting individual sensory attributes.

Model statistics	Cohesion of bollus	Particle size	Adhesion to lips	Hardness	Cohesiveness	Cohesiveness of mass
RMSEC[z]	0.53	0.13	0.67	0.25	0.28	0.43
RMSEP[y]	0.59	0.14	0.74	0.27	0.29	0.46
RMSEP/RMSEC	1.11	1.01	1.11	1.09	1.05	1.07
Stot[x]	2.11	0.92	2.83	0.84	1.07	1.72
Stot/RMSEP	1.21	1.01	1.77	1.55	1.15	1.44
Rcal[w]	0.67	0.36	0.86	0.80	0.56	0.76
R Val[v]	0.57	0.19	0.82	0.76	0.49	0.72
number of PCs[u]	3.00	2.00	3.00	4.00	2.00	2.00
Weighted regression coefficient (r) for each instrumental variables used in the final model						
v1 product height	0.03	0.02	0.36	0.06	0.02	0.07
v2 distance 25%	0.00	-0.02	-0.08	-0.05	-0.07	-0.10
v3 distance 50%	0.02	-0.01	-0.07	-0.10	0.00	-0.04
v4 distance 75%	-0.01	-0.01	-0.10	-0.11	0.00	-0.04
v5 force 100%	-0.09	0.01	-0.14	0.07	-0.05	-0.10
v6 distance 100%	-0.11	-0.01	0.10	-0.01	-0.01	-0.04
v7 distance 0g	0.03	0.00	0.14	0.02	0.04	0.09
v8 force -100%	-0.17	0.01	-0.35	-0.06	-0.05	-0.14
v9 distance -100%	-0.11	0.01	-0.22	-0.02	0.00	-0.09
v10 gradient initial	0.03	0.01	0.05	0.13	0.05	0.10
v11 total area	-0.10	0.01	-0.19	0.03	-0.04	-0.10
v12 area1	-0.08	0.00	-0.18	0.04	-0.06	-0.12
v13 small area 2	-0.10	0.01	-0.19	0.02	-0.03	-0.10
v14 negative area	-0.28	0.02	-0.62	0.21	-0.09	-0.29

continued

Table 2. Continued.

Model statistics	Roughness of mass	Toothpull	Toothpack	Loose particles	Residual film
RMSEC[z]	0.25	0.19	0.23	0.30	0.25
RMSEP[y]	0.26	0.21	0.25	0.33	0.27
RMSEP/RMSEC	1.05	1.09	1.10	1.11	1.08
Stot[x]	1.38	0.47	1.28	1.00	0.83
Stot/RMSEP	1.37	1.26	1.21	1.10	1.15
Rcal[w]	0.72	0.68	0.66	0.57	0.59
R Val[v]	0.68	0.61	0.56	0.43	0.49
number of PCs[u]	2.00	3.00	3.00	3.00	2.00
	Weighted regression coefficient (r) for each instrumental variables used in the final model				
v1 product height	-0.05	0.04	0.10	0.05	0.11
v2 distance 25%	-0.04	-0.08	-0.05	0.03	-0.05
v3 distance 50%	-0.04	-0.03	-0.03	0.00	-0.03
v4 distance 75%	-0.04	-0.04	-0.05	0.00	-0.05
v5 force 100%	0.03	-0.03	-0.02	0.07	-0.01
v6 distance 100%	-0.01	-0.01	0.03	-0.07	-0.01
v7 distance 0g	-0.05	0.03	0.03	0.00	-0.01
v8 force -100%	0.03	-0.06	-0.07	0.02	-0.07
v9 distance -100%	-0.02	-0.03	-0.05	0.02	-0.06
v10 gradient initial	0.03	0.06	0.04	-0.05	0.04
v11 total area	0.04	-0.09	-0.01	0.06	-0.01
v12 area1	0.03	-0.03	-0.01	0.06	-0.03
v13 small area 2	0.04	-0.04	-0.01	0.06	-0.01
v14 negative area	0.05	-0.02	0.11	0.08	-0.09

z RMSEC: root mean square error of calibration.

y RMSEP: root mean square error of prediction.

x Standard deviation of the sensory intensities across all samples for a particular attribute.

w Correlation coefficient for the calibration model

v Correlation coefficient for the validation model

u number of principal components in the model

Table 3. Optimized model statistics for predicting individual sensory attributes

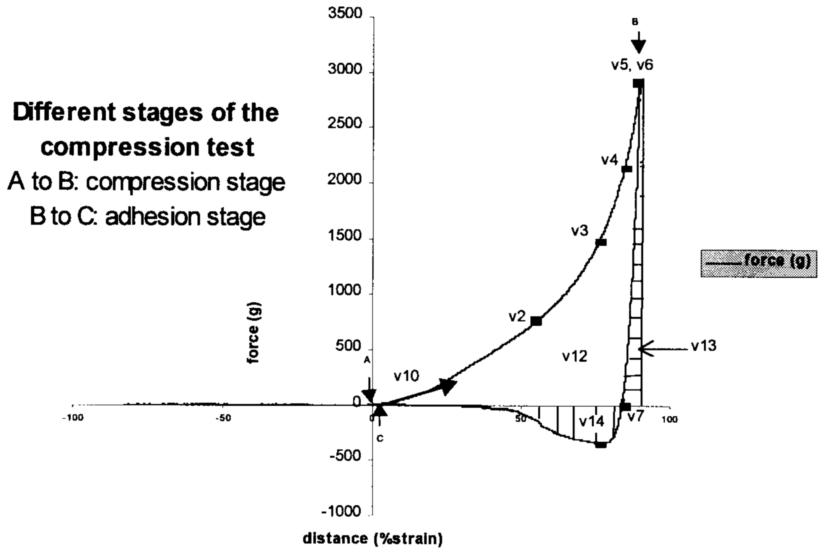
Model statistics	Cohesion of bollus	Particle size	Adhesion to lips	Hardness	Cohesiveness	Cohesiveness of mass
RMSEC[z]	0.52	0.13	0.67	0.25	0.28	0.43
RMSEPy	0.56	0.14	0.70	0.26	0.29	0.45
%improvement RMSEP[x]	4.18	2.35	4.97	5.08	1.10	3.21
RMSEP/RMSEC	1.07	1.07	1.05	1.04	1.04	1.04
Stot/RMSEP[w]	3.75	3.53	4.02	3.29	3.66	3.84
RCal[v]	0.67	0.42	0.86	0.80	0.55	0.76
R Val[u]	0.61	0.27	0.84	0.76	0.51	0.74
%improvement Rval[x]	7.99	43.78	2.34	0.49	4.79	2.93
number of PCs[t]	2	4	2	4	2	2
Weighted regression coefficient (r) for each instrumental variables used in the final model						
v1 product height		0.03	0.44	0.06	0.02	
v2 distance 25%	0.00			-0.02	-0.07	-0.09
v3 distance 50%	0.03	-0.05	-0.03	-0.09	0.00	-0.03
v4 distance 75%	0.01	-0.04	-0.08	-0.11	0.00	-0.03
v5 force 100%	-0.10		-0.07	0.09	-0.05	-0.10
v6 distance 100%	-0.10			-0.01		
v7 distance 0g		0.03	0.17	0.03	0.04	0.11
v8 force -100%	-0.18				-0.05	-0.16
v9 distance -100%	-0.08	0.03	-0.25	-0.03	-0.02	-0.08
v10 gradient initial	0.03			0.14	0.05	0.10
v11 total area	-0.11	0.02	0.14	0.02	-0.04	-0.10
v12 area1	-0.10	-0.01	-0.12	0.05	-0.06	-0.13
v13 small area 2	-0.11	0.03	-0.14	0.02	-0.03	0.09
v14 negative area	-0.28	0.03	-0.84	0.21	-0.09	-0.31
variables number	10	9	10	13	13	12

continued

Table 3. Continued.

Model statistics	Roughness of mass	Toothpull	Toothpack	Loose particles	Residual film
RMSEC[z]	0.24	0.19	0.23	0.30	0.25
RMSEPy	0.24	0.20	0.25	0.32	0.26
%improvement RMSEP[x]	8.44	2.80	1.97	4.54	5.12
RMSEP/RMSEC	0.99	1.06	1.07	1.07	1.02
Stot/RMSEP[w]	4.35	3.43	5.17	4.55	4.06
RCal[v]	0.74	0.68	0.65	0.57	0.58
R Val[u]	0.74	0.63	0.59	0.49	0.56
%improvement Rval[x]	8.83	3.75	3.97	14.96	13.41
number of PCs[t]	2	2	3	3	2
Weighted regression coefficient (r) for each instrumental variables used in the final model					
v1 product height		0.04	0.12	0.08	0.13
v2 distance 25%		-0.08			
v3 distance 50%					
v4 distance 75%	-0.06	-0.04	-0.14		-0.17
v5 force 100%	0.03		-0.07	0.10	-0.01
v6 distance 100%				-0.06	
v7 distance 0g	-0.05	0.03		0.03	
v8 force -100%	0.07	-0.06	-0.06		-0.06
v9 distance -100%	0.00	-0.03			
v10 gradient initial	0.08	0.06	0.05		
v11 total area	0.05	-0.03		0.07	0.01
v12 area1	0.02	-0.05		0.07	-0.03
v13 small area 2	0.06	-0.03			0.02
v14 negative area	0.11	-0.09	-0.12	0.13	-0.09
variables number	10	11	6	6	8

[z] RMSEC: root mean square error of calibration.
[y] RMSEP: root mean square error of prediction.
[x] % improvement represent RMSEP decreaseing and Rval increasing between the full regression model and the optimized model.
[w] Stot: Standard deviation of the sensory intensities across all samples for a particular attribute.
[v] Correlation coefficient for the calibration.
[u] Correlation coefficient for the validation
[t] number of principal components in the model



DEFINITION OF THE INSTRUMENTAL PARAMETERS NOTED ON THE CURVE
(v1 is not on the curve)

Code	Name	Description
v1	product height	height of the sample (mm): 5 kernels of rice are placed in a single layer on the base plate
v2	distance 25%	Distance traveled by the plunger (% strain) when the force value is 25% of the maximum positive force
v3	distance 50%	Distance traveled by the plunger (% strain) when the force value is 50% of the maximum positive force
v4	distance 75%	Distance traveled by the plunger (% strain) when the force value is 75% of the maximum positive force
v5	force 100%	Maximum positive force value (g) of the compression test, when the kernels are compressed to 90% of their original height
v6	distance 100%	Distance traveled by the plunger (% strain) when the force value is at its maximum (v5)
v7	distance 0g	Distance traveled by the plunger during the test (% strain), when the force returns to zero during the upward movement of the plate
v8	force -100%	Maximum negative force value (g) during the upward movement of the probe
v9	distance -100%	Distance traveled by the plunger (% strain) at the maximum negative force (v8)
v10	initial gradient	Initial slope of the compression curve when the distance traveled by the plunger is between 0% and 10% strain
v11	A Total	Total area under the curve for positive force values
v12	Area 1	Area under the compression curve for strains between 0 and 90 %
v13	Area 2	A2 = Atotal -A1
v14	Area 3	Area between the X axis and the compression curve for negative forces

Fig. 1. Compression curve. Compression force versus distance.

RICE KERNEL DRYING BEHAVIOR IN NEAR COMMERCIAL DRYING CONDITIONS AS DEPICTED IN A GLASS TRANSITION STATE DIAGRAM

W. Yang, T.J. Siebenmorgen, T.A. Howell, and A.G. Cnossen

ABSTRACT

This study is the initial step of applying the glass transition hypothesis proposed recently for explaining rice fissuring during the drying process to near-commercial drying conditions. This hypothesis has received plausible experimental confirmation in laboratory thin-layer drying tests. To extend the capability of the hypothesis to a typical commercial cross-flow dryer, drying experiments need to be conducted in commercial or near-commercial drying conditions. The drying behavior of individual rice kernels, with emphasis on individual kernel moisture distribution, was examined and compared to the glass transition state diagram developed previously. After moisture content distribution of individual kernels at different layers of the rice column is determined, the drying of rice kernels can be identified as to the state of the kernel in relation to the glass transition curve. The ultimate goal is to predict the rice milling quality at different drying conditions from the perspective of glass transition taking place inside rice kernels, combined with finite element modeling of the rice drying process.

INTRODUCTION

The glass transition hypothesis proposed recently to explain rice fissuring during the drying process (Perdon *et al.*, 1999) has received plausible experimental confirmation in laboratory thin-layer drying tests (Cnossen *et al.*, 1999; Chen *et al.*, 1999). To extend the capability of the hypothesis to a commercial rice dryer, experiments need to be conducted in commercial or near-commercial drying conditions. The drying behavior of individual rice kernels, with emphasis on single kernel moisture distribution, should be examined and compared to the glass transition state diagram developed by Perdon (1999) and Perdon *et al.* (1999). With moisture content (MC) distribution of individual kernels at different layers of the rice column, the drying of rice kernels can be identified as to the state of the kernel in relation to the glass transition curve. Inferences on fissuring potential of rice kernels can be made by combining the drying behavior and head rice yield data of the samples collected from the different layers. Since this study is ongoing, the temperature profile in the rice column of a cross-flow dryer and the kernel drying behavior relative to a state diagram are reported.

PROCEDURES

A pilot-scale cross-flow dryer manufactured by Grain Systems, Inc. was used in this study to dry the rice cultivar 'Cypress'. Plenum temperature was set at 140°F (60°C). Airflow rate was approximately 1600 CFM for a column of 36 x 36 x 15 in. (width, height, thickness). Five 1-in. holes were drilled on one side of the column at 1 in. (Location 1), 3 in. (Location 2), 6 in. (Location 3), 9 in. (Location 4), and 12 in. (Location 5) from the warm air intake screen, respectively, and 17.25 in. from the bottom of the column. On the other side of the column, five 3/16-in. holes were drilled, corresponding to each 1-in. hole. One type K thermocouple, tied to a ϕ 1/8-in. steel rod, was placed at the center of the column width by spanning the rod between one hole on one column wall and the other to measure the temperature in the column. One thermocouple was placed at the warm-air intake screen (Location 0) and another at the exhaust exit screen (Location 6) to measure the temperature of the air entering and leaving the column. A 1/2-in. grain probe was used to sample rice kernels from each of the five 1-in. holes at various time intervals. The moisture content of individual rice kernels and its standard deviation were measured using a Shizouka Seiki single-kernel moisture meter following a similar procedure as specified by Bautista and Siebenmorgen (1999). Perdon (1999) measured the glass transition temperatures of rice using two methods: differential scanning calorimeter (DSC) and Thermal Mechanical Analyzer (TMA). The glass transition temperatures used in this study were based on the results of DSC.

RESULTS AND DISCUSSION

Temperature Profile in Rice Column

Figs. 1A and 1B show the temperature profile across the thickness of the rice column at various times. Although actual drying duration in a commercial or farm dryer is usually not as long as shown, Fig. 1A is drawn to depict the temperature distribution in the rice column at extended times. There was a temperature gradient of approximately 15°C left across the column after 40 min of drying. This indicated that turn-flow or agitation in a cross-flow dryer was desired, since one drying pass in commercial drying is usually done in less than 40 min. Even after about 3 hr of drying, there was still a temperature gradient across the column thickness (Fig. 1A). A mathematical model to describe the temperature profile in the rice column is being developed on the basis of these data.

Individual Kernel Moisture Distribution

It was found that individual rice kernels followed a near-normal distribution, with a slightly skewed bell-shape toward the lower MC end, but as drying proceeded, the distribution approached a normal distribution. The standard deviation of the MCs of individual kernels ranged from 1.23 to 2.44% wet basis (w.b.) in the five locations. Figs. 2A-E show the behavior of rice kernel drying in the pilot-scale cross-flow dryer as depicted against the glass transition state diagram of the cultivar Cypress, as reported by Perdon *et al.* (1999). Figs. 2A-E also show the variation of individual kernel MCs when the standard deviation is taken into account.

Rice Kernel Drying Behavior Relative to the Glass Transition State Diagram

As can be seen in Fig. 2A (Location 1), all rice kernels were in the rubbery state during drying. In Location 2 (Fig. 2B), the medium-to-high MC kernels, exemplified by MC and MC+ curves, were dried in the rubbery region, while the low MC kernels, exemplified by MC– curve, were basically dried in the glassy region, although they might have reached the rubbery region with a very short retention considering the confidence limit around the glass transition line. In Location 3 (Fig. 2C), high-moisture kernels were dried in the rubbery region, low-moisture kernels were dried in the glassy region, and medium-moisture kernels were dried in the rubbery region with a short retention before coming back to the glassy region. In Location 4 (Fig. 2D), rice kernels were dried in the glassy region, except that high-moisture kernels entered the rubbery state for a short retention before coming back to the glassy state. In Location 5 (Fig. 2E), drying took place in the glassy region for all kernels. According to the glass transition hypothesis, if a state transition from the rubbery to the glassy occurred during drying or cooling, fissuring might develop as a result of unequal property behavior by various regions within the kernel if there was a sufficient MC gradient inside the kernel. This study is still ongoing, although some results (Yang *et al.*, 2000) have been analyzed for a presentation at the 2000 International Drying Symposium. The head rice yields of the samples taken from the dryer are being analyzed in conjunction with finite element simulation of the drying process. These data will be linked to the rice kernel drying behavior depicted in Figs. 2A-E and the effect of glass transition temperatures and intrakernel MC gradients on milling quality of rice.

SIGNIFICANCE OF FINDINGS

This work is an initial step leading to the examination of the capability of the glass transition hypothesis proposed recently for explaining fissure formation in rice due to the drying process for commercial drying operation. It is also very useful information in examining the effect of MC gradients built up inside rice kernels during drying on milling quality. If the validity of the glass transition hypothesis and the predicted effect of intrakernel MC gradients on milling quality are confirmed by the near-commercial drying tests, the impact on the way rice is currently dried will be tremendous. The ultimate goal is to predict the rice milling quality at various drying conditions from the perspective of glass transition taking place inside rice kernels in conjunction with computer simulation of rice drying.

ACKNOWLEDGMENTS

Funding for this research was provided by the industry sponsors of the University of Arkansas Rice Processing Program, especially through the financial and in-kind support of the Grain Systems, Inc., and the Institute of Food Science and Engineering through its matching program for industrial funds.

LITERATURE CITED

Bautista, R.C., and T.J. Siebenmorgen. 1999. Characterization of rice individual kernel moisture content and size distributions at harvest and during drying. ASAE Paper No. 996053, St. Joseph, MI: ASAE.

Chen, H., T.J. Siebenmorgen, and W. Yang. 1999. Finite Element simulation to relate head rice yield reduction during drying to internal kernel moisture gradient and rice state transition. ASAE Paper No. 996156, St. Joseph, MI: ASAE.

Cnossen, A., T.J. Siebenmorgen, J. Reid, and W. Yang. 1999. Incorporating the glass transition temperature in rice drying and tempering to optimize moisture removal rate and milling quality. ASAE Paper No. 996022, St. Joseph, MI: ASAE.

Perdon, A.A. 1999. Amorphous state transition in rice during the drying process. Ph.D. dissertation. Department of Food Science, University of Arkansas, Fayetteville.

Perdon, A.A., T.J. Siebenmorgen, and A. Mauromoustakos. 1999. Glassy state transition and rice drying: I. Development of a brown rice state diagram. Cereal Chem. (submitted).

Yang, W., C.-C. Jia, T.J. Siebenmorgen, and A.G. Cnossen. 2000. Cross-flow drying o rough rice as mapped on its glass transition state diagram. Paper No. 068, Proceedings International Drying Symposium IDS2000, Noordwijkerhout, The Netherlands, August 28-31, 2000.

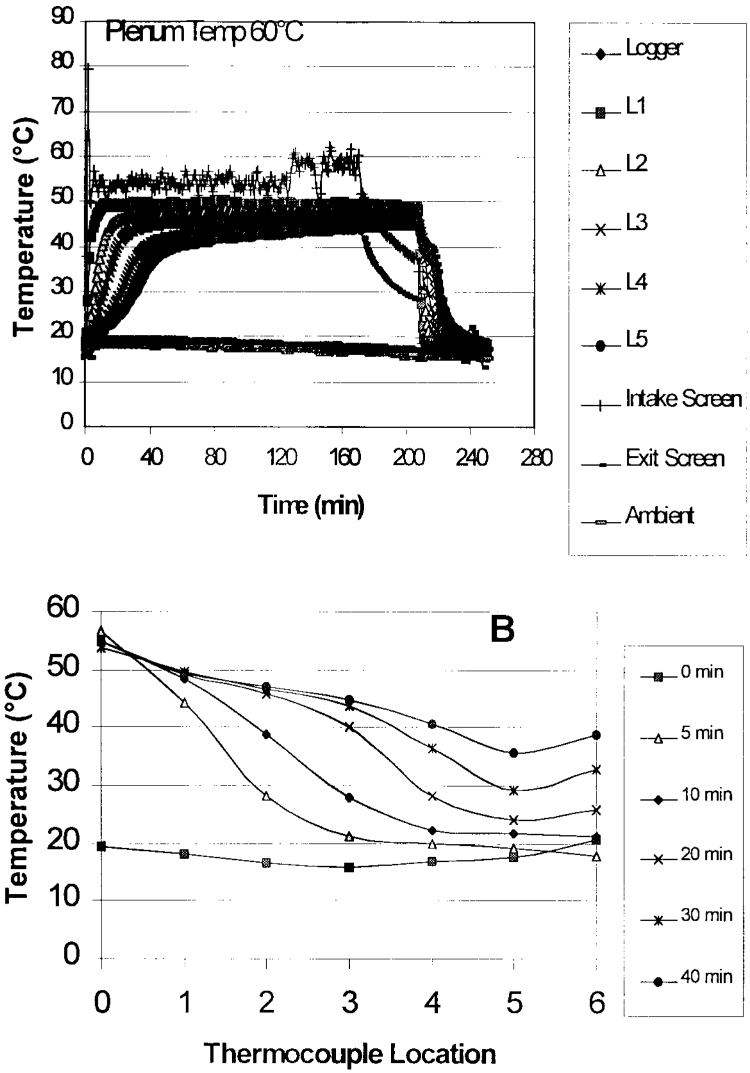
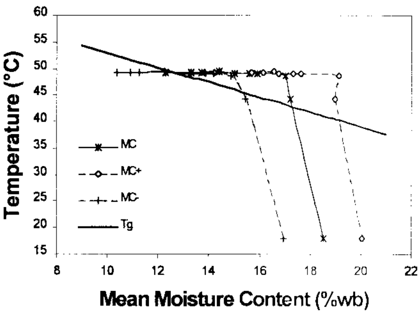
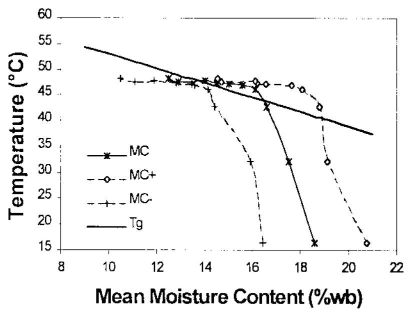


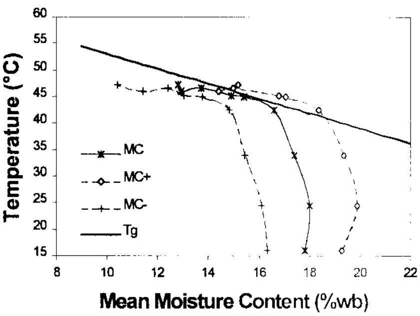
Fig. 1. Air temperatures across the column of Cypress rice in a pilot-scale cross-flow dryer at various drying times.
***A.* Temperaturehistory at the five locations (L1 to L5).**
***B.* Temperature profiles at the five locations as well as the warm-air inlet screen (0) and exit screen (6).**



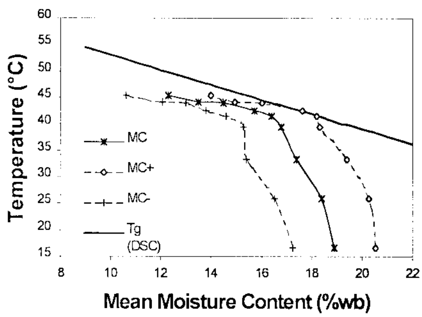
A. Location 1 (1" from air inlet)



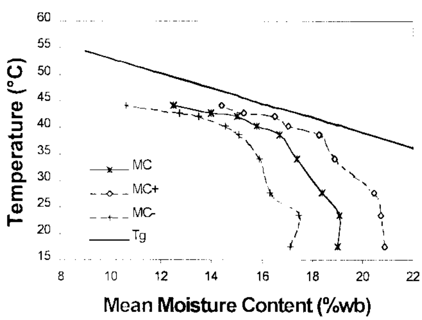
B. Location 2 (3" from air inlet)



C. Location 3 (6" from air inlet)



D. Location 4 (9" from air inlet)



E. Location 5 (12" from air inlet)

Fig. 2. Drying behavior of rice kernels depicted in the glass transition state diagram of the rice cultivar Cypress. In the figures, MC is the mean moisture content of 300 kernels, T_g the glass transition temperature curve, MC+ and MC– moisture variation at +1 standard deviation and –1 standard deviation, respectively (i.e., 66% confidence limit).

ARKANSAS GLOBAL RICE MODELING PROJECT

G. L. Cramer, E. J. Wailes, E. C. Chavez, and J. M. Hansen

ABSTRACT

United States rice prices are determined by international markets. Given recent developments in international and domestic agricultural and trade policies, the world rice economy is becoming more competitive; and market participants are more susceptible to price and income variability. The global rice market is also thinly traded and hence susceptible to price shocks coming from weather and political disturbances. In this kind of market environment, both current-year and long-term baseline projections by country are useful for researchers and market participants, not only for supply and demand analysis, but for policy analysis as well. The updated baseline results show that growth in world rice production would exceed 1% per year, mainly as a result of yield improvements. Changes in world rice consumption are determined primarily by population and income growth, and relative food grain prices. Potential for U.S. rice, on the other hand, is expected to remain favorable as growth in domestic use remains strong, driven by sustained growth in food use. While U.S. rice exports are expected to face an increasingly competitive environment, the potential for the rough rice segment remains promising.

INTRODUCTION

Rice is an important staple in the world, accounting for over 22% of global caloric intake. Rice is produced in nearly 100 countries and traded in over 40 more countries (Gudmunds, 1999). In the United States, rice is the ninth leading crop in revenues. Domestic rice consumption is growing steadily at nearly 3% a year.

The international rice market is particularly prone to short-term supply and demand shocks, mainly because rice is a thinly traded commodity, i.e., only about 4% of production is traded. Some potential causes of supply-and-demand shocks are production shortfalls due to unfavorable weather (e.g., Japan in 1993), government-mandated trade constraints (e.g., embargoes on Iran and Iraq), and technology changes.

The international rice economy is also undergoing a transition from a period of substantial government intervention to a market-oriented environment. Changes in international and domestic agricultural and trade policies are increasingly shaping the future of the world rice economy. Recent trade agreements at international, regional, and national levels have made the rice industry more market-oriented. These include the implementation of the General Agreement on Tariffs and Trade (GATT), which requires opening markets to imports, reduction in aggregate support levels, and reduction in export subsidies. MERCOSUR, a regional initiative that includes Argentina, Brazil, Paraguay, and Uruguay, is emerging as an important factor in global rice trade. Other changes include unilateral actions and national policy programs of other countries. The Federal Agricultural Improvement (FAIR) Act of 1996 in the United States is another relevant policy initiative that radically changed the nature of government intervention in the U.S. rice sector. The program eliminated the supply control mechanisms and decoupled the linkage of farm income support from production decisions using a new concept involving contract acreage and transition payments for 7 years, starting in 1996 (Wailes *et al.*, 2000).

OBJECTIVES

Given the changes occurring in the domestic and international rice industries, rice market participants will be faced with more market-oriented decision-making, increased use of risk-management tools, increased price and income variability, and readiness for increasingly competitive export markets. The rice market also is expected to be more susceptible to supply-and-demand changes; and market participants need to be informed how the rice market would respond under such conditions. This situation calls for a relevant analytical tool capable of generating results that market participants can use in their year-to-year production and marketing decisions.

A set of long-term baseline projections for the world rice economy is useful, as it provides the basis to conduct a wide variety of market and policy analyses on the rice economy, including evaluating and comparing alternative macroeconomic, policy, weather and technology scenarios.

The Arkansas Global Rice Modeling Project aims to address these needs. The model (AGRM) is a dynamic partial equilibrium econometric model that provides supply-and-demand projections for 24 selected countries/regions. In order to provide timely and relevant market information, the model needs to be continually updated, refined, and developed.

PROCEDURES

Current and long-term projections for each country include rice area, yields, production, consumption, and trade. The projections are based on the AGRM, a multi-country econometric model framework that provides projections for a set of 23 major rice-producing and/or -trading countries and one aggregate rest-of-the-world region.

Historical data for these variables are from the Economic Research Service, U.S. Department of Agriculture (USDA-ERS, 2000a,b). Estimates for these variables are based on a set of explanatory variables, including exogenous macroeconomic factors such as income, population, inflation rate, exchange rate, and policy variables. Macroeconomic data are from Wharton Econometrics Forecasting Associates (WEFA) and Project LINK. The baseline projections of rice consumption, production, trade, stocks, and prices in this report reflect the latest developments in the international rice industry.

The model is subject to continual updating, development, and refinement. Current developments in domestic and global rice economies are being monitored; and the model is updated monthly. A major component of the modeling effort is disaggregation of the regions into individual countries in the model structure to better capture the dynamics of the global rice markets.

RESULTS AND DISCUSSION

While the model covers 24 countries/regions, this report focuses on short-term (1999/2000) and long-term (through 2010) projections of rice consumption, production, trade, and prices in the United States and the world.

World Rice

World rice area is estimated to increase slightly to 153 million hectares in the crop year 2000 (Tables 1 and 2), 0.2% higher than last year. While lower production is projected for a number of countries such as the United States, China, Japan, South Korea, and Taiwan, this is offset by production increases in Thailand, Pakistan, Myanmar, Vietnam, India, Australia, Egypt, Indonesia, European Union, and the MERCOSUR countries. Average global rice yield is estimated to improve slightly in 2000 and is expected to grow annually by nearly 1% through 2010. With the combined effects of area and yield gains, production in 2000 would increase by 0.4% to nearly 1 million metric tons (mmt). Production is projected to continue growing slightly over 1% per year through 2010. Consumption is projected to grow at a slightly faster rate, mainly because of growing Asian populations. Global trade is expected to grow 7% in 2000, following an estimated drop of nearly 11% in 1999. World ending stocks are projected to increase to 59 mmt in 1999, after a substantial decline of 15% in 1998, mainly due to a weather-related production shortfall in China. The global rice stocks-to-use ratio is projected to be slightly lower in 2000 at 14.7%, compared to 15.1% in 1999.

Over the long-term, world rice output will grow by 1%, reaching 445 mmt by 2010, with growth mainly coming from improvements in yield. Consumption gains are expected to be driven mainly by growth in Asian populations, instead of gains in per capita use. Global trade will be characterized by stiffer competition as a result of implementation of the GATT, the FAIR Act of 1996, and other regional free-trade initiatives. Ending stocks are projected to decrease slightly to 58.6 mmt in 2000 and 53 mmt in 2006, before gradually recovering thereafter, reaching 58 mmt in 2010. The baseline international rice price (Thai 5% freight on board [f.o.b.]) is expected to remain in the range of $240 to $310 per metric ton over the baseline period.

United States Rice

United States rice acreage expanded nearly 9% in 1999 to 3.61 million acres compared to 1998 (Tables 3 and 4). Harvested acreage is projected to decrease 6.4% in 2000 to 3.38 million as producers respond to the weak rice prices in 1999, and to stabilize around 3.2 million acres thereafter. Average yield per acre is estimated to have recovered to 59 hundredweight (cwt) in 1999, from the weather-affected 1998 level; and is projected to return to the historical growth trend of around 1% per year in 2000, assuming normal weather. Total production in 1999 is estimated to be a record 212.9 million cwt, exceeding the previous record of 197.8 million cwt in 1994. Production in 2000 is projected to decrease 5.5%. As a result of the record production, carryover stocks would build up in 1999 to 39 million cwt—a 76% increase over the previous year. Stocks will remain high in 2000 and 2001 at 41 million cwt and could stabilize around 34 million cwt toward the end of the baseline period. Domestic use in the 1999 marketing year is expected to increase nearly 4%, to 120.6 million cwt, owing mainly to the strong growth in food use combined with lower prices. Strength in domestic use is expected to remain strong in 2000 and continue to grow an average of over 3% per year over the baseline period. Exports are projected to grow 1.3% to 86.4 million cwt in 1999 and to relatively stabilize around 90 million cwt over the baseline period as international rice trade becomes more competitive. Season average farm price is estimated to decrease to $6.43 per cwt in 1999 from the 1998 level of $8.83 and to decline further in 2000 as stocks continue to build up in the short-term.

Over the long-term, total U.S. rice area and production is expected to decline and remain around 3.2 million acres and 200 million cwt, respectively. Domestic consumption is expected to continue growing steadily as a result of the growing Asian and Hispanic populations in the United States, increasing health-consciousness, and growth of the processed rice sector. Imports are projected to continue growing with the increasing domestic demand for aromatic and specialty rice types. Despite growing competition from major rice-exporting countries such as Thailand, Vietnam, and India, U.S. exports are projected to stabilize around 90 million cwt because of the strength of rough rice exports to a number of Latin American countries. These countries prefer to import rough rice to improve utilization of their milling capacities. United States rough rice is well-positioned to maintain its competitive edge in this market segment, not only geographically, but because there are only a very few countries that allow rough rice exports. There is no other major rice supplier that exports significant volumes of rough rice. Season average farm prices are expected to remain in the range $7 to $8 per cwt over the projection period, depending on supply-and-demand dynamics.

It should be noted that we update our rice projections monthly as the most recent set of data becomes available. The most recent update of AGRM projections can be found in our Web site http://www.uark.edu/campus-resources/ricersch/.

SIGNIFICANCE OF FINDINGS

The foregoing set of baseline rice projections generated by the AGRM is useful as a benchmark against which changes in rice supply and demand and policies can be evaluated.

1. Baseline projections on domestic and international rice consumption, production, trade, stocks, and prices will guide the rice market participants, especially producers, in their production and market planning. This is very important considering the expected increase in competition among rice-producing countries.

2. Policy-makers have a useful tool in analyzing the potential impact of specific government programs affecting the rice industry.

3. Relevant information on the impacts of specific world or country events that influence the rice industry can be generated quickly and made available to interested parties in a timely manner.

LITERATURE CITED

Gudmunds, Karl. December 1999. PS&D View. U.S. Department of Agriculture, Economic Research Service.

U.S. Department of Agriculture, Economic Research Service. January 2000a. Rice Outlook. ERS-RCS-0100.

U.S. Department of Agriculture, Economic Research Service. January 2000b. World Agricultural Supply and Demand Estimates. WASDE-358.

Wailes, E.J., G.L. Cramer, E.C. Chavez, and J.M. Hansen. 2000. Arkansas Global Rice Model. International Baseline Projections for 1999-2010. Forthcoming as an Arkansas Agricultural Experiment Station Special Report.

Table 1. World rice supply and utilization–1998-2004.

Variable	Unit/Year	1998	1999	200	2001	2002	2003	2004
Area Harvested	1000 ha	152279	152907	153185	153116	153429	153525	153680
Yield	mt/ha	2.57	2.59	2.60	2.62	2.64	2.67	2.71
Production	1000 mt	391765	396333	397931	400775	405535	409945	415942
Total Consumption	1000 mt	389301	393926	398969	402535	407146	411404	416004
Net Exports	1000 mt	23455	20739	22422	22430	22828	23064	23527
Net Imports	1000 mt	23455	20739	22422	22430	22828	23064	23527
Ending Stocks	1000 mt	57141	59548	58511	56751	55140	53681	53620

Table 2. World rice supply and utilization–2005-2010.

Variable	Unit/Year	2005	2006	2007	2008	2009	2010
Area Harvested	1000 ha	153674	153800	153907	154103	154153	154348
Yield	mt/ha	2.73	2.76	2.79	2.82	2.85	2.88
Production	1000 mt	419684	424370	429229	434682	439525	444860
Total Consumption	1000 mt	420069	424494	428890	433571	437944	442621
Net Exports	1000 mt	23846	24336	24815	25460	25914	56480
Net Imports	1000 mt	23846	24336	24812	25460	25914	26480
Ending Stocks	1000 mt	53235	53112	53450	54562	56143	58382

Table 3. United States rice supply and utilization (in English units)–1998-2004.

Variable	Unit/Year	1998	1999	2000	2001	2002	2003	2004
Yield (rough basis)								
Actual	lb/acre	5669	5901	5957	6055	6113	6175	6233
Program	lb/acre	4827	4827	4827	4827	4827	4827	4827
Harvested Acreage								
Program Area/Contract Area	1000 acre	4157.0	4157.2	4157.2	4157.2	4157.2	4157.2	4157.2
Total Harvested Area	1000 acre	3317.0	3608.2	3357.2	3295.9	3584.3	3271.5	3345.6
Supply (rough basis)	mil. cwt	226.6	246.1	250.6	252.4	254.3	252.8	258.3
Production	mil. cwt	188.1	212.9	200.0	199.5	200.8	202.0	208.5
Beginning Stocks	mil. cwt	28.1	22.2	39.1	41.0	41.2	38.0	36.4
Imports	mil. cwt	10.5	11.0	11.5	11.9	12.4	12.8	13.3
Domestic Use (rough basis)	mil. cwt	119.1	120.6	123.9	126.0	128.0	130.0	132.1
Food	mil. cwt	87.3	90.5	94.0	97.0	100.0	102.8	105.8
Seed	mil. cwt	4.4	4.1	4.0	3.9	3.9	4.0	3.9
Brewing	mil. cwt	16.0	16.0	16.0	16.0	16.2	16.3	16.4
Residual	mil. cwt	11.4	10.0	10.0	9.0	8.0	7.0	6.0
Exports	mil. cwt	85.3	86.5	85.7	85.2	88.3	86.4	88.4
Total Use	mil. cwt	204.4	207.1	209.6	211.2	216.4	216.4	220.5
Ending Stocks	mil. cwt	22.2	39.1	41.0	41.2	38.0	36.4	37.8
S-T-U		0.11	0.19	0.20	0.19	0.18	0.17	0.17
Prices								
Loan Rate	US$/cwt	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Season Average Farm Price	US$/cwt	8.83	6.43	6.38	6.37	6.74	7.06	6.83
Long-Grain Farm Price	US$/cwt	8.49	5.62	5.75	5.75	6.21	6.63	6.32
Medium-Grain Farm Price	US$/cwt	9.8	08.35	7.79	7.83	8.01	8.06	8.06
LG-MG Margin	US$/cwt	-1.31	-2.73	-2.03	-2.08	-1.80	-1.44	-1.74

continued

Table 3. Continued.

Variable	Unit/Year	1998	1999	2000	2001	2002	2003	2004
Export Price, FOB Houston (U.S. No. 2)	US$/cwt	16.74	13.86	14.39	15.95	16.09	16.30	16.21
Medium-Grain Price, FOB CA (U.S. No. 2)	US$/cwt	21.32	21.26	18.97	19.46	19.33	19.15	18.83
Deficiency/CLD/Contract Pay Rate	US$/cwt	4.35	5.64	2.60	2.11	2.04	2.04	2.04
World Price	US$/cwt	7.37	4.81	4.91	6.05	6.12	6.23	6.11
EXPP-SAFP Margin	US$/cwt	4.00	4.61	5.28	6.86	6.47	6.22	6.45
Income Factors								
Production Market Value	mil. US$	1660	1368	1276	1270	1353	1426	1425
Deficiency/Contract Payments	mil. US$	745	930	443	358	348	348	348
Marketing Loan/Certificates	mil. US$	0	274	243	69	58	42	62
Total Income	mil. US$	2405	2572	1962	1697	1759	1815	1836
Market Returns Above Variable Cost	US$/acre	128.34	-6.71	-8.26	-9.96	11.03	29.85	13.60
Total Returns Above Variable Cost	US$/acre	352.95	327.03	196.07	119.53	134.77	149.01	136.26

Table 4. United States rice supply and utilization (in English units)–1998-2004.

Variable	Unit/Year	2005	2006	2007	2008	2009	2010
Yield (rough basis)							
Actual	lb/acre	6303	6365	6434	6484	6561	6621
Program	lb/acre	4827	4827	4827	4827	4827	4827
Harvested Acreage							
Program Area/Contract Area	1000 acre	4157.2	4157.2	4157.2	4157.2	4157.2	4157.2
Total Harvested Area	1000 acre	3273.6	3321.6	3285.9	3443.6	3320.6	3392.1
Supply (rough basis)	mil. cwt	257.9	261.7	262.0	272.7	271.0	275.3
Production	mil. cwt	206.4	211.4	211.4	223.3	217.9	224.6
Beginning Stocks	mil. cwt	37.8	35.9	35.6	33.9	37.0	34.0
Imports	mil. cwt	13.8	14.4	15.0	15.6	16.1	16.8
Domestic Use (rough basis)	mil. cwt	134.2	137.3	140.1	143.1	146.2	149.2
Food	mil. cwt	108.8	111.8	114.3	117.4	120.2	123.2
Seed	mil. cwt	3.9	3.8	4.0	3.8	3.9	3.9
Brewing	mil. cwt	16.5	16.7	16.8	16.9	17.0	17.2
Residual	mil. cwt	5.0	5.0	5.0	5.0	5.0	5.0
Exports	mil. cwt	87.9	88.7	88.0	92.6	90.8	92.0
Total Use	mil. cwt	222.1	226.0	228.1	235.8	237.0	241.3
Ending Stocks	mil. cwt	35.9	35.6	33.9	37.0	34.0	34.1
S-T-U		0.16	0.16	0.15	0.16	0.14	0.14
Prices							
Loan Rate	US$/cwt	6.50	6.50	6.50	6.50	6.50	6.50
Season Average Farm Price	US$/cwt	7.15	7.07	7.93	.742	7.88	7.82
Long-Grain Farm Price	US$/cwt	6.72	6.60	7.80	7.09	7.68	7.60
Medium-Grain Farm Price	US$/cwt	8.15	8.17	8.22	8.23	8.34	8.36
LG-MG Margin	US$/cwt	-1.43	-1.57	-0.42	-1.14	-0.65	-0.76

continued

Table 4. Continued.

Variable	Unit/Year	2005	2006	2007	2008	2009	2010
Export Price, FOB Houston (U.S. No. 2)	US$/cwt	16.70	16.89	17.16	17.25	17.69	17.82
Medium-Grain Price, FOB CA (U.S. No. 2)	US$/cwt	18.86	18.73	18.65	18.48	18.50	18.34
Deficiency/CLD/Contract Pay Rate	US$/cwt	2.04	2.04	2.04	2.04	2.04	2.04
World Price	US$/cwt	6.43	6.52	6.66	6.66	6.93	6.96
EXPP-SAFP Margin	US$/cwt	6.49	6.80	5.84	6.65	6.44	6.65
Income Factors							
Production Market Value	mil. US$	1475	1494	1676	1656	1716	1756
Deficiency/Contract Payments	mil. US$	348	348	348	348	348	348
Marketing Loan/Certificates	mil. US$	15	7	1	1	0	0
Total Income	mil. US$	1838	1849	2025	2005	2064	2104
Market Returns Above Variable Cost	US$/acre	33.04	26.63	80.85	45.53	74.84	75.50
Total Returns Above Variable Cost	US$/acre	143.95	133.46	187.08	146.91	179.64	178.09

RATE OF RETURN FOR SOUTHERN RICE PUBLIC RESEARCH

G.L. Cramer, E.J. Wailes, and J.M. Hansen

ABSTRACT

This research presents an analysis of the rate of return to public research investments (including rice checkoff funding) on rice production in the southern states. The rate of return to public rice research investments in four southern states is derived from an economic-surplus commodity model. Producer and consumer benefits and losses from research investments are used to derive an annual rate of return. The results indicate an annual rate of return to public research investments on rice in the southern states at 89%. Accurate assessment of rates of return from public rice research investment is essential for allocation of research funding at the federal and state level and increasingly important to decision-makers. Lack of growth in federal agriculture research expenditures places greater emphasis on proper allocation of public research.

INTRODUCTION

This study is based on the need by research and policy decision-makers to understand the effectiveness of public rice research investments in four southern states. These states (Arkansas, Mississippi, Louisiana, and Texas) account for 73% of U.S. rice production and exports. The United States is currently the third largest exporter of rice after Thailand and Vietnam. Accurate assessment on the rate of return from agricultural research investment is essential for allocation of research funding at the federal and state levels for various commodities and projects. Providing information on research benefits to producers, consumers, and other segments of the market is important for public decisions. Public expenditures are the dominant source of research and development funding for rice in the United States.

Rice yield in the United States has increased substantially over the past century, as indicated in Fig. 1. In 1900, U.S. rice yield averaged 1221 lb/acre, and by the late 1990s, average yield increased to almost 6000 lb/acre. This representa an annul increase of 1.64% per year. Yield increased only by 1.3% per year from 1900 to 1954 and by almost 2% per year from 1954 to 1996. The highest yield achieved for the United States and the southern states was in 1996.

Fig. 2 shows increased yields for the four major southern rice-producing states from 1960 to present. In 1960, the average yield in the southern states was 3100 lb/acre and increased to almost 5800 lb/acre by 1996, which is an increase of 1.75% per year. Increased yield is driven by new varieties, improved pesticides and herbicides, better soil fertilizer practices, new production technology, and better management skills.

OBJECTIVE

The objective of this paper is to evaluate the rate of return to public rice research investments from federal and state public institutions in the four major southern rice-producing states. The distribution of research gains among producers and consumers is obtained, and the national effects on producers and consumers welfare are derived.

PROCEDURES

The method used to calculate the rate of return on investment for rice research is the economic surplus method (Alston *et al.*, 1995). The economic surplus method uses an econometric estimated supply-and-demand model to calculate the producer and consumer benefits from a change in research expenditure. Total rice production for the southern states is estimated as a function of the appropriate research expenditures, the farm price of rice at harvest, and variable costs of production. The production equation is simulated in the Arkansas Global Rice Model, which is a structural, dynamic, partial equilibrium, commodity supply and demand econometric model of the world rice market (Wailes *et al.*). Shifts in production that are attributed to research investments in the four states are used in deriving producer and consumer surplus or benefits. The internal rate of return for research is calculated from the stream of benefits and research expenditure.

The research investment scenario is simulated through an increase in research investment for each year over an 18-year period, which is 1992 to 2010. The increased production is estimated from the increased investment. The model is then used to estimate new equilibrium prices, production, consumption, and trade in all countries. The baseline research expenditure is held constant in real terms from 1998 to 2010, based on rice research expenditure of approximately $16 million in 1997 for the four states. Variable costs of production are held constant in real terms throughout the simulated projection period.

The southern region supply equation includes Arkansas, Louisiana, Mississippi, and Texas. Missouri was not included because of its low production volume. Supply is total rice production in the four southern states. Long- and medium-grain rice production is aggregated in Arkansas and Louisiana. Texas and Mississippi are mostly long-grain-producing states.

The southern region rice supply equation model is estimated with OLS over the time period 1970 to 1998. The exogenous variables are average farm price per acre minus variable cost of production per acre deflated by consumer price index all lagged one period, total public research expenditure on rice in the southern region deflated by consumer price index lagged by 6 years, and two dummy variables for 1981 and 1983.

The elasticity of supply with respect to farm price is 0.18 in the 1970s and 0.07 in the 1990s. The coefficient of determination is 0.80, and the adjusted coefficient of determination is 0.76. The Durbin-Watson statistic is 1.8. The estimated coefficients were statistically significant.

The public rice research investments for the four states is obtained from USDA, Cooperative State Research, Education, and Extension Service, Current Research Information System for the period 1968 to 1997 (USDA, 1998a). USDA National Agricultural Statistics Service and Production, Supply and Utilization, PS&D, data are used to develop the U.S. state models and international country models (USDA 1998b). The price data and disaggregated rice harvested areas are obtained from individual country government agencies.

RESULTS

The results of the increased rice research expenditure on production, consumption, and trade are compared to the baseline (Table 1). In the first period, U.S. rice production in the southern region increased 18.32 million cwt (13%), from 141 million cwt to 159 million cwt. The last eight periods of simulation average an increase in production of 16.14 million cwt (10.3%). The effect of the increased research expenditure begins in the seventh period because of the assumed 6-year lag in research benefits. Food consumption increase averaged 2.06 million cwt/year from the base as a result of lower domestic prices. Brewers consumption increased by 30,000 cwt/year from the base. Retail price and farm prices are decreased under increased research expenditure. Retail price decreased by $1.61/cwt in the seventh period from $52.97 to $51.36/cwt. The decrease in retail price was $4.32/cwt by the last period of the simulation. Farm price decreased from $9.35 to $8.27/cwt in the seventh period of simulation. The average decrease in farm price throughout the simulation period from the base is $1.50/cwt. Exports increased in the seventh period by 8.59 million cwt, from 70 to 79 million cwt. The average increase in exports from the base over the simulation period was 11.87 million cwt/year.

The economic welfare effects of an increase in rice research investments are presented in Table 2. Benefits begin in the seventh period because of the 6-year lagged effect of research expenditure on production. The total welfare effect was positive throughout the simulation. Total welfare in the seventh period is $155 million, increasing to $375 million by the 19th period.

The rate of return is calculated by solving for an interest rate that equates net present value of benefits to the net present value of research investments: NPV(benefits) – NPV(research expenditure) = 0. In Table 3, the change in research expenditure from the base and the total producer and consumer benefits is $100. The expenditure and benefits are expressed in 1990 real terms. In Table 4, the present value of research expenditure and consumer and producer benefits are presented for solving the rate of return, which equates the two present values. The rate of return from rice research investments is 89.2%.

SIGNIFICANCE OF FINDINGS

The results of this study suggest that the benefits of public investment in rice research for the southern region are large and positive. The total welfare effect was positive throughout the simulation. The results indicate an annual rate of return from public research investments on rice in the southern states at 89%. Estimates of rates of return from public rice research investment are essential for allocation of research funding at the federal and state level and are increasingly important to public decision-makers.

LITERATURE CITED

Alston, J.M., G.W. Norton, P.G. Pardey. 1995. Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, Ithaca, NY.

U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service, 1998a. Inventory of Agricultural Research 1978-1997. Washington D.C., December update.

U.S. Department of Agriculture, Economic Research Service. 1998b. Production, Supply, and Demand Data, Washington D.C.

Wailes, E.J., G.L. Cramer, J.M. Hansen, and E. Chavez. 1997. Structure of the Arkansas Global Rice Model. Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville.

Table 1. Comparison of rice production, consumption, and trade under increased research investments.

Commodities and Period		7	8	9	10	11	12	13	14	15	16	17	18	19
Southern Prod. Scenario		159	165	168	168	168	167	168	169	170	171	172	173	174
(million cwt.)	Base	141	146	150	151	151	151	152	153	154	155	156	157	158
	Difference	18.32	18.95	18.43	16.77	16.24	16.17	16.15	16.14	16.14	16.14	16.14	16.14	16.13
Food Cons. Scenario		84.45	87.29	89.63	91.91	94.15	96.28	98.32	100.28	102.22	104.14	106.07	107.99	109.94
(million cwt.)	Base	83.64	85.82	87.75	89.87	92.07	94.20	96.26	98.22	100.16	102.08	104.01	105.93	107.87
Difference		0.80	1.47	1.88	2.04	2.08	2.07	2.06	2.06	2.06	2.06	2.06	2.06	2.07
Brew Cons. Scenario		15.5	15.7	15.6	15.7	15.8	15.9	15.9	16.0	16.1	16.2	16.3	16.3	16.4
(million cwt.)	Base	15.5	15.7	15.6	15.7	15.8	15.8	15.9	16.0	16.1	16.2	16.2	16.3	16.4
	Difference	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Long grain Export Scenario		79	78	81	83	82	81	80	79	79	79	78	77	77
(million cwt.)	Base	70	66	68	70	70	69	68	67	67	67	66	66	65
	Difference	8.59	12.13	13.17	12.79	12.37	12.14	12.02	11.95	11.90	11.87	11.84	11.82	11.78
Retail Price Scenario		51.36	49.71	48.89	48.71	48.74	49.00	49.39	49.95	50.54	51.19	51.84	52.49	53.10
(US$/cwt.)	Base	52.97	52.45	52.32	52.41	52.53	52.83	53.27	53.89	54.55	55.26	56.00	56.73	57.42
	Difference	-1.61	-2.75	-3.44	-3.70	-3.79	-3.83	-3.88	-3.94	-4.00	-4.08	-4.16	-4.24	-4.32
Export Price Scenario		17.36	18.45	18.51	18.53	18.52	18.48	18.58	18.88	19.12	19.32	19.47	19.52	19.58
(US$/cwt.)	Base	17.74	18.77	18.80	18.77	18.74	18.69	18.78	19.08	19.33	19.53	19.67	19.72	19.78
	Difference	-0.38	-0.32	-0.29	-0.24	-0.22	-0.21	-0.21	-0.21	-0.21	-0.20	-0.20	-0.20	-0.19
Avg Farm Price Scenario		8.27	7.92	7.72	7.76	7.73	7.78	7.84	7.97	8.06	8.17	8.25	8.31	8.34
(US$/cwt.)	Base	9.35	9.31	9.25	9.27	9.22	9.28	9.36	9.52	9.64	9.77	9.88	9.98	10.04
	Difference	-1.08	-1.39	-1.53	-1.51	-1.49	-1.50	-1.52	-1.54	-1.57	-1.60	-1.63	-1.67	-1.70

continued

Table 1. Continued.

Commodities and Period		7	8	9	10	11	12	13	14	15	16	17	18	19
Brew price Scenario		9.04	9.00	9.03	9.17	9.29	9.45	9.62	9.82	10.01	10.21	10.40	10.59	10.77
(US$/cwt.)	Base	9.59	9.70	9.80	9.93	10.04	10.20	10.38	10.60	10.81	11.02	11.23	11.44	11.62
	Difference	-0.55	-0.70	-0.77	-0.76	-0.76	-0.76	-0.77	-0.78	-0.80	-0.81	-0.83	-0.84	-0.86
Thai 5% price Scenario		285	288	288	286	287	286	289	298	305	310	314	315	316
(US$/mt)	Base	296	297	296	293	293	292	295	303	310	316	320	321	322
	Difference	-10.47	-8.69	-7.91	-6.56	-5.99	-5.76	-5.66	-5.68	-5.64	-5.60	-5.54	-5.42	-5.31

Table 2. Economic welfare effects from increased research investments (nominal million $).

Period	7	8	9	10	11	12	13	14	15	16	17	18	19
Total welfare	155	216	256	284	298	307	315	325	335	346	356	366	375

Table 3. Research Investments and Consumer and Producer Benefits.

	Research Investments	Consumer and producer benefits
1	31937	0
2	33638	0
3	37766	0
4	38848	0
5	36637	0
6	35969	0
7	35969	1261492
8	35969	1673281
9	35969	1889845
10	35969	2017937
11	35969	2031259
12	35969	2014593
13	35969	1987101
14	35969	1972032
15	35969	1948436
16	35969	1931157
17	35969	1911151
18	35969	1889570
19	35969	1858777

Table 4. Net Present Value with Rate of Return 89.2%.

	Net present value	
Period	Research Investments	Consumer and producer benefits
1	31937	0
2	17779	0
3	10550	0
4	5736	0
5	2859	0
6	1484	0
7	784	27502
8	414	19281
9	219	11510
10	116	6496
11	61	3456
12	32	1812
13	17	944
14	9	495
15	5	259
16	3	136
17	1	71
18	1	37
19	0	19

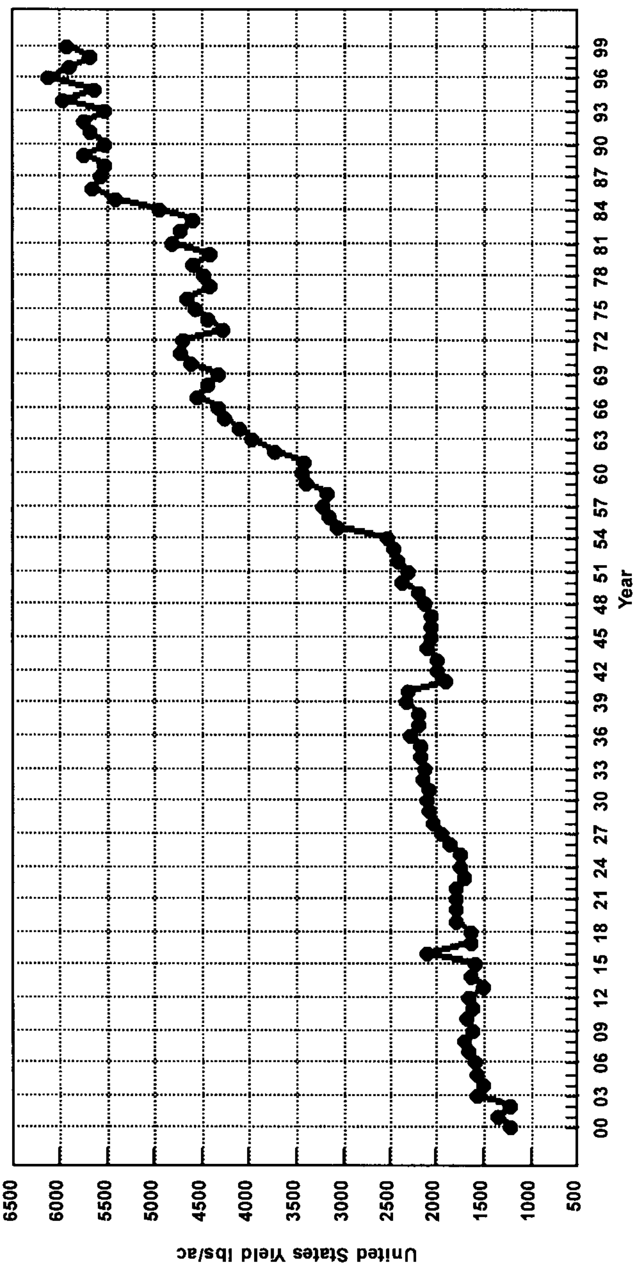


Fig. 1. United States average rice yield from 1900 through 1998.

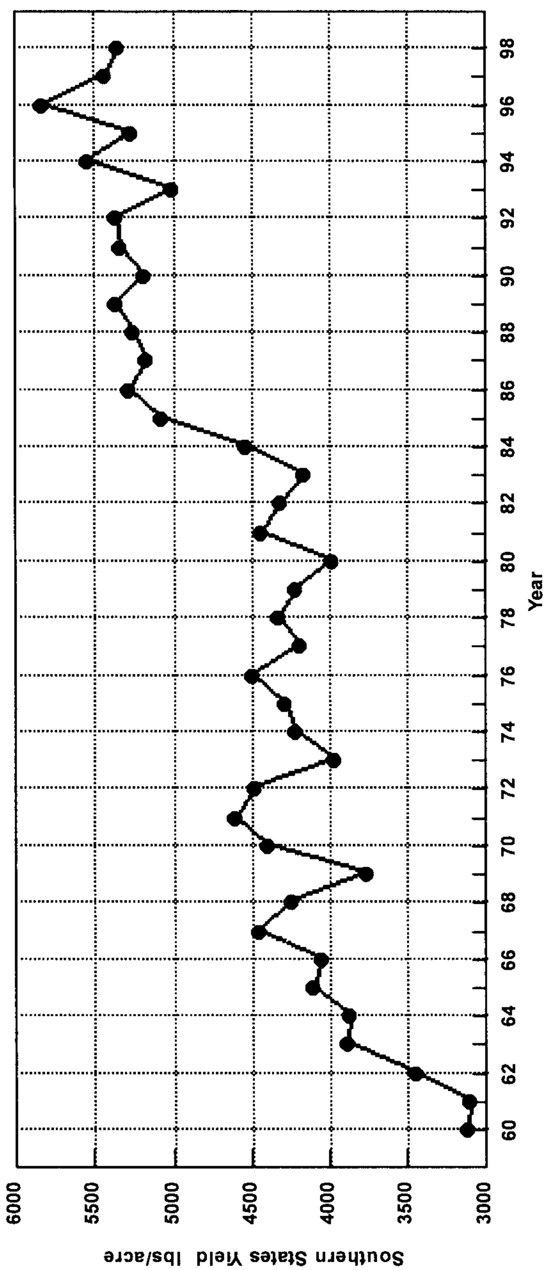


Fig. 2. Southern states average rice yield from 1960 through 1998.

ECONOMIC ANALYSIS OF ON-FARM RICE DRYING AND STORAGE

G. L. Cramer, E. J. Wailes, and K. B. Young

ABSTRACT

Data on construction and operating costs of new on-farm rice drying and storage systems were collected in 1999. Preliminary drying costs estimates for a 40,000-bu capacity on-farm operation are $0.46/bu with the auger system and $0.56/bu with the loop system. With the income tax benefits of on-farm ownership, the net cost will be reduced to be similar to rice cooperative dryer charges in Arkansas. On-farm systems provide high convenience and increased marketing flexibility for rice producers.

INTRODUCTION

On-farm rice drying and storage costs in the Arkansas Delta were last evaluated in the 1980s (Wailes, *et al.*, 1984). The changes affecting on-farm drying and storage costs in the 1990s include increased farm size, new crops such as corn, new technology to load in and load out of grain bins, and increased flexibility in marketing as a result of revisions in the farm program. There has also been a trend in recent years to harvesting rice with lower field moisture with the new rice varieties being planted. With reduced government price protection, growers have been forced to take a more active role in marketing, requiring them to increase their knowledge of marketing conditions and of the factors affecting the price of rice.

The objective of this research was to estimate the investment and operating costs of new on-farm drying and storage systems in the Arkansas Delta.

PROCEDURES

Meetings were scheduled with groups of producers in Poinsett and Arkansas counties in 1999 to estimate typical crop rotations and volume harvested. Data were collected from major suppliers of on-farm drying and storage equipment and from utility companies to estimate current cost data. Data were also collected from two producers in eastern Arkansas that had recently installed the newer "loop systems." Cost budgets were developed for representative on-farm drying and storage units including both auger systems and loop systems. New data were collected to update the OFDRY simulation model; however, additional work is needed to update this model.

RESULTS AND DISCUSSION

Estimated average farm production in 1999 from the sample of producers was 140,250 bu rice, 37,128 bu soybeans, and 1680 bu wheat for Poinsett County (Table 1). The average for Arkansas County was 80,000 bu rice, 40,000 bu soybeans, 14,000 bu wheat, and 7480 bu oats.

Examples of the budgeted cost for a two-bin auger and loop system with a working capacity of 37,400 bu of rice are shown in Table 2. Rice was assumed to be valued at the loan price to calculate the interest on storage for 6 months. Drying costs were calculated on the basis of 20% field moisture and 13% storage moisture.

Estimated rice drying cost is $0.46/bu with the two-bin auger system and $0.56/bu with the two-bin loop system (Table 2). The loop system has substantially higher capital cost ($0.40/bu) and about $0.01/bu lower labor cost. Additional cost for 6 months of storage in on-farm facilities is mostly interest, estimated at $0.12/bu. The estimated farm drying cost for this system capacity exceeds the 1999 cooperative drying charge of $0.35/bu to dry rice at 19.0 to 21.9% field moisture. However, the cooperative would assess a storage charge of $0.03/bu /month if the rice is not committed to the pool within a few weeks' grace period after harvest.

Producers with their own on-farm drying and storage facilities may receive tax benefits in years when they have taxable income to help defray the investment cost. The Internal Revenue Service permits grain bins to be depreciated in as little as 7 years. Assuming that the producer is in a 28% federal tax bracket and a 7% state tax bracket, the depreciation tax benefit would represent about 35% of the capital cost. Using the example in Table 2, this tax benefit would reduce the fixed cost per bushel to about $0.21 for the auger system and about $0.28 for the loop system. Thus, the total cost per bushel for drying may be reduced to about $0.36 for the auger system and $0.43 for the loop system.

The on-farm drying and storage costs of a loop system would decline substantially with expansion of the facilities to increase the number of bins or with multiple crop use, since the fixed capital costs of the loop are a major cost component. The on-farm loop system enables a one-person trucking operation to handle up to two combines with a filling capacity to unload a 400-bu box in 15 min or a 11,000-bu trailer truck in 35 to 40 min. The convenience of unloading quickly was cited as an important factor in owning their own facilities by producers in our cost survey. An average waiting time to unload of 1.5 hr was reported as typical during the harvest season at one cooperative dryer.

SIGNIFICANCE OF FINDINGS

Estimated on-farm rice drying and storage costs with a two-bin, 40,000-bu system are similar to cooperative rates when the tax benefits to producers are taken into account. With increased size of facilities and multiple crop use, the on-farm loop systems will become more economical. The "convenience factor" to unload more quickly at harvest time and to be better prepared to evaluate marketing opportunities after harvest are also important factors in choosing to invest in on-farm systems.

ACKNOWLEDGMENTS

The financial support of the Arkansas Rice Research and Promotion Board is gratefully acknowledged.

LITERATURE CITED

Wailes, E.J., S.H. Holder, and W.P. Welch. 1984. An Economic Analysis of On-Farm Rice Drying and Storage Facilities, University of Arkansas Agricultural Experiment Station Bulletin 875.

Table 1. Average crop data from sample of crop producers in Poinsett and Arkansas Counties, 1999.

Crop Data	Poinsett County	Arkansas County
Rice:		
acres/farm	935	500
yield/acre	150 bu	160 bu
harvest date	Sep-Oct 1	Aug 20-Oct 1
production	140,250 bu	80,000 bu
Soybeans:		
acres/farm	952	1,000
yield/acre	39 bu	40 bu
harvest date	Oct 1-Nov 10	Sep 25-Oct 20
production	37,128 bu	40,000 bu
Wheat:		
acres/farm	28	200
yield/acre	60 bu	70 bu
harvest date	Jun 10	May 25-June 1
production	1,680 bu	14,000 bu
Oats:		
acres/farm		68
yield/acre		110
harvest date		May 25-Jun 10
production		7,480 bu

Table 2. Estimated cost comparison for a 2-bin (37,400-bu working capacity) auger and loop rice drying and storage system, 1999.

Cost Item	Auger		Loop	
	Total	Per Bu	Total	Per Bu
Investment Cost:				
2 36-ft bins & acces.[z]	$59,569	$1.59	$59,569	$1.59
handling equipment[y]	25,786	0.69	66,358	1.77
land (½ acre)	1,000	0.03	1,000	0.03
subtotal	86,355	2.31	126,927	3.39
Annual Fixed Cost:				
depreciation[x]	$6,413	$0.17	$7,757	$0.21
insurance[w]	765	0.02	949	0.03
investment interest[v]	3,454	0.09	5,077	0.14
property tax[u]	765	0.02	1,125	0.03
subtotal	11,397	0.30	14,908	0.40
Annual Variable Cost:				
labor[t]	$1,041	$0.03	$752	$0.02
pest control	100	0.00	100	0.00
electricity[s]	1,872	0.05	1,918	0.05
propane[r]	1,728	0.05	1,728	0.05
building repair	265	0.01	307	0.01
equipment repair	708	0.02	230	0.01
interest on op cap.	5,943	0.16	5,972	0.16
Total Annual Drying Cost	$17,340	$0.46	$20,880	$0.56
Interest on Crop (6 months)	$4,488	0.12	$4,488	0.12

[z] Each bin includes a full floor option, a side wall and ladder option, a 25HP centrifugal fan, a propane heater, 3 stirrer units (3x2HP) and a power sweep (8 in. by 36 ft by 2 HP)

[y] Handling equipment for the 2-bin auger system includes 2 load out augers (8 in. by 36 in. by 3HP), 1 transport auger (8 in. by 62 ft by 15HP), $7,500 electrical work, $4,510 cement work, and $6,400 installation labor. Handling equipment for the 2-bin loop system includes an 8" loop inloader/outloader with ramp ($43,950), $10,000 electrical work, $6,050 cement work, and $6,358 installation labor.

[x] Depreciated bins, cement, electrical and loop-20 years, stirrers and loadin/loadout augers-7 years, and heaters, fans and sweep augers-10 years.

[w] Arkansas County Farm Bureau, Oct. 1999 estimate of $449 per $100,000 in buildings and equipment plus $0.0019/day/$100 of crop value.

[v] Interest at 8%.

[u] Property tax quote from Stuttgart Revenue Dept. in October 1999 of 20% assessment rate and 443 mill rate.

[t] Labor cost of $7.50/hour. For the auger system the estimated bin fill labor time is 1600 BPH, the loadout time is 1200 BPH, plus 4 hours/season to move augers, 20 hours/season to adjust heat and monitor, drying, and 60 hours/season for other monitoring and maintenance. This totaled 139 hours. For the loop system, the bin fill time was estimated at 4,000 BPH and the loadout time also 4,000 BPH since the loop system is highly automated.

[s] Electricity was charged at general service rates with a demand charge of $13.72/kW for May-Sep and $7.41/kW for Oct.-Apr. The non-use customer charge is $11.00/month and the use charge is 3.17¢/kW h. According to long term average September Little Rock weather records ie., 74.1°F and 74% RH, the recommended heat setting is 6°F to dry rice down from 20% field moisture to 12.5% storage moisture. The recommended CFM is 3, requiring an estimated drying time of 228 hours. Fan drying electric cost is estimated at $.0243/bu, fan aeration cost is $0.011/bu and other conveyance electric costs are based on HP rating and BPH.

[r] Propane at $0.76/gallon and 6°F temperature rise for 228 hours (see footnote 8).

A WHOLE-FARM INVESTIGATION OF PRECISION AGRICULTURE: IMPACTS OF RISK AVERSION OPTIMAL CROP MIX

M.P. Popp and C.A. Oriade

ABSTRACT

Precision farming may lead to increased returns and more stable yields for producers who have production resources that exhibit significant variability. Allocation of resources to different crops, with the target of maximizing returns subject to various risk attitudes of decision-makers may entail the use of both conventional and precision farming practices.

INTRODUCTION

Advances in information technology are beginning to impact agriculture through developments in biotechnology and a growing interest in precision agriculture (PA), which aims at employing exact production and management at an intrafield level. This is not entirely novel, as site-specific practices have received attention lately (Lowenberg-DeBoer and Swinton, 1997). The interest in PA may therefore be defined as an attempt to profit from superior, site-specific production management practices without sacrificing the economic advantages of agricultural intensification and mechanization. Developments in geographic information and global positioning systems are perhaps the crucial technological drivers of PA. Together with yield monitors and variable-rate equipment, these systems provide the capability to automate data processing and management of spatial and/or temporal variation in resources.

Some studies that looked into the economic potential of PA have typically restricted the scope of their analyses to single crops and a choice of either precision or conventional management techniques. It is doubtful whether the findings of these studies are consistent within the context of making decisions on a whole-farm level. When several crops and/or production factors are considered, it is possible that an exclusive use of either precision or conventional production practices for all crops may not be optimal. Current, ongoing research is therefore targeted at revealing to what extent PA practices may be adopted in rice and soybeans across various levels of risk attitudes of producers and the degree to which the choice of optimal enterprise mixes is affected by PA practices in a whole-farm framework.

PROCEDURES

Among benefits of PA are the site-specific management and resultant optimal allocation of inputs across subsections of fields that may reduce input use, increase output, and stabilize output within fields. Quantifying these benefits is often difficult and farm-specific. Some studies are summarized in Table 1.

For this study, average marginal yield and production costs reported in the above studies were used to compare PA to conventional production systems. This resulted in an annual 10% yield increase and an additional $12/acre custom charge for precisely managed rice and soybean fields. Average gross margins and their standard deviation—calculated using annual yield, price, and production cost estimates for both conventionally and precision managed crops over the period from 1990 to 1997—are reported in Table 2 (Arkansas Agricultural Statistics Service, USDA-ERS, 1997). Rice, soybeans, cotton, and wheat make up the four major field crops in terms of acreage and value of production in Arkansas. These crops lead to 13 crop enterprise choices. Gross margins are used as depreciation, interest, taxes, insurance, and returns to land, labor, and management are less tractable across farming operations and would not change significantly as custom PA rates are used.

This information is used to model gross margin returns attainable on 100 acres, with a $25,000 annual operating capital budget. This capital constraint was set at a level so that capital is easily available to the producer. The irrigation constraint on cotton and soybeans allows for irrigation on only 40% of their acreage. This is in line with the observed 5-year average for eastern Arkansas (USDA-NASS, 1999.). Crop rotation restrictions are used to model double-cropping of dryland soybeans and winter wheat, as well as a popular irrigated rice, winter wheat, irrigated soybean crop sequence. Finally, note that the 100-acre size is chosen only so that results are easily represented. In other words, the impact of scale of operation and associated economies of size are not modeled.

With the aid of mathematical programming, a utility maximization problem is formulated and solved to obtain optimal acreage allocations and to model various levels of risk aversion, from risk-neutral to risk-averse, using McCarl and Bessler's (1989) approach.

RESULTS

The base case scenario, using resource constraints and gross margin averages and variability, resulted in predicted acreage allocations that are commonly observed in Arkansas. Table 3 shows the impact of various levels of risk aversion on acreage allocations. As indicated in the table, not all crops benefit from PA, and in fact, rice and soybeans are grown using both conventional and PA practices at various risk levels. As risk aversion increases, from left to right in the table, changes occur in the proportion of acres of rice and soybeans devoted to precision farming, the ratio of irrigated compared to dryland farming for soybeans and cotton, the overall crop mix, and the farm gross margins. Specifically, precision farming shifts from being used exclusively and equally across rice and soybean acres to only roughly 56% of rice and soybean acres. Further, the use of PA declined more so for rice production than soybean production. In terms of the crop mix, only rice, soybean, and wheat are grown in rotation under risk neutrality, with cotton entering the crop mix as risk aversion increases. Further, rice and soybean acreage continually decline. Both dryland and irrigated cotton enter the crop mix with increasing risk aversion. Double-cropped winter wheat acreage declines from risk neutrality to risk aversion. The percentage of soybean and cotton produced using irrigation is constant across all levels of risk aversion.

There are several possible reasons for these findings. Given our yield increase assumption for precision-farmed acres, it is not surprising that the initial crop mix contains all precision-farmed land as the value of yield increases more than offsets additional production costs. As risk aversion increases, increased variation in yields over time with PA (not within year or within field variation) leads to a decline in precision-farmed acreage. In other words, producers would choose to work conventionally as yield variation over time is less with the lower conventional yields. The decline in double-cropped wheat acreage is a function of the increase in cotton acreage as double-cropped wheat is grown in rotation with rice and soybeans. It appears that cotton and single-cropped soybeans provide overall farm income risk reduction to the detriment of rice and winter wheat production. Also, production shifts from three-crop enterprises under risk neutrality to four under risk aversion. This is evidence that diversification, growing more different crops, works to reduce overall risk. The fact that the proportion of irrigated-to-dryland production for soybeans and cotton shows that the irrigation constraint on these crops is always limiting.

SIGNIFICANCE OF FINDINGS

The findings in this whole-farm modeling of PA show that adoption of precision farming is likely not an all-or-nothing decision except for risk-neutral producers. In fact, reductions in within field yield risk due to site-specific management may not necessarily lead to additional acreage allocated to that production practice, as whole farm variability in gross margin over time may be the overriding concern to producers. Since economies of size were not targeted in this analysis, decisions regarding adoption of PA may be less continuous. It is unlikely, for example, that farmers would choose to grow a crop on less than 10% of their total acreage. Further research is required to make the analysis more representative of Arkansas conditions.

ACKNOWLEDGMENTS

This research was supported jointly by the Arkansas Rice Research and Promotion Board and the Arkansas Soybean Promotion Board. We appreciate the participation of Dr. Terry Keisling and Dr. T. Windham.

LITERATURE CITED

Arkansas Agricultural Statistics Service. 1998. Arkansas Agricultural Statistics for 1997. University of Arkansas Cooperative Extension Service, Miscellaneous Publication 400.

Lowenberg-DeBoer, J. and S. Swinton 1997. Economics of Site-Specific Management in Agronomic Crops. *In:* F.J. Pierce and E.J. Sadler (eds.). The State of Site-Specific Management for Agriculture. Madison, WI. Agronomy Society of America. Pages 369-396.

McCarl, B.A. and D. Bessler. 1989. Estimating an Upper Bound on the Pratt Risk Aversion Coefficient when the Utility Function in Unknown. Australian Journal of Agricultural Economics. 33:56-63.

United States Department of Agriculture, National Agricultural Statistics Service. 1999. 1997 Census of Agriculture, Arkansas State and County Data.

U.S. Department of Agriculture, Economic Research Service. 1997. Cost of Production Estimates, Delta Region, 1975-1997 at http://www.econ.ag.gov/briefing/FarmIncome/car/soybean3.htm as of 1/10/00.

Table 1. Summary of research studies on precision versus conventional farming practices.

Production Factor	Crop	Location (State)	Study Period	Average PA Cost	Avg. PA Return	Source
		(state)		---------- ($/acre)	----------	
Nitrogen	Corn	Kansas	1994-97	13.05	17.16	Snyder *et al.*, 1998
Seeding Rate	Corn	Kentucky	1993-95	± 7.40	20.90 to 32.64	Barnhisel *et al.*, 1996
Nitrogen	Wheat	Montana	1994-95	5.89 to 7.58	2.79 to 28.79	Long *et al.*, 1996
Nitrogen and Phosphorus	Wheat and Barley	North Dakota	1989-91	0.00 to 66.18	-66.12 to -51.72	Wibawa *et al.*, 1993
Nitrogen	Winter Wheat	Washington	1990-91	NA[z]	-0.13 to 14.80	Fiez *et al.*, 1994

[z] NA = not available.

Table 2. Summary of Per Acre Production Information on Rice, Soybean, Wheat, and Cotton Crop Enterprises for Irrigated, Dryland, Conventional, and Precision Farming Practices, 1990 to 1997, Arkansas.

Crop	Variable Name	Description	Avg. Yield	Avg. Price	Operating Costs[z]	Gross Margin[y] Avg.	Gross Margin[y] Std. Dev.
			(lb/acre)	($/lb)	($/acre)		
Rice	CONRICE	Conventionally managed irrigated	2,464	$0.18	$304.46	$136.80	$105.73
	PRERICE	Precision farmed irrigated	2,710	$0.18	$316.47	$168.93	$116.40
Soybean	CSDSOY	Conventionally managed dryland single season	1,796	$0.11	$80.81	$108.31	$24.53
	CDDSOY	Conventionally managed dryland double season	1,770	$0.11	$80.81	$105.92	$22.96
	PSDSOY	Precision farmed dryland single season	1,976	$0.11	$92.81	$115.23	$27.34
	PDDSOY	Precision farmed dryland double season	1,947	$0.11	$92.81	$112.59	$25.57
	CSISOY	Conventionally managed irrigated single season	2,123	$0.11	$97.86	$126.15	$24.17
	CDISOY	Conventionally managed irrigated double season	2,037	$0.11	$97.86	$117.03	$25.90
	PSISOY	Precision farmed irrigated single season	2,335	$0.11	$109.86	$136.55	$27.07
	PDISOY	Precision farmed irrigated double season	2,241	$0.11	$109.86	$126.52	$28.89
Cotton	IRRCOT	Irrigated	848	$0.64	$362.65	$181.37	$75.79
	DRYCOT	Dryland	749	$0.64	$343.78	$137.35	$83.34
Wheat	WHEAT	Double cropped winter wheat in rotation with either soybean or rice	2,535	$0.06	$53.43	$92.41	$45.93

[z] Operating costs are cash expenses listed by USDA Economic Research Service (1997) and custom precision farming fees of $12/acre regardless of crop.

[y] Gross margin is calculated by multiplying annual yield data with the annual average seasonal price and subtracting annual operating costs per acre. The data are not adjusted for inflation.

Table 3. Optimal Crop Acreage Allocation Across Various Risk Preferences of Producers for Base Case Scenarios.

		Optimal Crop Acres for Different Risk Preferences									
		Risk Neutral								Risk Averse	Change[w]
Crop[a]	Irr.[b]	R_0 [c]	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	(R_8 - R_0)
CONRICE	y	0	0	7	11	13	14	14	15	15	15
PRERICE	y	50	43	25	14	11	7	4	2	0	-50
CSDSOY	n	0	0	0	0	0	3	6	7	9	9
PDISOY	y	20	17	7	0	0	0	0	0	0	-20
PDDSOY	n	30	26	25	25	25	21	19	17	15	-15
PSISOY	y	0	0	9	16	16	16	16	16	16	16
WHT	n	47	40	30	23	22	19	17	15	14	-34
DRYCOT	n	0	9	16	20	21	23	25	26	27	27
IRRCOT	y	0	6	10	14	14	15	17	17	18	18
Whole Farm Gross Margin											
Average		$18,064	$17,698	$16,631	$15,903	$15,798	$15,489	$15,256	$15,079	$14,933	($3,131)
Std. Dev.		$6,986	$6,081	$4,301	$3,189	$3,051	$2,739	$2,533	$2,398	$2,304	($4,682)

[z] Crop enterprise definitions may be found in Table 2. 'CON' or C stands for conventional production, 'PRE' or 'P' stands for precision farming, 'S' and 'D', the second letter for the SOY enterprises represent single season and double season cropping, respectively, 'D' and 'I', the third letters for the SOY enterprises represent dryland and irrigated production, respectively.

[y] 'y' and 'n' represent irrigated and dryland production, respectively.

[x] R0 through R8 represent risk aversion coefficients that are used to model the decision makers' level of risk aversion. A risk aversion coefficient of R0 = 0 represents risk neutrality and R8 = 0.000367 represents strong risk aversion. The maximum risk aversion coefficient (R8) is set using McCarl and Bessler's (1989) technique with intermediate levels of risk aversion based on 50% to 90% likelihoods in 5% increments.

[w] Represents the difference in the maximum and minimum acreage utilized for each production scenario over the range of risk preferences.

ECONOMIC IMPACTS ON ARKANSAS RICE FROM GROUNDWATER DEPLETION

E.J. Wailes, G.L. Cramer, K.B. Young, J. Smartt, and P. Tacker

ABSTRACT

Groundwater depletion is seriously eroding the long-term sustainability of rice production in Arkansas. Representative farm analysis shows that investment in on-farm reservoirs is profitable in areas subject to critical groundwater depletion. The value of irrigated cropland is estimated to decline by $11.25/acre for 1-ft decline in saturated depth of groundwater.

INTRODUCTION

Groundwater depletion is a significant problem facing farmers in eastern Arkansas. The Arkansas Soil and Water Conservation Commission (ASWCC, 1999) declared six counties in eastern Arkansas critical groundwater areas by 1998 as a result of over-pumping. Five other counties have incurred significant aquifer decline levels. Depletion of the Alluvial Aquifer is also contributing to increased soil salinity and alkalinity problems in various parts of the delta. Surplus surface water is available in the region including rainfall runoff and irrigation tailwater; however, many farmers have been reluctant to invest in on-farm reservoirs until their groundwater supply becomes critical. With an average annual Alluvial Aquifer recharge rate as low as 3.3 cm., the long-term sustainability of irrigated cropping in eastern Arkansas based on groundwater is extremely limited (Scott *et al.*, 1998).

One major constraint on the substitution of surface water use for irrigation is the poor incentives to conserve groundwater because the aquifer decline is related to pumping by all farmers. Furthermore, short-run investment costs of reservoir construction are much higher than the costs of drilling a new well. Proposals to address the water supply problem include increased surface water use from on-farm reservoirs and stream diversion, improved field efficiency, improved water management, and increased public assistance for groundwater conservation. The purpose of this study is to provide benefit and cost information to the rice producers, industry, and public policy decision-makers on the use of surface water for irrigation of Arkansas rice.

PROCEDURES

MARORA, an irrigation system analysis model, has been developed to evaluate net economic benefits of groundwater conservation practices for rice and soybean production. Developed initially for soybean irrigation only, MARORA estimates the present value of 30 years of projected annual net farm income and identifies the optimal on-farm reservoir size to supplement groundwater use. For this study, we have substantially modified the original model (Wailes *et al.*, 1999). Rice production was added in the cropping system to reflect the typical soybean and rice crop mix in eastern Arkansas. A tailwater recovery system and access to diverted surface water have been added. The model also has been refined to evaluate multiple-use benefits (e.g., wildlife habitat) of on-farm reservoirs and to assess the need for public funding assistance. MARORA simulates crop production by calculating daily irrigation requirements on the basis of daily weather data and crop stage of growth. Thirty years of production are simulated to determine whether investment in an on-farm reservoir will result in higher net returns.

The MARORA model was validated for investment and use of on-farm reservoirs on representative farms in northeast Arkansas and the Grand Prairie regions in 1999. Representative farm level data were collected from panels of selected producers in Poinsett and Arkansas counties, respectively. Common assumptions in the model used for the two study regions for model application include: (1) initial saturated thickness levels; (2) annual water table decline rates; (3) production costs based on Arkansas Cooperative Extension Service budget data for 1999; (4) farm production area of 320 acres with two irrigation wells; (5) discount rate of 8% to calculate the present worth of 30-year annual net farm income; (6) silty loam soils; 7) field irrigation application efficiency of 90% for rice and 65% for soybeans; and (8) assumed annual fill of the reservoir plus refill of tailwater runoff during the growing season only. The major cropping system difference in the study regions (Poinsett County in the Northeast and Arkansas County in the Grand Prairie) is the crop rotation, with 1:2 ratio of rice to soybeans in Arkansas County and a 1:1 ratio of rice to soybeans in Poinsett County. Water requirements are higher with more rice in the rotation. Annual duck habitat benefits, used only for Arkansas County, were valued at $10 per surface acre of the reservoir area. Initial groundwater depth is 100 ft in Poinsett County compared to 200 ft in Arkansas County.

RESULTS AND DISCUSSION

Representative farm conditions were simulated over a 30-year period for Poinsett and Arkansas counties to estimate the optimal reservoir size and present worth of net returns. Analysis using MARORA has already shown that given the choice of drilling more wells versus investing in a reservoir, the producer will drill wells to maximize the present worth of net income, without public subsidies (Young *et al.*, 1998). The analysis presented below is based on answering the following questions: (1) What is the optimal size of a reservoir if a representative farm is constrained from drilling more wells to increase groundwater supply? (2) What are the effects on net returns from limiting farms to existing wells, given the alternatives of constructing an optimal size reservoir or none at all? The present value of the net returns estimate can be interpreted as land value, since all other costs, except management, of producing rice and soybeans are subtracted from the gross returns. The present value of net income is calculated by summing the discounted stream of annual net incomes for 30 years, generated by rice and soybean production, including the cost of the reservoir investment and the foregone value of production on the land used for the reservoir. The model was simulated by varying three parameters: (1) initial saturated depth at 25 and 50 ft, (2) annual rate of decline of saturated thickness at 0.5, 0.75, 1.0 ft per year, and (3) low, medium, and high crop prices, i.e., \$4, \$5, and \$6/bu for rice and \$5.40, \$6.75, and \$8.10/bu for soybeans, respectively.

The optimal reservoir size for the 320-acre production area in Poinsett County was 620 acre-ft (82 surface acres), for an initial saturated depth of 25 ft and an 180 acre-ft (25 surface acres) reservoir at the initial saturated depth of 50 ft. In Arkansas County, slightly smaller reservoirs were optimal; 540 acre-ft (72 surface acres) was the optimal size at 25-ft saturated depth and 120 acre-ft (17 surface acres) at 50-ft saturated depth. These reservoir sizes were optimal for all price levels and rates of decline in the water table. Increases in reservoir capacity were approximately 18 acre-ft or 2.25 surface acres/1-ft of decline in saturated thickness.

Table 1 shows the present worth of net returns for representative farms in both counties assuming medium price levels. The results show the effect on present worth of net returns at alternative groundwater saturated depths and rates of decline in the water table. For example, in Poinsett County, at an initial saturated depth of 50 ft, the difference in the present worth of net returns for a decline rate of 0.5 ft/year compared 1.0 ft/year is \$58,000. This difference translates into a 30-year investment value of \$181.25/acre for land with the lower water table decline rate. At the 25-ft saturated depth, simulation results for variation in the rate of water table decline show only small differences in land values. The effect of the initial saturated depth is estimated by comparing the same rate of decline in the water table for the 25- and 50-ft saturated depth estimates. For example, for Arkansas County, the difference in the present worth of net returns at a 1-ft/year decline rate at the 50-ft initial saturated depth compared to the 25-ft initial saturated depth is \$90,000 (Table 1). This translates into an impact on the land value of the 320-acre production area of $11.25/acre for each 1 ft of saturated depth.

The estimated differences in present worth of income with and without a reservoir are shown in Tables 2 and 3. The representative farm in Poinsett County with 25-ft initial saturated thickness and medium level crop prices, incurred a negative $131,000 income without a reservoir compared with $474,000 with a reservoir. When converted to a land investment value, sustaining the cropping system with a reservoir adds an estimated $1891/acre. This difference is a result of rice production being discontinued after the sixth year of the 30-year simulation without a reservoir and the assumption that additional wells cannot be added to the farm. The difference in income with and without a reservoir for the representative farm in Arkansas County was $445,000 ($1391/acre) at the 25 ft initial saturated thickness and medium level prices. Differences in income at the 50-ft initial saturated thickness with and without reservoirs were less but still important.

SIGNIFICANCE OF FINDINGS

The analysis in this study shows that estimated benefits of an on-farm reservoir are influenced by the initial groundwater saturated depth, the rate of water table decline, the level of crop prices, and the importance of rice in the cropping system. The results show that investment in on-farm reservoirs can have a significant impact on the representative farm's net income. Differences in the present worth of income and land value with and without a reservoir were substantial, particularly with an initial saturated thickness of 25 ft. The estimates were based on a limiting assumption that the representative farmer is prevented from drilling additional wells to supplement existing groundwater supplies. While this constraint does not hold currently, the continuing groundwater depletion in eastern Arkansas is beginning to make this a reality.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Rice Research and Promotion Board and the U.S. Department of Interior, U.S. Geological Survey. We appreciate the participation of the following individuals who assisted in our representative farm analysis: Mr. Hank Bueker, Mr. Jerry Burkett, Mr. Kenneth Maier, Mr. Phil Sims, Mr. George Berger, Mr. Jerry Clark and Sons, Mr. Gary Sitzer, Mr. Tom Wimpy, Mr. Rick Thompson, Mr. David Yocum, Mr. Bobby Miller, and Mr. Carl Hayden.

LITERATURE CITED

Arkansas Soil and Water Conservation Commission (ASWCC). 1999. Arkansas Ground Water Protection and Management Report for 1998. Little Rock, Arkansas.

Scott, D.H., 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.

Wailes, E., K. Young, and J. Smartt. 1999. Economic Analysis of On-farm Reservoirs to Sustain Irrigated Agriculture in Eastern Arkansas. *In:* Proceedings, Arkansas Water Resource Center Conference. Fayetteville, Arkansas. April, 1999. Pp 65-72.

Young, K.B., E.J. Wailes, and J. Smartt. 1998. Analyzing Conjunctive Use of On-farm Reservoirs and Irrigation Wells in the Arkansas Delta. *In:* H.D. Scott (ed.) Vulnerability and Use of Ground and Surface Waters in the Southern Mississippi Valley Region. Pub. No. 269, Arkansas Water Resources Center, Fayetteville, Arkansas.

Table 1. Present worth of net returns for optimal reservoir size under alternative water table saturated depths and rates of decline for representative farms (320 acres).

Saturated Depth	Rate of Decline	Poinsett County	Arkansas County
(ft)	(ft/year)	--------------- (thousand $)	---------------
25	0.5	477	516
25	0.75	477	516
25	1.0	474	516
50	0.5	671	644
50	0.75	669	642
50	1.0	613	606

Table 2. Effect on present worth of net returns for Poinsett County representative farm with optimal size reservoir compared to no reservoir under alternative crop price levels and initial saturated depth of water table declining at 1 ft/year.

Crop Price Level	Saturated Depth	With Reservoir	Without Reservoir	Total Difference	Difference
	(ft)	-------------------	(thousand $)	-------------------	($/acre)
Low	25	196	-237	433	1,353
Low	50	282	116	166	519
Medium	25	474	-131	605	1,891
Medium	50	613	353	260	813
High	25	751	-24	775	2,422
High	50	945	589	356	1,113

Table 3. Effect on present worth of net returns for Arkansas County representative farm with optimal size reservoir compared to no reservoir under alternative crop price levels and initial saturated depth of water table declining at 1 ft/year.

Crop Price Level	Saturated Depth	With Reservoir	Without Reservoir	Total Difference	Difference
	(ft)	-------------------	(thousand $)	-------------------	($/acre)
Low	25	244	-69	313	978
Low	50	281	256	25	787
Medium	25	516	71	445	1,391
Medium	50	606	532	74	231
High	25	787	211	576	1,800
High	50	930	808	122	381

EFFECTS OF FALL RICE STUBBLE MANAGEMENT AND WINTER FLOODING ON SUBSEQUENT CONVENTIONAL- AND NO-TILL IRRIGATED AND RAINFED SOYBEANS

M.M. Anders, T.E. Windham, J.F. Robinson, R.W. McNew, and K. Reinecke

ABSTRACT

Three seasons of field experiments on the effects of rice stubble management combined with various winter flooding strategies on conventional- and no-till irrigated and rainfed soybeans were conducted at the Rice Research and Extension Center between 1996 and 1999. Results indicate there was no significant effect on grain yield in a following soybean crop if the rice stubble was disked, rolled, or left standing, and the field was drained, pumped, or managed to collect rainfall during the winter. Conventional-till soybean plots had higher grain yields but resulted in lower net returns when 3 years of data were pooled. None of the rainfed soybean plots resulted in a positive net return in 1997 or 1999. Higher rainfed plot yields in 1998 resulted in six rainfed management combinations posting positive net returns. Additional operations necessary to flood fields for winter waterfowl habitat incurred additional expenses that made this strategy less profitable than not pumping fields. Water volume measurements indicated the majority of water required to maintain a 4-in. water level came with the initial pumping.

INTRODUCTION

Arkansas' 1.5 million acres of rice lies in the flight path of 2 to 3 million mallards and other migratory waterfowl and is the primary wintering habitat for these birds. Currently, it is estimated that approximately 200,000 acres of rice land is flooded in the Mississippi Delta during the time these waterfowl overwinter. The North American

Waterfowl Management Plan (Canadian Wildlife Service and U.S. Fish and Wildlife Service, 1986) calls for a significant increase in the area being flooded. Those lands that are currently flooded support a substantial hunting industry and provide individual farmers with recreation. To significantly increase the amount of land under winter flood, farmers will need to better understand the benefits and/or problems associated with winter flooding.

In the rice-producing areas of Arkansas, it is common practice for farmers to rotate soybeans with rice. Flooding rice fields provides migratory waterfowl with feed and can potentially benefit weed control in the following crop through weed seed predation (Smith and Sullivan, 1980; Wright, 1959; Forsyth, 1965) and decreased weed seed viability (Buehler, *et al.*, 1998; Baskin and Baskin, 1998). It has been estimated that Arkansas rice and soybean farmers could lose up to $840 million each year if they do not control the weeds that infest their fields (Bridges, 1992). Better understanding the costs and benefits of winter flooding will assist farmers who choose to flood fields by minimizing costs associated with and benefits from flooding. It will also assist wildlife workers in their efforts to persuade more farmers to flood fields. The work reported here was initiated with the following objectives:

1. To provide farmers with crop (rice and soybean) management recommendations that will result in maximum benefits from winter flooding.
2. To provide wildlife specialists with relevant information on the benefits and problems related to winter flooding for waterfowl habitat.

PROCEDURES

In 1996, 1997, and 1998, rice fields used for foundation seed production at the Rice Research and Extension Center, Stuttgart, were selected for these studies. In all years, the preceding rice crop was ‘Cypress’, which was managed as a commercial crop. The soil in the experimental area is a DeWitt silt loam (fine, montmorillonitic, thermic Typic Albaqualf) with a hard pan 6 to 8 in. below the soil surface. Following the rice harvest, straw treatments were applied (Table 1). Winter flooding treatments were initiated between the third week of November and the first week of December, with a water level of 4 in. maintained in the pumped plots. All plots were drained during the first week of March. The soybean variety ‘Holladay’ was sown into 25- x 200-ft plots and managed as indicated in Table 2. At harvest, two subplots were collected in each treatment and yields adjusted to a 12% moisture content.

In 1996-97, a split-split-split plot design was used with three replications. In 1997-98 and 1998-99, a split-strip-split design was used with five replications in 1997-98 and six replications in 1998-99. Data from 1996-97 and 1998-99 were analyzed using the SAS Statistical Software Package (1991) GLM procedure. The 1997-98 data were analyzed using the SAS Statistical Software Package (1991) MIXED procedure. All yield data are least square means values generated in the analysis. Economic projections were generated using the procedure outlined in the Mississippi State Budget Generator Users Guide, version 3.0 (Spurlock and Laughlin, 1992). Economic returns were calculated using a $6 soybean price and with a 25% land cost.

RESULTS AND DISCUSSION

In 1997, soybean grain yields were significantly higher in the conventional-tilled plots than the no-till plots (Table 3). This difference was attributed to poor plant stands in the no-till plots that resulted in severe weed infestations. There were no significant differences in the main effect comparisons of straw management and winter flooding, nor were there any significant interactions in the 1997 analysis. Differences between the irrigated and rainfed treatments were highly significant in 1997.

Results in 1998 differed from those in 1997 in that the yields for the rainfed treatments were higher and there was not a significant difference between the conventional- and no-till treatments. As in the previous year, there were no differences in the straw management and winter flooding treatments, nor were there any significant interactions. Grain yields in both the irrigated and rainfed treatments increased equally in 1998; however, increased variability in treatments resulted in this difference being significant at a lower level than in the previous year.

Soybean grain yields in 1999 were similar to those of the previous 2 years with the exception of the no-till treatments compared to the conventional-till treatments, where there was only a 1-bu/acre difference. These results continued a trend of decreasing differences in the conventional- and no-till treatments that highlight the evolving of a better understanding of how to properly manage no-till treatments. There was a significant interaction between irrigation and tillage treatments in 1999, with no-till treatments having the higher yields in the irrigated treatments and lower yields in the rainfed treatments. These results are attributed to the higher plant populations in the no-till treatments and extremely dry conditions later in the growing season. The effects of this dry period are reflected in the rainfed treatment yields (15 bu/acre), which were the lowest of the 3 years. Grain yields from irrigated plots were the highest of the three years (59 bu/acre) and reflect the excellent growing conditions early in the season combined with the benefits of irrigation. As in the two previous years, there were no significant differences in the straw management and winter flooding treatments.

Net returns averaged over the 3 years of the study indicate an advantage to no-till compared to conventional-till, irrigated over rainfed, and a financial disadvantage to pumping plots for winter flooding (Table 4). Net returns were higher on the conventional till plots only in 1997 (data not presented), the year there was a significant difference between tillage treatments. By 1999, the management used in the tillage treatments was consistent with good farming practices, and the results are better illustrated in the net return rankings. Positive net returns on rainfed treatments occurred only in 1998, with the highest returns being $58.26/acre. The fact that the 3 years of pooled data have no rainfed treatments showing a positive net return questions the common practice of sowing soybeans after wheat into fields that cannot be irrigated. Additional production costs resulting from winter flooding resulted in lower net returns from the pumped treatments (Table 4). These costs are likely to restrict the area of land that farmers are willing to flood. Net returns on rainfall plots suggest that capturing available winter rainfall is a viable strategy to reduce pumping costs.

Water volume measured in the 1998-99 winter (Fig. 1) indicate that the largest volume of water is required when the plots are initially pumped to the 4-in. depth. Reduction of this cost will be possible if levees are repaired by early November in order to maximize rainfall capture. In a normal rainfall year, this should result in sufficient water to attract waterfowl without the added pumping costs.

SIGNIFICANCE OF FINDINGS

These findings provide guidelines to farmers on what they can expect from the straw management and winter flooding options tested. They illustrate the financial advantages of no-till management and suggest that soybeans that are reliant on rainfall will probably not be profitable. Additional costs of winter flooding can be offset somewhat by constructing levees early in the winter and maximizing rainfall capture.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research Promotion Board, Arkansas Soybean Promotion Board, USFWS, and USGS for their contributions to this work.

LITERATURE CITED

Baskin, C.C., and J.M. Baskin. 1998. Seeds: ecology, biogeography, and evolution of dormancy and germination. Academic Press, New York. 666 pp.

Bridges, D.C. 1992. Crop losses due to weeds in the United States. Weed Science Society of America, Champaign, IL. 403 pp.

Buehler, D.A., W.G. Minser, and M.R. Short. 1998. Avian use of wetlands in western Tennessee. 1997 Annual Report Winter Crop Flooding Study and Shorebird Study. Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville.

Canadian Wildlife Service and U.S. Fish and Wildlife Service. 1986. North American Waterfowl Management Plan. U.S. Fish and Wildlife Service, Washington, D.C.

Forsyth, B. 1965. December food habits of the mallard (Anas platyrhynchos Linn.) in the Grand Prairie of Arkansas. Arkansas Academy Science Proceedings 19:74-78.

SAS Institute. 1991. SAS user's guide. Statistics. SAS Inst., Cary, NC.

Smith, R.J., Jr., and J.D. Sullivan. 1980. Reduction of red rice grain in rice fields by winter feeding of ducks. Arkansas Farm Research 29:(4):3.

Spurlock, S.R. and D.H. Laughlin. 1992. Mississippi State Budget Generator Users Guide, version 3.0. Department of Agricultural Economics, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University. Agricultural Economics Technical Publication No. 88, July 1992.

Wright, T.W. 1959. Winter floods of marshlands in Arkansas. Proceedings Annual Conference Southeastern Association Fish and Game Commissions. 25:289-294.

Table 1. Rice stubble, winter flooding, tillage, and irrigation treatments used in 1997, 1998, and 1999.

Treatment	1996-97	1997-98	1998-99
Fall Rice stubble	disked standing rolled	standing rolled	standing rolled
Winter flooding	pumped rainfall drained	pumped rainfall drained	pumped rainfall drained
Spring Tillage (soybeans)	conventional no-till	conventional no-till	conventional no-till
Summer Irrigation (soybeans)	irrigated rainfed	irrigated rainfed	irrigated rainfed

Table 2. Soybean plot management used in 1997, 1998, and 1999.

Management	1997		1998		1999	
	conventional	no-till	conventional	no-till	conventional	no-till
Field preparation	disked (2) triple K (2) float (2)	none	disked (2) triple K (3) rolled (1)	none	disked (1) triple K (2)	none
Weed control	Scepter 1.4 pt/acre Dual 1.5 pt/acre Post plus 1E 1.5 pt/acre Crop oil 1 qt/acre	Roundup Ultra 2 pt/acre Post Plus 1E 1.5 pt/acre Crop oil 1 qt/acre	Scepter 1.4 pt/acre Dual 1.5 pt/acre Post plus 1E 1.5 pt/acre Crop oil 1 qt/acre Cultivated (2)	Roundup Ultra 2 pt/acre Post Plus 1E 1.5 pt/acre Crop oil 1 qt/acre	Scepter 1.4 pt/acre Dual 1.5 pt/acre Cultivated (1)	Roundup Ultra 2 pt/acre Post Plus 1E 1.5 pt/acre Crop oil 1 qt/acre
Irrigation	3 x 3 in.	3 x 3 in.	6 x 1.5 in.	6 x 1.5 in.	5 x 1.5 in.	5 x 1.5 in.
Row spacing	32 in.	7.5 in.	32 in.	7.5 in.	32 in.	7.5 in.

Table 3. Soybean grain yields for main effects in the 1997, 1998, and 1999 soybean crop.

Operation	Treatment	Grain yield 1997	1998	1999	mean
		------ (bu/acre) ------			
Straw management	disked	32	-	-	32
	standing	32	37	37	35
	rolled	34	38	36	36
Winter flooding	drained	33	37	36	35
	rainfall	31	40	37	36
	pumped	33	35	37	35
Tillage	conventional tillage	37*	40	37	38
	no-till	29*	35	36	33
Irrigation	irrigated	46**	51*	59**	52
	rainfed	19**	24*	15**	19

* Treatments were significantly different at the 0.01 level.

** Treatments were significantly different at the 0.001 level.

Table 4. Summary of pooled net returns for the top ten treatments in the 1997, 1998, and 1999 soybean crops.

Treatments: rice straw	winter flooding	tillage	irrigation	Net returns $*
standing	drained	no-till	irrigated	$159.32
rolled	rainfall	no-till	irrigated	$155.40
standing	rainfall	no-till	irrigated	$155.05
standing	rainfall	conventional	irrigated	$146.01
rolled	drained	conventional	irrigated	$130.32
7standing	rainfall	conventional	irrigated	$122.84
standing	pumped	no-till	irrigated	$103.10
rolled	pumped	no-till	irrigated	$101.49
rolled	rainfall	conventional	irrigated	$94.14
standing	pumped	conventional	irrigated	$83.00

z Calculated at a soybean price of $6.00/bu and a 25% land cost.

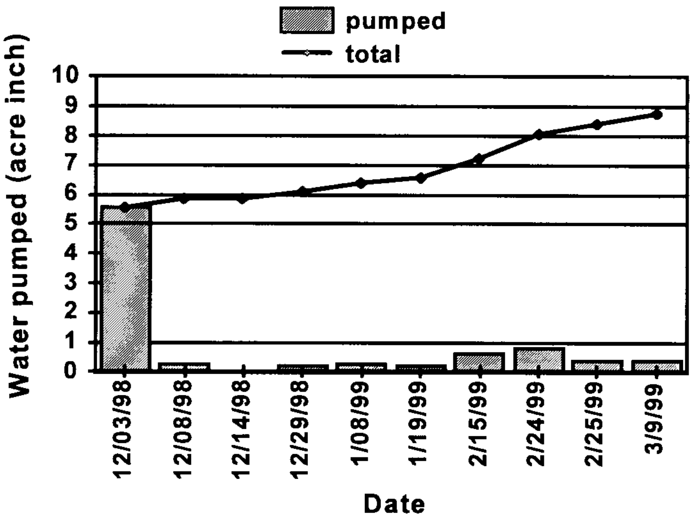


Fig. 1. Incremental and total water (acre inches) pumped to maintain a 4-in. water depth during the 1998-99 winter.

INTERFERENCE BETWEEN RED RICE AND RICE IN A REPLACEMENT SERIES STUDY

L.E. Estorninos, Jr., D.R. Gealy, and R.E. Talbert

ABSTRACT

A greenhouse study was conducted in 1998 and 1999 to evaluate the response of rice cultivars 'Kaybonnet' (medium-tall, commercial cultivar in Arkansas) and PI312777 (semi-dwarf and possibly allelopathic rice) when grown in the presence of Katy red rice (KatyRR: presumed cross between Katy rice and a strawhull red rice) and LA3 (tall red rice from Louisiana). The study also included monoculture of the two red rice ecotypes and the two rice cultivars. The proportions were 3:0, 2:1, 1:2, and 0:3 (rice:red rice) plants per pot. Plant heights and leaf areas of both rice and red rice were measured 28, 49, and 70 days after emergence (DAE), and dry weights of plant leaves, stems, and roots were determined.

Heights of Kaybonnet and PI 312777 were not different when grown with KatyRR and LA3 until 70 DAE. At 70 DAE, height of KatyRR was reduced when planted with PI 312777 at 2:1 rice:red rice proportions compared to the other mixtures, while LA3 was not affected by the rice cultivars and mixture proportions. Leaf area index of Kaybonnet at 70 DAE was lower than of PI 312777 at all planting mixtures. Shoot dry weight of Kaybonnet was lower than of KatyRR or LA3 which indicates that Kaybonnet was less competitive than KatyRR and LA3. In the PI 312777 and KatyRR mixture, the shoot dry weight of PI 312777 was comparable to KatyRR and LA3.

These greenhouse results were in contrast with previous field research results, which showed KatyRR to be much less competitive than LA3 against Kaybonnet and PI 312777. These results also indicate that Kaybonnet was less competitive than PI 312777 against KatyRR and LA3 red rice ecotypes.

INTRODUCTION

Red rice is one of the most damaging weeds in rice fields in the southern United States. Several methods or approaches have been developed to study competition from weeds in mixed stands (Radosevich, 1987, Kwon *et al.*, 1991, Pantone *et al.*, 1992). Each method considers density, spatial arrangement, and proportion (Radosevich, 1986). One of the most common methods is the substitutive method or replacement series. In this approach, total plant density is kept constant, while the proportions of the two species vary (De Wit and van den Bergh, 1965) or the planting density of one species is proportionately decreased as the planting density of the second species is increased (Jolliffe *et al.*, 1984). The yield of the mixtures is determined by comparing to the yield of the monoculture of each species (relative yield). The method is most valuable for assessing the competitive effects of species proportion at a single total density and determining the relative effects of intraspecific and interspecific interference (Radosevich, 1987).

The objectives of the study were to evaluate the growth of rice cultivars Kaybonnet and PI 312777 when grown together with KatyRR and LA3 red rice and the growth response when planted at various planting mixture proportions.

PROCEDURES

The experiment was conducted in the greenhouse at the Altheimer Laboratory of the University of Arkansas in Fayetteville from February to May, 1998 and 1999. The pots were arranged in a 2 x 2 x 4 factorial of a randomized complete block design with three replications. The treatments included Kaybonnet (popular commercial cultivar) and PI 312777 (T65*2/TN1; a possible allelopathic variety from the USDA World Rice Collection). The red rice ecotypes were KatyRR (short statured, suspected hybrid of Katy and a red rice biotype) and LA3 (tall and awned ecotype from Louisiana). The planting proportions were: 3:0, 2:1, 1:2, and 0:3 rice:red rice.

The soil was a DeWitt silt loam from Stuttgart. Each pot (5.1 x 5.1 x 6.3 in.) was filled to about 3/4 (depth) with air dry soil. Three species were planted in a triangular arrangement with two seeds per species. After planting, the seeds were covered with 1/4-in. dry soil and slightly compacted to simulate field conditions. The pots were placed on trays filled with water. The seedlings were thinned to one plant 3 to 5 DAE. One inch of standing water was maintained from 5 DAE until 70 DAE.

Fertilizer in the form of urea was applied at 27 lb/acre per application at 30 and 50 DAE. Tillers and leaves per plant were determined and plant height was measured at 28, 49, and 70 DAE. At each sampling, plants were removed from the pots and washed carefully as not to damage the roots and shoots. After washing, the roots, stems, and leaves were separated, leaf area was measured, and each organ was put into separate bags and dried. Leaf area index (LAI) is the ratio of total leaf area produced per ground area. Competitiveness of the species was evaluated based on the relative yield (dry weight of each species in mixture/dry weight of the species in monoculture) of roots and shoots. The data was subjected to analysis of variance (ANOVA) and means separated using least significant difference (LSD) at the 5% level of probability.

RESULTS AND DISCUSSION

The height of rice was not influenced by the two red rice ecotypes and planting mixture proportions until 70 DAE. The height of red rice ecotypes was not affected by the rice cultivars and planting proportions until 70 DAE. At 70 DAE KatyRR, when planted with PI 312777 at 2:1 rice, red rice proportions, was shorter than the other treatments including monocultures (Table 1). This indicates that KatyRR is less competitive than PI 312777 when grown at reduced density in a mixture. Height of LA3 was not affected when grown with the rice cultivars. The height of KatyRR was comparable to that of LA3 in the other proportions. This is in contrast to our results from the field where KatyRR was the least competitive among the three red rice ecotypes including LA3.

LAI of Kaybonnet and PI 312777 was not influenced by either KatyRR or LA3 red rice ecotypes in all planting proportions until 70 DAE. At 70 DAE, the LAI of Kaybonnet was lower than that of PI 312777 when planted as monoculture as well as with red rice (Table 2). Both cultivars showed LAI reduction as their density in the mixture decreased. Leaf area index of KatyRR and LA3 was not affected by either Kaybonnet or PI 312777 until 70 DAE. At 70 DAE, the LAI of KatyRR was higher than that of LA3 when planted together with domestic rice at 2:1 rice, red rice proportions (Table 3). No differences were observed in the other planting mixtures. Leaf area index of both ecotypes increased as their density in the mixture increased indicating that at this stage, the rice cultivars had no influence on the growth of red rice.

The competitiveness of each species was also examined onthe basis of the relative yield of the shoot dry weights. The response curve for each combination would either be convex (more competitive), concave (less competitive), or a straight line (equal competition). The relative yield of the shoot dry weights of Kaybonnet and KatyRR or LA3 showed that the curves for Kaybonnet were more concave while those of KatyRR and LA3 were more convex (Figure 1). These results indicate that Kaybonnet was less competitive than either KatyRR or LA3. The relative yield for either PI 312777 and KatyRR or PI 312777 and LA3 produced almost a straight line. These data indicate that PI 312777 was as competitive as both KatyRR and PI 312777 under greenhouse conditions.

Results of the 2-year study in the greenhouse indicate that growth response of a species may differ under greenhouse conditions compared to its growth under field conditions. Kaybonnet, which is a medium-tall rice cultivar, was a poor competitor with KatyRR and LA3 in all proportions. This is in agreement with our results under field conditions in 1997 and 1998. KatyRR showed better competitiveness against Kaybonnet and PI 312777 in the greenhouse, while it was a poor competitor under field conditions.

SIGNIFICANCE OF FINDINGS

Growth response of KatyRR and LA3 red rice differed from each other under greenhouse conditions. KatyRR was very competitive against Kaybonnet, and height was comparable to LA3, a tall red rice, until 70 DAE. Kaybonnet and PI 312777 responded differently when grown together with KatyRR and LA3. Kaybonnet was less competitive than PI 312777 against red rice, which may be due in part to its lower LAI and relatively fewer tiller numbers. PI 312777, however, did not show increased competitiveness against the two red rice ecotypes. A study is needed to evaluate these responses until maturity.

ACKNOWLEDGMENTS

This research was supported in part by the Arkansas Rice Research and Promotion Board. We would like thank Howard Black for collecting the soils.

LITERATURE CITED

De Wit, C.T., and J.P. van den Bergh. 1965. Competition between herbage plants. Neth. J. Agric. Sci. 13:212-221.

Jolliffe, P.A., A.N. Minjas, and V.C. Runecles. 1984. A reinterpretation of yield relationships in replacement series experiments. J. Appl. Ecol. 21:227-243.

Kwon, S.L., R.J. Smith, Jr., and R.E. Talbert. 1991. Interference of rice, *Oryza sativa*, densities in rice, *O. sativa*. Weed Sci. 39:169-174.

Pantone, D.J., J.B. Baker, and P.W. Jordan. 1992. Path analysis of red rice, *Oryza sativa*, competition with cultivated rice. Weed Sci. 40:313-319.

Radosevich, S.R. 1986. Methods of interference study. *In:* M.A. Altier and M.Z. Liebman (eds). Plant Competition and Other Ecological Approaches to Weed Control in Agriculture. CRC Press Handbook. Boca Raton, FL.

Radosevich, S.R. 1987. Methods of interactions among crops and weeds. Weed Technol. 1:190-198.

Table 1. Height of red rice ecotypes at 70 DAE as influenced by cultivars and proportions[z].

	Red rice ecotypes	
Proportion	KatyRR	LA3
(rice:red rice)	inches	
Kaybonnet		
2:1	43 a	43 a
1:2	41 a	41 a
PI 312777		
2:1	34 b	39 a
1:2	39 a	40 a
Monoculture	41 a	42 a

[z] Average of three replications. In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 2. Leaf area index at 70 DAE as influenced by red rice ecotypes and proportions[z].

	Rice cultivar	
Proportion	Kaybonnet	PI 312777
(rice:red rice)		
Monoculture	4.1 b	6.6 a
2:1	2.0 c	4.7 b
1:2	1.0 d	2.2 c

[z] Average of three replications and two red rice ecotypes. In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 3. Red rice leaf area index at 70 DAE as influenced by red rice ecotypes and proportions[z].

	Rice cultivar	
Proportion	KatyRR	LA3
(rice:red rice)		
2:1	2.6 c	1.6 d
1:2	4.2 b	4.0 b
Monoculture	5.7 a	6.5 a

[z] Average of three replications and two red rice ecotypes. In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

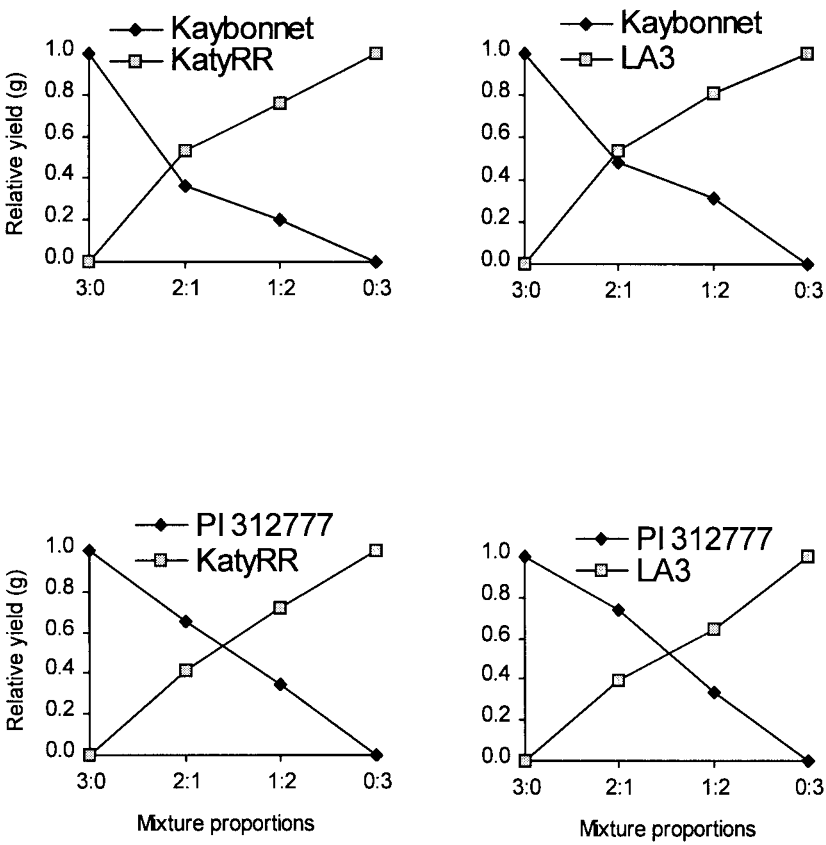


Fig. 1. Relative shoot dry weight yield of rice and red rice at 70 DAE as influenced by 3:0 (monoculture rice); 2:1 (two rice, one red rice), 1:2 (one rice, two red rice), and 0:3 (monoculture red rice) mixture proportions.

SILICON SOIL AMENDMENTS DO NOT INCREASE ROUGH RICE YIELD OR REDUCE RICE SHEATH BLIGHT SEVERITY

F.N. Lee, R.D. Cartwright, N.A. Slaton, S. Ntamatungiro, C.E. Parsons, B.L. Candole, and E. Gbur

ABSTRACT

Rough rice yield and sheath blight response to a single application of silicon applied as either rice hull ash or calcium silicate were monitored for 2 years. Treatments were preplant-incorporated in 1998 with varieties being drill-seeded soon after treatment application. Plots were left undisturbed until replanting in 1999 using a no-till drill. Silicon soil amendment did not significantly increase rough rice yields and dry matter accumulation. Sheath blight severity ratings corresponded with known relative tolerance of test cultivars 'Cypress', 'LaGrue/Wells', and 'Drew'. Sheath blight severity and incidence in plots amended with silicon were compared to plots not amended with silicon. The data strongly indicate no additional benefits are to be gained by amending soils with silicon as a standard production practice to increase rough rice yields or to reduce sheath blight severity.

INTRODUCTION

Silicon (Si) is an essential element for plant growth. Rough rice yields are increased by Si application in some rice production systems (Savant *et al.*, 1997). The yield response to Si application typically occurs where soils are naturally Si-deficient or when the available silicon has been reduced through leaching and/or longtime rice production. Recently, silicon soil amendment tests conducted in Florida and other rice-producing areas around the world (Datnoff *et al.*, 1991) showed increased Si content in rice plants with greatly enhanced rice blast and brown spot control and, in turn, substantial increases in rough rice yield and grain quality. There were multi-year responses to a single Si application.

In Arkansas however, nutrition studies conducted many years ago indicated that our soils provide adequate available Si for optimum growth by the rice plant and only minimal rough rice yield responses occur from extra Si soil amendment. This was confirmed in more recent research in Arkansas where Si soil amendment with high per acre applications of rice hull ash containing 93% amorphous Si resulted in only a small reduction in rice blast incidence (Lee *et al.*, 1998). The general conclusion among Arkansas scientists is that the small yield and blast control response gained from Si applications represent an unnecessary expense in Arkansas rice production.

However, only limited information is available concerning Si applications to control other rice diseases found in Arkansas production systems. Also, the Si source is thought to affect plant utilization and, in turn, the response to Si soil amendments. Field tests were conducted to determine whether Si sources using either calcium silicate slag or rice hull ash increase rough rice yield or reduce rice sheath blight severity.

PROCEDURES

In 1998, calcium silicate slag (0.6% phosphorus, 44.8 % SiO_2, 44.3 % CaO, 4.7% Al_2O_3, Fe_2O_3 2.3% CaF_2, and trace elements MnO, MgO, K_2O, and Na_2O) and rice hull ash (93% amorphous Si, 0.25% Ca, 0.03% Fe, 0.15% P, and 0.79% K) were preplant-incorporated at rates of 0, 1000, 2000, 4000, 8000, and 12,000 lb/acre in replicated 20- x 20-ft plots at the Rice Research and Extension Center (RREC), Stuttgart. Each treatment was replicated four times. The experiments were conducted as an unbalanced factorial experiment (rates of application x source of Si x cultivar x year). Four days before seeding, a single initial soil amendment for the individual treatments was made to the plots in 1998 only and was immediately incorporated to a depth of 3 in. using a tractor mounted rotary tiller. Rice cultivars used in the tests were selected based on sheath blight susceptibility. In 1998, Cypress, rated as very susceptible to rice sheath blight, LaGrue, rated susceptible, and Drew rated moderately susceptible, were drill seeded into the plots in 7-inch row spacings. After harvest, plots were left undisturbed until 1999 when plots were replanted using a no till drill. The same varieties were seeded again in the 1999 planting, with the exception that the newly released variety Wells, also rated susceptible, was used to replace the variety LaGrue (designated as LaGrue/Wells when data were combined for analysis). Seeding dates were 5 May 1998 and 13 May 1999. Plots were grown using standard fertility and production practices.

Plots were inoculated with alginate encapsulated pellets of Rhizoctonia solani at the panicle initiation growth stage. Sheath blight severity was assessed at the mature grain growth stage and was subsequently expressed using the following severity index:

$$\text{sheath blight severity index} = \left(\frac{\text{lesion height}}{\text{plant height}} \times 100\right) \times \text{sheath blight incidence}$$

where lesion height = the height of the lesion from the soil surface; plant height = the height of the plant from the soil surface to the tip of the flag leaf; and sheath blight incidence = the proportion of infected plants to healthy plants multiplied by 100. Sheath blight severity was also assessed using the standard visual rating scale of 0 (no sheath blight) to 9 (very severe sheath blight).

In 1998 only, plant tissue samples were collected from 3-ft segments of the center plot rows of the Drew cultivar at midseason and again at grain maturity. Plant samples were dried and weighed to estimate the rice straw and head dry weight treatment responses. Rough rice was combine-harvested, weighed, and adjusted to bushels per acre at 12% moisture for each year.

RESULTS AND DISCUSSION

Plant growth was not adversely affected by the various soil amendments. However, there was a tendency for increased bronzing of plants in the higher rates of Si per acre.

Increasing rates of Si did not increase dry matter accumulation in the Drew variety as measured by leaf, straw, and head dry weights (data not presented). Mean rough rice yields for the individual treatments are presented in conjunction with the mean sheath blight severity index (Table 1). As with dry matter, rough rice yields were not affected by increasing rates of Si.

In general, the sheath blight severity in each variety was consistent with known susceptibility, i.e,. sheath blight was always most severe in Cypress and least severe in Drew. Visual scoring for sheath blight severity did not differentiate disease incidence, nor did the sheath blight severity index. Within varieties, sheath blight was as severe in treated plots as in untreated plots. Also, as with rough rice yields, increasing Si rates did not increase sheath blight control.

Data from the 2 years were pooled by relative variety susceptibility to sheath blight and by Si source to remove variations due to variety and year and to better evaluate response to Si source. The pooled 2-year mean for rough rice yield are presented in Table 2, and those for the sheath blight indices are presented in Table 3. Rough rice yield differences between cultivars grown with the same soil amendment are due to different varietal susceptibility to sheath blight. Yield, within a cultivar, was not affected by soil amendment.

In summary, the test data indicate that Si soil amendments do not increase yields or control sheath blight and do not justify the additional materials and application costs anticipated from use in Arkansas rice production. The data do suggest a practical disposal method for rice hull ash, since preplant incorporating high per acre rates of rice hull ash did not adversely affect rice production.

SIGNIFICANCE OF FINDINGS

Initial reports indicating substantial rice disease control using Si soil amendments generated favorable popular press, leading many rice growers to question results from previous research. Data presented here show Si applications do not provide increased rough rice yield or increased sheath blight disease control. These results, taken in conjunction with those of previous Si research on rice blast, indicate there are no useful benefits to be gained from the practice. Data presented here should help growers avoid unnecessary expenses incurred from ineffective production practices.

ACKNOWLEDGMENTS

This research was made possible by grower funding through the Arkansas Rice Research and Promotion Board and funding through the University of Arkansas Agriculture Experiment Station.

LITERATURE CITED

Datnoff, L.E., R.N. Raid, G.J. Snyder, and D.B. Jones. 1991. Effect of calcium silicate on blast and brown spot intensities and yields of rice. Plant Dis. 75:729-732.

Lee, F.N., R.J. Norman, and L.E. Datnoff. 1998. The evaluation of rice hull as a silicon soil amendment to reduce rice diseases. *In:* R.J. Norman and T.H. Johnson (eds.) Arkansas Rice Research Studies 1997. University of Arkansas Agricultural Experiment Station Research Series 460:132-136.

Savant, N.K., G.H. Snyder, and L.E. Datnoff. 1997. Silicon management and sustainable rice production. Advances in Agronomy 58:151-199.

Table 1. Mean rough rice yield and sheath blight index recorded during 1998 and 1999 from test plots following additions of calcium silicate slag or rice hull ash and inoculation with the sheath blight pathogen, *Rhizoctonia solani*.

	Cypress				LaGrue		Wells		Drew			
	1998		1999		1998		1999		1998		1999	
Source/rate of application	Yield	Sheath blight index[z]	Yield	Sheath blight index	Yield	Sheath blight index	Yield	Sheath blight index	Yield	Sheath blight index	Yield	Sheath blight index
(lb/acre)	(bu/acre)		(bu/acre)		(bu/acre)		(bu/acre)		(bu/acre)		(bu/acre)	
Control	136	61	114	56	143	61	144	60	143	60	128	29
Calcium silicate slag												
1000	135	70	120	57	141	59	136	42	132	51	118	42
2000	129	75	122	59	156	60	155	47	152	51	131	39
4000	127	71	115	44	148	57	142	45	148	45	118	52
8000	138	70	128	52	144	63	147	45	146	59	129	45
12000	117	63	95	52	137	56	143	45	143	63	117	48
Rice hull ash												
1000	129	73	116	56	138	69	128	47	114	62	128	38
2000	130	69	116	48	138	58	139	43	151	52	127	38
4000	136	69	122	43	151	50	139	55	151	61	122	41
8000	147	69	112	39	154	63	153	54	142	64	113	47
12000	135	38	117	36	150	57	148	43	150	66	142	45

[z] Sheath blight severity index = $\left(\frac{\text{lesion height}}{\text{plant height}} \times 100\right) \times$ sheath blight incidence

Table 2. Two year mean rough rice yield comparisons in the sheath blight-inoculated Cypress, LaGrue/Wells, and Drew test plots following a single 1998 soil amendment with either calcium silicate or rice hull ash.

	Rough rice yield			
Soil Treatment	Cypress	LaGrue/ Wells	Drew	Variety $LSD_{0.05}$
	(bu/acre)			
Control	125	139	143	15
Calcium silicate	123	140	140	6
Rice hull ash	126	140	148	7
$LSD_{0.05}$ for silicon source comparisons				
control-calcium silicate	12	12	17	
control-rice hull ash	24	24	33	
calcium silicate-rice hull ash	7	7	10	

Table 3. Two year mean sheath blight severity index recorded in *R. solani*-inoculated Cypress, LaGrue/Wells, and Drew test plots following a single 1998 soil amendment with either calcium silicate or rice hull ash.

	Sheath blight index[z]			
Soil Treatment	Cypress	LaGrue/ Wells	Drew	Variety $LSD_{0.05}$
	(bu/acre)			
Control	79	73	60	15
Calcium silicate	83	74	55	6
Rice hull ash	80	75	61	7
$LSD_{0.05}$ for silicon source comparisons				
control-calcium silicate	11	11	16	
control-rice hull ash	11	11	16	
calcium silicate-rice hull ash	6	6	10	

[z] Sheath blight severity index = $(\frac{\text{lesion height}}{\text{plant height}} \times 100) \times$ sheath blight incidence

COMPLETED STUDIES

CHARACTERISTICS OF *Pyricularia grisea* "MICROSCLEROTIA" PRODUCED IN SHAKE CULTURE

F.N. Lee, M.A. Jackson, and N.R. Walker

ABSTRACT

Blast, a common yield-limiting rice disease, is caused by *Pyricularia grisea* (Cooke) Sacc. [teleomorph *Magnaporthe grisea* (T.T. Hebert) Yaegashi & Udagawa]. Typically, *P. grisea* is cultured on plant tissue or solid agar media. Although growth rate and appearance vary with individual isolate and media, the fungus grows well in shake culture, producing individual and clumped hyphae fragments. This report details procedures for formation of well-formed, uniformly shaped hyphae structures having smooth margins, tentatively designated as "microsclerotia," in *P. grisea* shake cultures. Microsclerotia were produced in 7-day-old shake cultures growing at 28°C or 34°C and shaken at 300 rpm on a rotary shaker incubator. Cultures were first sieved through a 425-µm mesh sieve and then through a 180-µm mesh sieve, where microsclerotia were collected. Typically between 70% and 100% of the microsclerotia initiated mycelial growth after a 24- to 78-hr incubation on Noble agar. Mean microsclerotia length from three individual cultures was 445, 472, and 555 µm with a mean width of 259, 168, and 239 µm, respectively. Sectioned and stained microsclerotia appeared to consist primarily of unorganized heavily melanized hyphae. Microsclerotia mixed with diatomaceous earth (5% w/v) and dried were viable. Conidiophores producing typical *P. grisea* conidia were observed on rehydrated microsclerotia. Typical blast lesions developed on rice plants inoculated with the conidia.

The biological significance of the microsclerotia is unclear. They may be an artifact of the shake culture, since analogous structures are not observed developing within or upon diseased rice tissue. However, other fungi are known to produce microsclerotia under these conditions.

INTRODUCTION

Blast, a common yield-limiting rice disease, is caused by *Pyricularia grisea* (Cooke) Sacc. [teleomorph *Magnaporthe grisea* (T.T. Hebert) Yaegashi & Udagawa]. Typically, *P. grisea* is cultured on plant tissue or solid agar media for research and inoculum production purposes. Although growth rate and appearance vary with individual isolate and media, the fungus grows well in shake culture producing individual and clumped hyphae fragments. Under appropriate nutritional and environmental conditions, a number of well-formed, uniformly shaped hyphae aggregates with smooth margins, tentatively designated as "microsclerotia," were also observed in *P. grisea* shake cultures. This study was conducted to investigate the production, viability, and histology of *P. grisea* microsclerotia produced in shake culture.

PROCEDURES

Microsclerotia were produced in 1-L Erlenmeyer flasks containing 100-ml media shaken at 300 rpm on a rotary shaker incubator at 28°C or 34°C. Shake culture media for growing *P. grisea* consisted of the following: glucose: 80 g; casamino acids: 13.2 g; KH_2PO_4: 2 g; $CaCl_2 \cdot 2H_2O$: 0.4 g; $MgSO_4 \cdot 7H_2O$: 0.3 g; $CoCl_2 \cdot 6H_2O$: 37 mg; $MnSO_4 \cdot H_2O$: 50 mg; $FeSO_4 \cdot 7H_2O$: 16 mg; $ZnSO_4 \cdot 7H_2O$: 14 mg; thiamine: 500 µg; riboflavin: 500 µg; pantothenate: 500 µg, niacin: 500 µg, pyridoxamine: 500 µg, thiotic acid: 500 µg, folic acid: 50 µg; biotin: 50 µg; and vitamin B_{12}: 50 µg per liter of distilled water. Initial inoculum for the shake cultures was either 10 to 40 ml of suspensions having 5 x 104 spores/ml or 15 to 20 1-mm-square agar pieces obtained from 2-wk-old sporulating *P. grisea* race IB-49 cultured on rice polish agar. Flasks were hand-shaken frequently during the incubation period to inhibit mycelial growth on the flask wall. A minimum of three flasks were used for each experiment, and each experiment was repeated at least twice. Microsclerotia were harvested by first sieving contents of 7-day-old shake cultures through a 425-µm (40) mesh screen and then through a 180-µm (80) mesh screen. Microsclerotia collected on the 180-µm mesh screen were rinsed and washed from the screen using sterile distilled water (SDW).

The number of microsclerotia produced in culture was determined by placing 100 µl of a microsclerotia suspension of known dilution onto a glass slide. The number of well-formed hyphae aggregates with smooth margins was examined with a light microscope and recorded.

For histological studies, wet-sieved microsclerotia were aseptically placed in a formalin/acetic acid/alcohol solution and stored at 4°C until use. Microsclerotia were dehydrated in ethanol/tertiary butyl alcohol and thermally embedded in Tissueprep2 compound (Fisher Scientific Co., Suanee, Georgia). Embedded microsclerotia were sectioned at 10 µm with a rotary microtome. Sections were thermally mounted on glass slides with gelatin (Sigma-Aldrich Inc., St. Louis, Missouri) and the embedding compound removed with Hemo-De (Fisher Scientific co., Suanee, Georgia). Sections were stained in either 1% safranin O in 50% ethanol or in 1% aqueous crystal violet for 2 min, then examined with a light microscope. Physical dimensions were determined by ocular micrometer examination of 25, 30, and 30 randomly selected microsclerotia from three different preparations. Statistical analysis of dimensions was obtained using JMP (SAS Institute, Cary, North Carolina).

Dried preparations were obtained by decanting excess water from wet-sieved microsclerotia and then adding 5% (w/v) diatomaceous earth (HYFLOR, Celite Corp). The mixture was vacuum-filtered using Whatman #1 filter paper. The resulting filter cake was broken up and air-dried overnight in a biological containment hood at room temperature. Moisture content was determined using a moisture analyzer (Mark I, Denver Instruments). Dried microsclerotia formulations were placed into ziploc bags and stored at 4°C.

Viability was assessed by microscopic examination of 100 microsclerotia spread onto Noble water agar or potato dextrose agar and incubated for 24 to 78 hr under room temperature.

RESULTS AND DISCUSSION

The number of microsclerotia retained by the 180-µm mesh screen varied with isolate and preparation. For example, three separate trials yielded 66, 75, and 47 ml containing 6, 8.8, and 20 x 103 microsclerotia/ ml, respectively, in 1 L of shake culture harvested. Larger microsclerotia were collected on the 425-µm mesh screen, but the number was more variable. Although sometimes very low, viability typically varied between 70 and 100%.

The mean length of sectioned microsclerotia from three separate preparations was 445, 472, and 555 µm with a mean width of 259, 168, and 239 µm, respectively. The mean length and width were dependent upon preparation (length $P < 0.0167$, width $P < 0.0001$). Stained sections showed an unorganized collection of heavily melanized hyphae resembling the *P. grisea* hyphae commonly observed in low-nutrient-agar media amended with defatted rice bran (Figure 1).

In the absence of diatomaceous earth, dried microsclerotia strongly adhered to each other in a crusty mat that was not easily separated even with vigorous and prolonged shaking and/or stirring. Those dried in diatomaceous earth easily disassociated and rehydrated when exposed to moisture. Viability in the mixture was variable and appeared to be affected by final moisture of the filtrate after drying. However, mycelia readily formed from many individual rehydrated microsclerotia incubated 48 to 72 hr on moist filter paper. A number of individual conidiophores producing typical *P. grisea* conidia were observed developing directly from microsclerotia and mycelia. Typical blast lesions developed on rice plants inoculated with these conidia.

The biological significance of the structures produced by *P. grisea* in shake culture is unclear. Microsclerotia are defined as a compact mass of hypertrophied cells that are aggregated together, and darkly pigmented over most of the surface by melanin

(Webster, 1989). Microsclerotia are usually observed on agar media and are formed at the initiation of rhizomorph formation in Ascomycete and Basidiomycete fungi. Structures described here meet many criteria of Webster's definition and raises the possibility that true microsclerotia do develop in *P. grisea* shake culture. On the other hand, they may indeed be an artifact arising from media movement in the shake culture because analogous structures are not observed developing within or upon diseased rice tissue. However, their general appearance does resemble mycelia mats sometimes found growing beneath the seed coat of sterilized grain sorghum inoculated with *P. grisea*. Also, heavily melanized *P. grisea* hyphae much like those described here are commonly found in low-nutrient-agar cultures. In addition, the medium used in these studies has been shown to induce microsclerotia production by the plant pathogenic fungus *Colletotrichum truncatum.*

SIGNIFICANCE OF FINDINGS

The observation and characterization of microsclerotia formed by *P. grisea* provides further information about the biology of the rice blast pathogen. They were discovered during efforts to produce large quantities of inexpensive stable blast nursery inoculum that remains viable for a period of time under field conditions. Currently, it is very expensive to produce and store the fragile, short-lived *P. grisea* conidia to inoculate field blast nurseries for evaluating breeding lines and exotic germplasm. Exacting environmental conditions, especially the need for 10 hr or more free moisture, often necessitate multiple inoculations because of the conidia having failed in a one-time opportunity to infect the rice plant.

ACKNOWLEDGMENTS

This research was made possible by grower funding through the Arkansas Rice Research and Promotion Board and funding through the University of Arkansas Agricultural Experiment Station. The talents and significant contributions of Dr. Byron Candole is also gratefully acknowledged.

LITERATURE CITED

Webster, J. 1989. Introduction to fungi. Cambridge University Press, London. 669 pp.

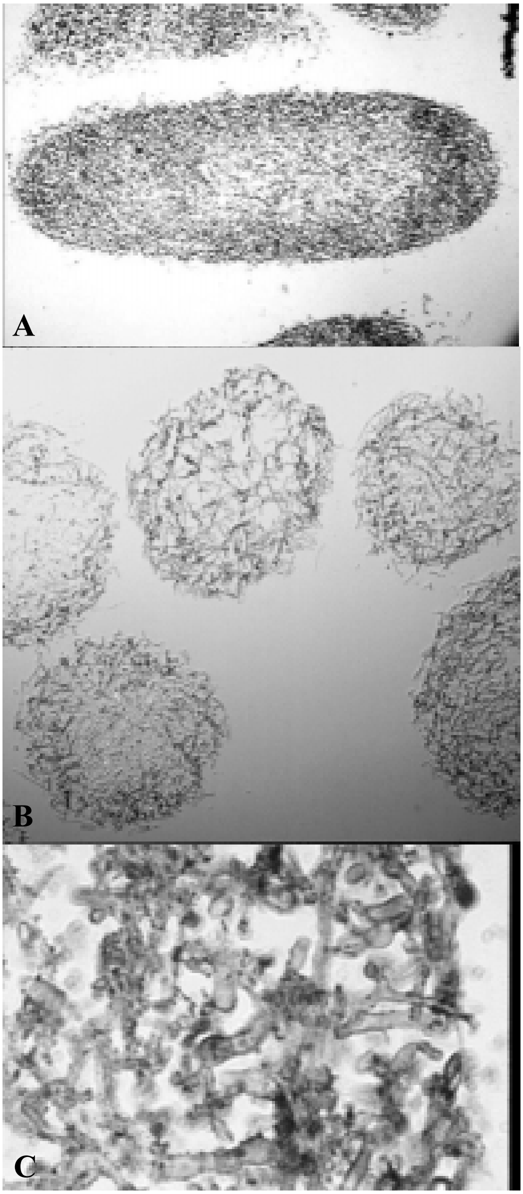


Fig. 1. Photomicrographs of sectioned *P. grisea* microsclerotia formed in shake culture.
***A*: longitudinal section (100X),**
***B*: transverse section (100X),**
***C*: aggregated hyphae forming the microsclerotia (400X).**

COMPLETED STUDY

TECHNOLOGY FOR RAPID DETECTION, IDENTIFICATION, AND QUANTIFICATION OF THE RICE BLAST FUNGUS *Pyricularia grisea*

R. Nannapaneni, R.C. Gergerich, and F.N. Lee

ABSTRACT

A very specific antibody probe that binds with a 16-kDa protein produced by the rice blast pathogen *Pyricularia grisea* was produced by a stabilized single-cell monoclonal antibody producing hybridoma line, MAb 57D3. In all tests against available fungal isolates and plant materials to date, the MAb 57D3 antibody is very specific for and reacts only with proteins found in rice blast isolates of *P. oryzae*, which represent predominant races occurring in the United States. MAb 57D3 does not have any undesirable reactions with proteins from *P. grisea* grass-weed isolates, other common pathogenic and saprophytic fungi found on rice, or uninfected rice plant tissue. In laboratory tests, MAb 57D3 reacts with intracellular and cell wall antigens of the rice blast fungus and has a particularly strong reaction with the extracellular antigens of the rice blast isolate LO1-24. MAb 57D3 reacted more strongly with proteins from races IB-33, IB-45, IB-49, and IH-1 with $A_{490} > 4$ than with proteins from races IC-17, IB-1, or IG-1 (A_{490} = 1.6 to 2.7). In additional testing, MAb 57D3 reacted strongly with the blast fungus extracts from blast leaf lesions, but not with extracts of healthy leaves. In immunofluorescence tests, MAb 57D3 showed an antigenic reaction over the entire surface of spores and conidiophores of the rice blast fungus, but not with comparable fungal structures of the grass-weed blast fungus. To date, the antibody produced by MAb 57D3 has exhibited all the uniquely desirable characteristics required for the rapid detection, identification, and quantification of the rice blast fungus *P. grisea* in leaf tissue and in fungal spore mixtures.

INTRODUCTION

Rice blast, incited by *Pyricularia grisea*, frequently causes significant yield loss as a dynamic niche disease in U.S. rice production areas. Favorable conditions begin with wide utilization and excessive fertilization of blast susceptible cultivars. Dew periods in excess of 10 hr and/or frequent rain showers keep the plant surface saturated with the free water necessary for spore germination and plant infection. Initial symptoms of the disease are not evident the first 2 to 3 days as the fungus grows rapidly within the infected plant. Enlarging necrotic lesions resemble those of less severe rice diseases and the characteristic diagnostic fungal spores are not produced until 5 to 8 days after infection.

Effective grower management of rice blast depends upon the rapid detection, identification, and quantification of diseased plants and rice blast spore showers. The special technical skills and time constraints of current detection techniques limit available critical information needed for practical prediction of rice blast epidemics and the application of control measures. By the time the disease is identified as blast, one or more new disease cycles are well under way with wind currents quickly moving spores within and between production fields. Prediction and control efforts are greatly complicated by similar airborne spores originating from certain grass-weeds infected by a genetically different non-rice-infecting strain of *P. grisea*.

One practical method of detection providing the speed and accuracy needed uses highly sensitive antibodies that react only with the target fungus. Most commonly, these antibodies are utilized in conjunction with other detection technologies in the laboratory, but if the antibodies are sufficiently stable and sensitive, portable kits for use by growers can be developed.

Research reported here describes a highly sensitive and very specific antibody that binds with only the targeted rice blast pathogen *P. grisea* in both infected leaf tissue and in spore mixtures.

PROCEDURES

Stock cultures of *P. grisea* races from rice, *P. grisea* isolates from grasses other than rice, and other saprophytic and pathogenic fungi associated with rice were collected and stored. Soluble metabolic byproducts, spores, and hyphal mats were obtained from cultures of these fungi growing on sterilized liquid medium at 25°C for 4 wk.

The sporulating hyphal mat was gently washed using 20-mM phosphate-buffered saline, pH 7.2 containing 0.1% Tween 20 (PBS). The resulting spore suspension was separated from the fungal mat and centrifuged at 300 x *g* for 10 min. The supernatant containing soluble extracellular proteins was carefully removed. Blast spores pelleted by the centrifugation were re-suspended and washed twice in PBS by centrifugation. Spore concentrations were determined using a hemocytometer. The hyphal mat from cultures was transferred to sterile tubes, washed three times in PBS using the centrifugation process, and then disrupted by sonication in ice for 10 min. PBS-soluble intracellular proteins were separated from cellular debris by centrifugation at 14,000 x *g* for 10 min. All protein antigens were aliquoted into 1-ml portions and stored at –20°C until utilized. Protein concentration of all antigen preparations was determined by bicinchoninic acid (BCA) assay using bovine serum albumin (BSA) as a standard (Micro BCA assay, Pierce, Rockford, Illinois).

Two 6-wk-old BALB/c mice were immunized to the intracellular PBS soluble protein from rice blast isolate LO1-24 of *P. grisea* race IC-17 by 11 intraperitoneal injections made at 2-wk intervals. Hybridoma cell lines were generated by fusing aseptically harvested spleen cells from the mice with murine myeloma PE/NS11/1-Ag-4-1 (NS1) cells. Hybridoma cell lines were screened for production of desired antibodies, which react only with intracellular, extracellular, cell wall antigens, and spore suspension of isolate LO1-24, but not with similar antigens from *P. grisea* grass-weed isolates, other fungal species found on rice or the rice plant.

RESULTS

One hybridoma cell line, MAb 57D3, exhibited the desired high stability, specificity, and sensitivity to the rice blast proteins without any undesirable reactions with non-rice-blast antigens (Fig. 1). MAb 57D3 was stabilized as single clones for detailed characterization. An additional 56 hybridoma cell lines exhibiting desirable characteristics are currently frozen in liquid nitrogen pending future retrieval and continued evaluation.

Antibody produced by MAb 57D3 reacted with all antigens extracted from LO1-24. Strong reactions occurred at high antibody concentrations (10 µg protein/ml), with minimum detection levels for each being 0.1 µg protein/ml of extracellular, 0.5 µg protein/ml of intracellular, and 1.0 µg protein/ml of cell wall antigens.

When tested at 5 µg protein/ml, MAb 57D3 antibody reacted more strongly against the extracellular proteins extracted from blast races IB-33, IB-45, IB-49, and IH-1 with $A_{490} > 4$ than with those extracted from blast races IC-17, IB-1, or IG-1 (A_{490} = 1.6 to 2.7). MAb 57D3 antibody did not react with antigen preparations of *P. grisea* isolates from grass-weeds or 20 other saprophytic or pathogenic fungal species commonly found on rice ($A_{490} < 0.1$). At the 5-µg protein/ml level, MAb 57D3 antibody could detect and identify as few as 10 rice blast spores in 1 ml of PBS. MAb 57D3 antibody reacted strongly with tissue extracts from rice leaves infected with blast isolate LO1-24 but did not react with extracts from uninfected leaves.

In the tests against protein profiles of six rice blast isolates and two grass-weed blast isolates, MAb 57D3 antibody reacted with a 16-kDa protein band common to all rice blast isolates but did not react with any proteins of the grass-weed blast isolates. Immunofluorescence tests indicated MAb 57D3 antibody strongly attached to the surface of spores, conidiophores, and hyphal fragments of rice blast isolate LO1-24 but not with those of five *P. grisea* grass-weed isolates. A very weak, nonspecific, sparse, or discontinuous immunofluorescence that was visible with the hyphal fragments of the grass-weed blast isolates did not interfere with the 57D3 detection method.

DISCUSSION

The extensive testing conducted to date indicates that MAb 57D3 antibody has all essential characteristics necessary for detecting and identifying the rice blast fungus. The sensitivity level of detecting and identifying as few as 10 rice blast spores in 1 mL of PBS compares to finding a single blast spore in one large drop of water. The problem of incorrect diagnosis is eliminated, since the MAb 57D3 antibody binds only with antigens of the rice blast fungus *P. grisea* and not with those of the closely related grass-weed blast fungus, of the rice plant, or of other fungi commonly associated with rice. Although the MAb 57D3 does not distinguish between different blast races, the apparent higher differential reaction with certain groups of races could be a positive characteristic where fungal detection is increased by a combined utilization of additional group-specific Mabs. Utilizing the sensitivity and specificity MAb 57D3 in conjunction with polymerase chain reaction amplification technology would lead to a greatly enhanced ability to detect, identify, and quantify the rice blast fungus.

Other potential enhancements and uses exist. For example, this new tool will enhance our understanding of rice blast epidemics and could lead to better control methods. Also, a MAb 57D3 probe can be utilized to determine the function of the 16-kDa antigen in the growth and reproduction of the rice blast fungus. However, this potentially powerful tool requires additional testing. The reaction of MAb 57D3 with older uncommon U.S. rice blast races should be determined. Field tests should be conducted to specifically target rice and grass-weed plant tissue that would be sampled and to ensure a negative reaction with all airborne materials that may be found in rice fields and result in misleading results.

SIGNIFICANCE OF ACCOMPLISHMENTS

The MAb 57D3 does have potential for use as a diagnostic tool at the grower level. More likely, however, the application will be in laboratory tests where rice tissue samples are routinely collected and assayed for the rice blast disease or where airborne spore showers are monitored to detect and identify rice blast spores as a means for predicting rice blast epidemics. Practical application of the technology could greatly benefit growers when properly utilized as a production tool that empowers the grower to accurately time, limit application of, and even document the need for expensive rice blast fungicides. These applications will be particularly valuable when growing blast susceptible rice cultivars were justified by a greatly increased yield and/or other economic reasons.

ACKNOWLEDGMENTS

The sophisticated technology described here originated through initial Arkansas Rice Research and Promotion Board grant funding approximately 14 years ago. During that period of time, additional funding was obtained through the University of Arkansas Agriculture Experiment Station and commercial interests.

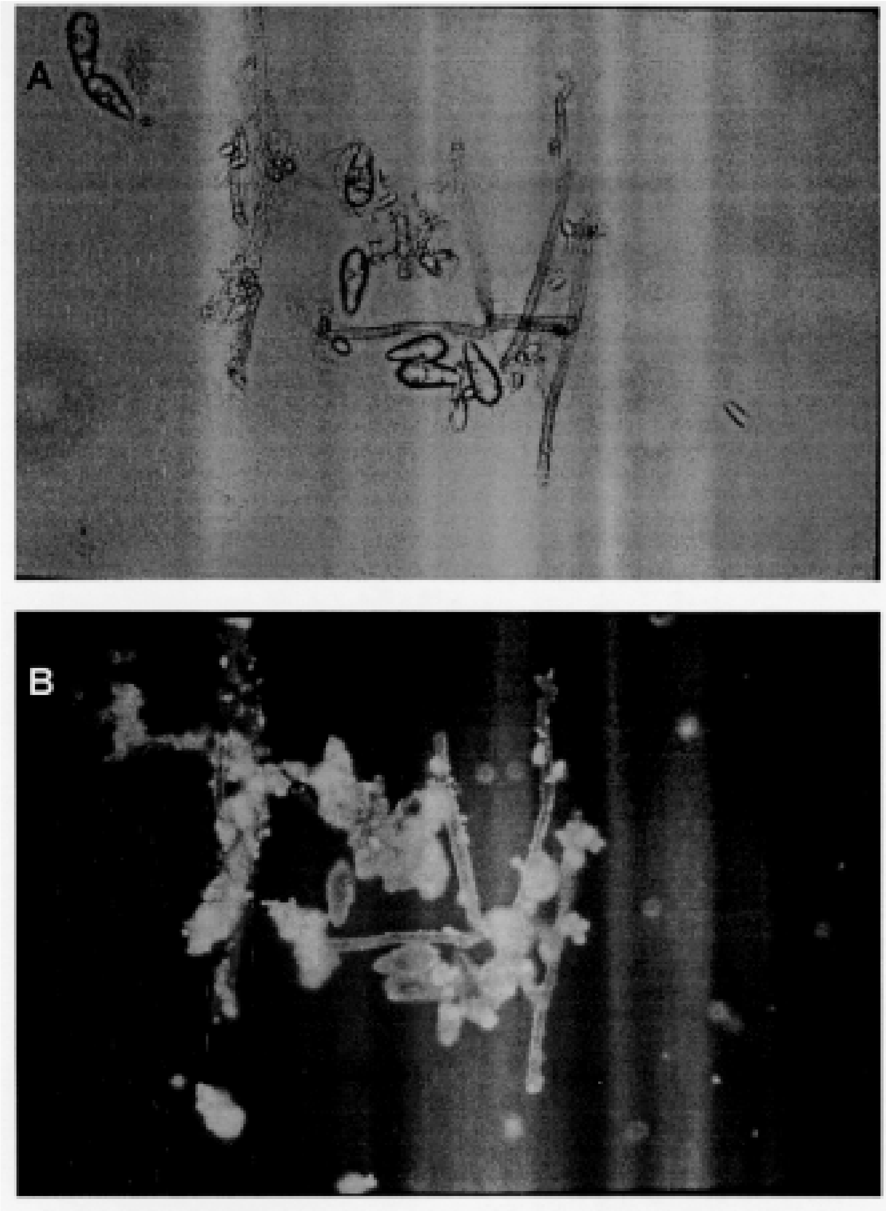


Fig. 1. Appearance of rice blast fungus spores and conidiophores previously exposed to MAb 57D3 and goat anti-mouse IgG-FITC conjugate as viewed with (*A*) a light microscope and (*B*) an epifluorescent microscope where an intense typical green fluorescence indicates the surface bound MAb 57D3 conjugate.

YIELD RISK FOR ARKANSAS RICE PRODUCTION

L.D. Parsch and M. Becerra

ABSTRACT

Measuring yield risk—the year-to-year variability in crop yield—is a first step in providing risk management information that can be used by rice producers in their cropping decisions. Yield risk for 32 rice-producing counties in Arkansas was estimated using 15 years of time-series data collected over the period 1981 to 1995. Over this period, the state of Arkansas had average annual yield increases of 80 lb/acre. However, there was great diversity among counties in both yield trends and yield risk. Individual rice-producing counties within the state experienced significant annual yield increases, ranging from as low as 19 lb/acre to as high as 119 lb/acre. With use of trendline analysis, the yield risk of some counties was shown to be nearly double that of other counties. In general, counties with lower yield risk were concentrated in the northeastern and east-central parts of the state, whereas the higher risk counties were scattered throughout the southeast, southwest, and central parts of the state. Cumulative probability functions were developed to enable producers to associate the likelihood of attaining specified yields in each county.

INTRODUCTION

The implementation of the 1996 Farm Bill has placed increased attention on the need for risk management information because the new "freedom to farm" has exposed crop producers to greater risk as government support payments are gradually being phased out. Although many producers, researchers, and extension personnel are aware of the need for risk management information, little research has been done to quantify the risk of attaining specified yield levels associated with the production of the Arkansas rice crop. The purpose of this research is to characterize and quantify rice yield risk for the major rice-producing counties in Arkansas. Measuring and quantifying the yield risk of rice is a first step in providing risk management information that can be used by rice producers in their cropping decisions. These measures of yield risk also provide baseline reference material for CES and AES personnel in making recommendations to producers.

PROCEDURES

Research in the decision sciences follows the pioneering work of Knight (1921), who first proposed that risk is a probability-based concept that is typically quantified with statistical variance (or standard deviation). Because rice yields are uncertain and vary from one year to the next, the goal in quantifying yield risk is to measure year-to-year yield variability and to associate probabilities with alternative yield levels experienced by Arkansas rice producers. This information is conveniently captured in a cumulative distribution function (CDF), which conveys the probability that a specified rice yield will be attained (Hardaker *et al.*, 1997). Given a historical time-series of yield data, parameters of a rice yield probability distribution (e.g., mean, variance) are estimated, and the results are presented in cumulative frequency form, i.e., as a CDF.

One of the main problems in quantifying the risk associated with crop production is to obtain yield data collected over a sufficiently long time-frame to enable risk estimates. Each year, the Arkansas Agricultural Statistics Service (1996) surveys producers around the state and subsequently publishes annual estimates of rice yield and production on a county-by-county basis. Because these data are available over a long time-series, statistical techniques were used to analyze this database in order to determine trends and variability (risk) in rice yield on a county-by-county basis for the major rice producing counties in Arkansas.

The analysis was conducted for each of the 32 counties in Arkansas that have been continuously engaged in rice production over the 15-year period 1981 to 1995. These 32 counties—26 counties in eastern Arkansas' crop reporting districts 3, 6, and 9, and 6 additional counties in southwestern (district 7), and west-central Arkansas (districts 4 and 5)—account for 99% of all rice production in the state.

Summary statistics computed for each county included the 15-year mean yield, and the county's average annual share of the state's total rice production. Subsequently, the estimate of probability distribution parameters for rice yield in each county was taken from a linear trend regression line fitted through the 15-year (1981 to 1995) time-series of yield data for each county. Variance (risk) of yield was measured as the root mean squared error (RMSE) of the residuals around each yield trend line. Mean yield over the 15-year series was measured as the trend line predicted rice yield for 1995. RMSE was used as the absolute measure of rice yield risk. A relative measure of yield risk was computed as the coefficient of variation (CV) by dividing each county RMSE by its predicted trendline yield. Subsequently the CVs for the 32 counties were indexed to a unitless scale where 1.00 measures the average CV across all counties. This index enables comparison of any county's yield risk to the risk of an "average" county. Residuals from all trendline regressions were tested for normality (Jarque and Bera, 1987).

Finally, cumulative distribution functions of yield were plotted as normally distributed random variables based on the parameters (trendline predicted yield, RMSE) estimated from the 15-year county data series. CDFs were presented in tabular form at nine arbitrarily chosen probability levels ranging between 0.05 and 0.95 for each county data series.

RESULTS AND DISCUSSION

Summary Statistics

Over the period 1981 to 1995, the largest rice county was Arkansas County, which produced over 9% of the state's rice annually (Table 1), followed by Poinsett at 8%. AASS Crop Reporting District 6 (east-central) was the most important district in the state, with an average 43% of the state's rice production. For the 32 rice-producing counties, annual mean yield over the same period ranged between 5558 lb/acre (Arkansas County) and 3950 lb/acre (Little River County).

Trendline Analysis

Trendline analysis of the 32 rice-producing counties showed that 28 of them had statistically significant yield increases over the 1981 to 1995 period, amounting to an average annual statewide increase of 80 lb/acre (Table 1). However, the annual yield increase was as low as 19 lb/acre (Lafayette County) and as high as 119 lb/acre (White County). These yield increases resulted in trendline predicted average annual yields ranging between 6169 lb/acre (Arkansas County) and 4429 lb/acre (Lafayette County). Over the same period, yield risk—measured as the root mean squared error (RMSE) of residuals around each yield regression trendline—also varied dramatically among counties. Counties with the highest and lowest absolute yield risk over the 15-year period had RMSEs of 577 lb/acre (Miller County) and 268 lb/acre (Lafayette County), respectively, which indicates that some counties experienced nearly twice the yield risk encountered in other counties.

The CVs in Table 1 convert the RMSEs to relative measures of yield risk by reporting them as percentages relative to the county projected trendline yield. Counties whose CV index (Table 1) exceeds 1.00 have higher yield risk than the average county. Those with CVs below 1.00 have lower than average risk. In general, lower yield risk counties are located in the northeast and east-central districts of the state, whereas higher risk counties are scattered throughout the central, southwestern, and southeastern districts of the state.

Cumulative Distribution Functions

Cumulative distribution functions of rice yield for the 32 major producing counties (Table 2) provide an estimate of the probability of attaining specified yield levels in each county. For example, Phillips County can expect yields below 4969 lb/acre in 1 out of 4 years (i.e., 25% probability) and yields below 5672 lb/acre in 9 out of 10 years (90% probability). Conversely stated, Phillips County yield will surpass 4969 lb/acre 3 years out of 4, and farmers there will exceed 5672 lb/acre 1 year in 10. The Phillips County mean predicted trendline yield of 5211 lb/acre from Table 1 appears at the 50th percentile in Table 2. This indicates that one-half of the time, yields will fall below the mean, but that they will exceed the mean the other half.

Cumulative distribution functions in Table 2 also enable the probabilistic bracketing of yields within a specified range. For example, in Arkansas County, there is a 5% chance that yield will fall below 5618 lb/acre and a 95% chance that it will be less than 6720 lb/acre. Conversely, there is a 95% chance that Arkansas County yield will surpass 5618 lb/acre, but only a 5% chance that it will exceed 6720 lb/acre. Thus, in 9 years out of 10 (90% probability bracket), Arkansas County yield will range between 5618 lb/acre and 6720 lb/acre.

Finally, CDFs in Table 2 permit probabilistic comparison of yield levels among counties. For example, examination of Phillips and Arkansas counties reveals that whereas there is an approximate 90% chance that Phillips County yield will be below 57 cwt/acre, there is about a 90% likelihood that Arkansas County yield will surpass 57 cwt/acre.

SIGNIFICANCE OF FINDINGS

These findings suggest that rice production in Arkansas is not homogeneous with respect to either yield trends or yield risk. Rather, among the 32 rice-producing counties in Arkansas, there is a great diversity of yield levels, and the probability of attaining these yields varies dramatically from county to county. The implementation of the 1996 Farm Bill ushered in the phasing out of government deficiency payments for rice producers. In the absence of government support, crop producers—increasingly exposed to production and market risk—need to manage risk more effectively. Measuring and quantifying the yield risk of rice is a first step in providing risk management information that can be used by rice producers in their cropping and marketing decisions.

ACKNOWLEDGMENT

This research was supported in part by funding provided by the Arkansas Rice Research Promotion Board.

LITERATURE CITED

Arkansas Agricultural Statistics Service. 1996. 1995 Arkansas Agricultural Statistics. University of Arkansas Agricultural Experiment Station Report Series 334.

Hardaker, J.B., R.B.M. Hurine, and J.R. Anderson. 1997. Coping with Risk in Agriculture. CAB International, Wallingford, UK.

Jarque, C.M. and A.K. Bera. 1987. A test for normality of observations and regression residuals. International Statistical Review 55(2):163-172.

Knight, F.H. 1921. Risk, Uncertainty, and Profit. Houghton, Mifflin, and Co.

Table 1. Summary yield statistics and trend line analysis for major rice producing counties in Arkansas, 1981 to 1995.

County Name	Annual Share of State Production	Mean Yield	Yield Trend	Trendline Yield	RMSE	CV	CV Index
	(%)	(lb/acre)	(lb/acre/year)	(lb/acre)	(lb/acre)	(%)	(dec)
			District 3 Northeast				
Clay	5.04	5,012	76.1*	5,544	334	6.02	0.85
Craighead	5.59	5,138	71.6*	5,639	301	5.33	0.75
Greene	3.64	4,864	53.7*	5,239	345	6.58	0.93
Independence	0.61	4,899	41.0	5,186	443	8.54	1.21
Jackson	5.86	4,953	90.0*	5,583	435	7.78	1.10
Lawrence	5.08	5,220	79.2*	5,774	433	7.50	1.06
Mississippi	1.32	5,021	67.9*	5,497	407	7.41	1.05
Poinsett	8.26	5,270	52.3*	5,636	346	6.14	0.87
Randolph	1.62	5,158	76.7*	5,695	375	6.58	0.93
White	1.91	4,685	119.2*	5,519	354	6.41	0.91
			District 6 East Central				
Arkansas	9.03	5,558	87.4*	6,169	335	5.43	0.77
Crittenden	1.38	5,058	76.0*	5,590	403	7.21	1.02
Cross	6.74	5,199	80.8*	5,764	289	5.02	0.71
Lee	2.57	4,852	112.3*	5,638	339	6.02	0.85
Lonoke	6.15	5,364	90.5*	5,998	360	6.01	0.85
Monroe	3.30	4,964	101.2*	5,672	414	7.29	1.03
Phillips	1.55	4,722	69.9*	5,211	360	6.90	0.98

continued

Table 1. Continued.

County Name	Annual Share of State Production	Mean Yield	Yield Trend	Trendline Yield	RMSE	CV	CV Index
	(%)	(lb/acre)	(lb/acre/year)	(lb/acre)	(lb/acre)	(%)	(dec)
			District 6 East Central - Continued				
Prairie	5.32	5,368	78.5*	5,917	310	5.24	0.74
SaintFrancis	3.23	4,895	69.1*	5,378	318	5.92	0.84
Woodruff	3.97	4,837	65.1*	5,293	279	5.26	0.74
			District 9 Southeast				
Ashley	1.55	4,791	80.9*	5,357	440	8.22	1.16
Chicot	3.12	4,979	74.2*	5,499	370	6.73	0.95
Desha	3.24	5,092	88.2*	5,710	385	6.75	0.95
Drew	1.29	5,120	118.0*	5,946	378	6.35	0.90
Jefferson	3.70	4,993	100.8*	5,699	541	9.50	1.34
Lincoln	2.32	5,003	84.2*	5,592	410	7.32	1.04
			Miscellaneous Counties (and Districts)				
Yell (4)	0.16	4,536	52.3	4,901	534	10.89	1.54
Faulkner (5)	0.21	5,010	101.6*	5,721	279	4.87	0.69
Pulaski (5)	0.45	4,871	110.1*	5,641	540	9.58	1.35
Lafayette (7)	0.44	4,298	18.8	4,429	268	6.05	0.86
Little River (7)	0.09	3,950	95.1*	4,616	420	9.10	1.29
Miller (7)	0.58	4,400	41.9	4,693	577	12.29	1.74

continued

Table 1. Continued.

County Name	Annual Share of State Production	Mean Yield	Yield Trend	Trendline Yield	RMSE	CV	CV Index
	(%)	(lb/acre)	(lb/acre/year)	(lb/acre)	(lb/acre)	(%)	(dec)
	Aggregated Districts						
Dist 3 Northeast	38.92	5,022	73.2*	5,584	311	5.57	0.79
Dist 6 EastCentral	43.24	5,082	84.0*	5,774	293	5.07	0.72
Dist 9 Southeast	15.23	5,044	89.5*	5,628	399	7.09	1.00
State Total[z]	100.00	5,092	80.3*	5,654	303	5.36	0.76

[z] 100.00% 15-yr average production for Arkansas State = 61,847,400 cwt.
* Slope coefficient significant at the 0.05 level.

Table 2. Predicted rice yield at alternative cumulative probability levels for major rice producing counties in Arkansas.

County	Cumulative Probability[1]								
	0.05	0.10	0.25	0.33	0.50	0.67	0.75	0.90	0.95
	(lb/acre)								
	District 3 Northeast								
Clay	4,995	5,117	5,319	5,401	5,544	5,688	5,770	5,972	6,094
Craighead	5,145	5,254	5,436	5,510	5,639	5,768	5,842	6,024	6,133
Greene	4,672	4,798	5,007	5,091	5,239	5,388	5,472	5,681	5,807
Independence	4,458	4,618	4,887	4,995	5,186	5,377	5,484	5,753	5,914
Jackson	4,868	5,026	5,290	5,396	5,583	5,770	5,876	6,140	6,298
Lawrence	5,062	5,219	5,482	5,588	5,774	5,960	6,066	6,329	6,486
Mississippi	4,827	4,975	5,222	5,321	5,497	5,672	5,771	6,018	6,166
Poinsett	5,067	5,193	5,403	5,487	5,636	5,785	5,869	6,079	6,205
Randolph	5,078	5,214	5,442	5,533	5,695	5,856	5,948	6,175	6,311
White	4,938	5,066	5,281	5,367	5,519	5,672	5,758	5,972	6,101
	District 6 East Central								
Arkansas	5,618	5,740	5,943	6,025	6,169	6,313	6,395	6,598	6,720
Crittenden	4,927	5,074	5,318	5,417	5,590	5,764	5,862	6,107	6,253
Cross	5,288	5,393	5,569	5,640	5,764	5,889	5,959	6,135	6,240
Lee	5,080	5,203	5,409	5,492	5,638	5,784	5,867	6,073	6,196
Lonoke	5,405	5,536	5,755	5,843	5,998	6,153	6,241	6,459	6,590
Monroe	4,992	5,142	5,393	5,494	5,672	5,850	5,951	6,202	6,353
Phillips	4,620	4,750	4,969	5,057	5,211	5,366	5,454	5,672	5,803
Prairie	5,407	5,520	5,708	5,783	5,917	6,050	6,126	6,314	6,427
Saint Francis	4,855	4,970	5,164	5,241	5,378	5,515	5,593	5,786	5,902
Woodruff	4,835	4,936	5,105	5,173	5,293	5,413	5,481	5,650	5,752

continued

Table 2. Continued.

	Cumulative Probability[1]								
County	0.05	0.10	0.25	0.33	0.50	0.67	0.75	0.90	0.95
	(lb/acre)								
	District 9 Southeast								
Ashley	4,633	4,793	5,060	5,168	5,357	5,547	5,655	5,922	6,082
Chicot	4,890	5,024	5,249	5,340	5,499	5,659	5,749	5,974	6,108
Desha	5,076	5,216	5,450	5,544	5,710	5,876	5,969	6,203	6,343
Drew	5,325	5,462	5,691	5,783	5,946	6,109	6,201	6,431	6,568
Jefferson	4,808	5,005	5,334	5,465	5,699	5,932	6,064	6,393	6,589
Lincoln	4,918	5,067	5,316	5,416	5,592	5,768	5,868	6,117	6,266
	Miscellaneous Counties (and Districts)								
Yell (4)	4,023	4,217	4,541	4,671	4,901	5,131	5,261	5,585	5,779
Faulkner (5)	5,263	5,364	5,533	5,601	5,721	5,841	5,909	6,079	6,180
Pulaski (5)	4,753	4,949	5,277	5,409	5,641	5,874	6,006	6,334	6,530
Lafayette (7)	3,989	4,086	4,249	4,314	4,429	4,545	4,610	4,773	4,870
Little River (7)	3,925	4,077	4,332	4,435	4,616	4,797	4,899	5,154	5,307
Miller (7)	3,744	3,953	4,304	4,444	4,693	4,941	5,082	5,432	5,642
	Aggregated Districts								
Dist 3 Northeast	5,072	5,185	5,374	5,450	5,584	5,718	5,794	5,983	6,096
Dist 6 East Central	5,292	5,398	5,576	5,648	5,774	5,900	5,971	6,149	6,256
Dist 9 Southeast	4,972	5,117	5,359	5,456	5,628	5,800	5,897	6,139	6,284
State Total	5,156	5,266	5,450	5,524	5,654	5,785	5,859	6,043	6,153

[1]The probability that county yield will be less than or equal to the level specified.

COMPLETED STUDIES

PREDICTION OF COOKED RICE TEXTURE PROFILES USING INSTRUMENTAL SPECTRAL EXTRUSION DATA MODELED WITH PARTIAL LEAST SQUARES REGRESSION AND ARTIFICIAL NEURAL NETWORKS (ANN)

C. Sitakalin and J-F.C. Meullenet

ABSTRACT

Spectral Stress Strain Analysis (SSSA) was used in combination with Partial Least Squares (PLS) regression and Artificial Neural Networks (ANN) to predict nine sensory texture attributes of cooked rice. The models calculated with ANN were slightly more accurate in predicting most of sensory texture characteristics evaluated than those from PLS regression. Furthermore, the models from ANN were more robust and discriminative than those from PLS regression.

INTRODUCTION

Correlations between instrumental mechanical tests and sensory evaluation techniques of cooked rice texture have been evaluated using multivariate regression (Meullenet *et al.*, 1998; Meullenet *et al.*, 1999). However, the use of multivariate regression is limited by the necessity of the human's understanding in describing rules to a computer or a software (Bomio, 1998). Artificial Neural Networks were developed almost four decades ago as tools that could work similarly to the human brain and have the ability to handle information-processing problems (Ni and Gunasekaran, 1998). Artificial Neural Networks have recently gained more attention because of advanced technology of computer hardware and software (Bomio, 1998). The aims of this study were (1) to further investigate the use of SSSA as a means of predicting sensory texture characteristics of cooked rice and (2) to compare PLS regression and ANNs as two modeling techniques.

PROCEDURES

Three rice cultivars, two long-grain (‘Cypress’ and ‘Kaybonnet’) and one medium-grain (‘Bengal’) harvested from Stuttgart and Dewitt in 1996 and 1997 were used in this study. Rice samples were collected from the Rice Research and Extension Center in Stuttgart (1996) and a farm in Dewitt (1997). Samples were then dried and stored under conditions illustrated in Fig. 1. Samples were pulled for evaluation after various storage durations.

Sensory Evaluation

Rice samples were cooked in household rice cookers with a rice-to-water ratio of 1:2 (vol/vol) and served to panelists in a preheated glass bowl at 75 ± 2°C. Panelists were instructed to monitor temperature closely during the tests and taste rice samples before the temperature of samples reached 60°C. Complete sample preparation and sensory evaluation procedures are given in Meullenet *et al.* (1998, 1999). A list of attributes evaluated is provided in Table 1.

Extrusion Cell Test

Samples were prepared according to the procedures described by Meullenet *et al.* (1998, 1999). An extrusion test, using 35 g of cooked rice at room temperature, was performed using a cylindrical extrusion cell (40 mm in diameter and 70 mm deep) in conjunction with a Texture Analyzer (model TA-XT2, Texture Technologies Corp., Scarsdale, New York) using procedures described by Meullenet *et al.* (1998, 1999).

Data Analysis

A multivariate analysis software, Unscrambler (version 6.11a, CAMO, Throndheim, Norway) was used to determine predictive models of texture attributes. Points extracted from the force-deformation curve (i.e., 217 points) were used as variables in the regression model to predict each sensory attribute, a procedure known as Spectral Stress Strain Analysis (Meullenet *et al.*, 1999). Neural Unscrambler (version 1.02, CAMO ASA, Trondheim, Norway), a software for multivariate calibration applying ANN, was used in the next step to determine predictive models for texture attributes and to compare its ability in predicting sensory attribute with that of PLS regression.

Root Mean Square Error of Prediction (RMSEP), the average difference between predicted and measured response values, was used to express the predictive ability of each model. The ratio RMSEP/RMSEC (i.e., C stands for alibration) was calculated and used as an indication of model robustness. A ratio close to 1 indicates a robust model. Furthermore, a ratio of the standard deviation of a sensory attribute (Stot) and

RMSEP was calculated to indicate model discrimination ability. Models with a large ratio (i.e., the ratio ≥ 2) were considered to be discriminative.

RESULTS AND DISCUSSION

Predictive models for adhesiveness to lips from ANN with a (8, 4, 2, 1), a (7, 4, 2, 1), and a (4, 3, 2, 1) architecture (RMSEP = 0.463, 0.445, and 0.456, respectively) were better than the model evaluated by PLS regression (test set) (RMSEP= 0.588; Tables 2, 3, and 4). The RMSEP from ANN was improved by 22%. The most robust model from ANN consisted of seven input parameters (ANN (7, 4, 2, 1)) (RMSEP/RMSEC = 1.00, RMSEP = 0.445, S_{tot}/RMSEP = 3.99). The most robust model was acquired when using a (4, 3, 2, 1) architecture (RMSEP/RMSEC = 1.09). Furthermore, RMSEP for this model (RMSEP = 0.326) was lower than the value acquired from PLS regression with a test set validation (RMSEP=0.359). However, the RMSEP for the best model [ANN (4, 3, 2, 1)] (RMSEP=0.326) was higher than that reported by Meullenet *et al.* (1999) using PLS regression with random cross-validation method (RMSEP = 0.19). A larger number of samples in this study (n = 130) might have resulted in a higher RMSEP value than that reported by Meullenet *et al.* (1999) (n = 74).

Prediction of cohesiveness of mass evaluated after three chews dramatically improved by 28 to 40% when using an ANN (Table 4). The RMSEP value of the test set using PLS regression was 1.25, while it was reduced to 0.73 with a (4, 3, 2, 1) architecture (Tables 2 and 3). However, the ANN models evaluated were not very discriminating (S_{tot}/RMSEP = 1.84 and 2.26). Cohesiveness of mass evaluated after eight chews was fairly successfully predicted using ANN (RMSEP = 0.538, 0.513, and 0.573). The RMSEP values were lower than the values obtained using PLS regression with the test set validation method (RMSEP = 0.614). However, the RMSEP values were higher than those reported by Meullenet *et al.* (1999) using PLS regression with a random cross-validation method (RMSEP = 0.44). Roughness of mass was successfully predicted using ANN (RMSEP = 0.168 and 0.182). The models were also the most discriminating among the models calculated for all sensory attributes (S_{tot}/RMSEP = 6.03 and 6.53). In addition, in comparison to the model from PLS regression with test set validation method, the RMSEP for ANN models were improved by 25.99% with a (7, 4, 2, 1) architecture and 19.82% with a (6, 4, 2, 1) and a (4, 3, 2, 1) architecture. However, the latter architecture resulted in the most robust model (RMSEP/RMSEC = 1.05). ANN was found useful in predicting toothpull of cooked rice. RMSEP values from all three architectures (RMSEP = 0.263, 0.277, and 0.269) were lower than the value from PLS regression (RMSEP = 0.356); however, the values from ANN were similar to the values reported by Meullenet *et al.* (1999). RMSEP values from ANN were reduced by 26.12% with a (7, 4, 2, 1) architecture. However, the number of inputs in this architecture (i.e., equal to seven) caused overfitting (RMSEP/RMSEC = 2.12). The most robust and discriminating model was obtained from a (4, 3, 2, 1) architecture

(RMSEP/RMSEC = 1.14, RMSEP = 0.269, S_{tot}/RMSEP = 3.60,). Prediction of particle size using two different ANN architectures was effective (RMSEP = 0.079 and 0.086). However, RMSEP values for ANN models were not largely decreased in comparison to the model obtained from PLS regression with test set validation method (% improvement = 13.19 and 5.49). The most robust and discriminating model was obtained with a (2, 4, 2, 1) architecture (RMSEP/RMSEC = 1.11, S_{tot}/RMSEP = 3.70). As for most other attributes, a model with a higher number of inputs (e.g., ANN (4, 3, 2, 1)) tended to be less robust (RMSEP/RMSEC = 1.30).

Toothpack was fairly well predicted using ANN (RMSEP = 0.340, 0.342, and 0.350), with RMSEP improvements between 20.09 and 22.37%. Although ANN models offered relatively low RMSEP values (RMSEP = 0.35), the models exhibited a serious lack of robustness (RMSEP/RMSEC > 2.10). Models with higher number of inputs had a tendency to be less robust. ANN was also useful in predicting loose particles, with RMSEP values ranging between 0.353 and 0.423 with three different networks. The RMSEP values reported here were somewhat larger than those reported by Meullenet *et al.* (1999) (RMSEP = 0.22) using PLS regression with random cross-validation. All ANN models were somewhat discriminating (S_{tot}/RMSEP>3). Models with a (8, 4, 2, 1) and a (7, 4, 2, 1) architectures yielded lower RMSEP values (RMSEP = 0.380 and 0.353, respectively) than the model evaluated with PLS regression (test set validation method) (RMSEP = 0.437). This represents an improvement of 13.04 and 19.22 %, respectively. The model with a (4, 3, 2, 1) architecture (RMSEP = 0.423) provided the least improvement in term of RMSEP value (% improvement = 3.20). The most robust model was obtained from a (8, 4, 2, 1) architecture (RMSEP/RMSEC = 1.01).

SIGNIFICANCE OF FINDINGS

Artificial Neural Networks in combination with SSSA were successfully used to predict sensory texture profiles of cooked rice and showed potential as an effective modeling technique, permitting the development of rapid and accurate instrumentation for predicting cooked rice texture. Root Mean Square Error of Prediction values for all sensory attributes were lower with ANN. However, prediction model for toothpack was less robust with ANN. Improvements offered by ANN over PLS regression varied from attribute to attribute between 10.86 and 41.6%. In addition, the ratio between RMSEP and RMSEC, an indication of model robustness, was closer to 1.0 with ANN for most attributes evaluated. The results, even if not dramatically improved, showed the potential of ANN as a modeling tool for predicting rice texture from instrumental measurements. It was also confirmed that SSSA is a viable method for relating sensory perception of rice texture to instrumental data. Overall, ANN and SSSA used in combination showed potential for developing as an intelligent system capable of predicting cooked rice texture profiles for most of the sensory attributes evaluated.

ACKNOWLEDGMENTS

The authors would like to acknowledge the funding provided by the Arkansas Rice Research and Promotion Board and the U.S. rice industry.

LITERATURE CITED

Bomio, M. 1998. Neural networks and the future of sensory evaluation. Food Technol. 52(8):62- 63.

Meullenet, J-F.C., J. Gross, B.P. Marks, and M. Daniels. 1998. Sensory descriptive texture analyses of cooked rice and its correlation to instrumental parameters using an extrusion cell. Cereal Chem. 75(5):714-720.

Meullenet, J-F.C., C. Sitakalin, and B.P. Marks. 1999. Prediction of rice texture by spectral strain analysis: a novel technique for treating instrumental extrusion data used for predicting sensory texture profiles. J. Texture Studies. 30(4):435-450.

Ni, H., and S. Gunasekaran. 1998. Food quality prediction with neural networks. Food Technol. 52(10):60-65.

Table 1. Vocabulary for sensory textural attributes of cooked rice.

Term	Definition	Technique
SURFACE:		
Adhesiveness to lips	The degree to which the sample adheres to the lips.	Compress sample between lips, release, and evaluate.
Particle size	The amount of space the particle fills in your mouth.	Place sample in center of mouth and evaluate.
FIRST CHEW:		
Hardness	The force required to compress the sample.	Compress or bite through sample with molars or incisors.
CHEWDOWN:		
Cohesivenss of mass	The degree in which the chewed sample holds together.	Chew sample with molar teeth up to 3 times and evaluate.
Roughness of mass	The amount of roughness perceived in the chewed sample.	Chew sample with molar teeth 8 times and evaluate.
Toothpull	The force required to separate the jaws during mastication.	Chew sample up to 3 times and evaluate.
RESIDUAL:		
Toothpack	The amount of product packed into the crowns of your teeth after mastication.	Chew samples up to 8 times, expectorate, and feel the surface of the crowns of the teeth with tongue.
Loose particles	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample up to 8 times with molars, swallow and evaluate.

Table 2. Models statistics for Partial Least Squares regression using the full cross validation method[z].

Sensory Attribute	R_p [y]	RMSEP[x]	R_c [w]	RMSEC[v]	RMSEP/RMSEC	RAP[u]
Adhesiveness to lips	0.79	0.60	0.87	0.48	1.25	0.90
Hardness	0.82	0.32	0.87	0.28	1.14	0.85
Cohesiveness of mass (after 3 chews)	0.39	1.08	0.45	1.04	1.04	0.58
Cohesiveness of mass (after 8 chews)	0.68	0.47	0.74	0.43	1.09	0.91
Roughness of mass	0.77	0.21	0.82	0.18	1.17	0.98
Toothpull	0.82	0.37	0.88	0.31	1.19	0.87
Particle size	0.56	0.08	0.59	0.08	1.00	0.94
Toothpack	0.80	0.31	0.87	0.25	1.24	0.90
Loose particles	0.84	0.47	0.88	0.41	1.15	0.87

[z] Total number of observations = 130, total number of instrumental variables = 217.
[y] Correlation for the validation model.
[x] Root Mean Square Error of Prediction.
[w] Correlation for the calibration method.
[v] Root Mean Square Error of Calibration.
[u] Relative Ability of Prediction = $(S^2_{tot}\text{-RMSEP}^2)/(S^2_{tot}-S^2_{ref})$, where S_{tot} is the standard deviation of a sensory attribute across all samples, : $S_{ref}=(MSE/[PxR])^{1/2}$, where MSE is the mean square error derived from two-way analysis of variance with samples and panelists as class-variables and P and R are the number of panelists (P=9) and replications (R=2), respectively.

Table 3. Models statistics for Partial Least Squares regression using the test set validation method .

Sensory Attribute	R_p [z]	RMSEP[y]	R_c [x]	RMSEC[w]	RAP[v]	RMSEP/RMSEC
Adhesiveness to lips	0.827	0.588	0.871	0.477	0.91	1.23
Hardness	0.842	0.359	0.911	0.219	0.81	1.64
Cohesiveness of mass (after 3 chews)	0.382	1.250	0.436	1.057	0.43	1.18
Cohesiveness of mass (after 8 chews)	0.641	0.614	0.778	0.364	0.84	1.69
Roughness of mass	0.800	0.227	0.836	0.168	0.97	1.35
Toothpull	0.882	0.356	0.862	0.305	0.88	1.17
Particle size	0.561	0.091	0.586	0.076	0.92	1.20
Toothpack	0.698	0.438	0.880	0.231	0.78	1.90
Loose particles	0.857	0.437	0.882	0.401	0.89	1.09

[z] Correlation for the prediction (test set) model (n=30).

[y] Root Mean Square Error of Prediction.

[x] Correlation for the calibration method (n=100).

[w] Root Mean Square Error of Calibration.

[v] Relative Ability of Prediction = $(S^2_{tot}-RMSEP^2)/(S^2_{tot}-S^2_{ref})$, where S_{tot} is the standard deviation of a sensory attribute across all samples, : $S_{ref}=(MSE/[PxR])^{1/2}$, where MSE is the mean square error derived from two-way analysis of variance with samples and panelists as class-variables and P and R are the number of panelists (P=9) and replications (R=2), respectively.

Table 4. Models statistics for various ANN architectures.

Sensory Attributes	Design[z]	Architecture	R_p [y]	RMSEP[x]	R_c [w]	RMSEC[v]	RMSEP/ RMSEC	S_{tot} [u]/ RMSEP	% improvement[t]
Adhesiveness to lips	1	8, 4, 2, 1	0.884	0.463	0.942	0.337	1.37	3.83	21.26
	2	7, 4, 2, 1	0.885	0.445	0.894	0.445	1.00	3.99	24.32
	3	4, 3, 2, 1	0.882	0.456	0.877	0.476	0.96	3.89	22.45
Hardness	1	8, 4, 2, 1	0.865	0.331	0.947	0.175	1.89	2.35	7.80
	2	6, 4, 2, 1	0.875	0.315	0.958	0.155	2.03	2.47	12.26
	3	4, 3, 2, 1	0.865	0.326	0.836	0.299	1.09	2.39	10.86
Cohesiveness of mass (after 3 chews)	1	-	-	-	-	-	-	-	-
	2	2, 4, 2, 1	0.663	0.894	0.661	0.886	1.01	1.84	28.48
	3	4, 3, 2, 1	0.795	0.730	0.830	0.669	1.09	2.26	41.60
Cohesiveness of mass (after 8 chews)	1	5, 4, 2, 1	0.742	0.538	0.834	0.327	1.65	2.77	12.38
	2	4, 4, 2, 1	0.769	0.513	0.879	0.280	1.83	2.90	16.45
	3	4, 3, 2, 1	0.712	0.573	0.866	0.301	1.90	2.60	6.68
Roughness of mass	1	7, 4, 2, 1	0.895	0.168	0.909	0.131	1.28	6.53	25.99
	2	6, 4, 2, 1	0.874	0.182	0.857	0.160	1.14	6.03	19.82
	3	4, 3, 2, 1	0.873	0.182	0.828	0.174	1.05	6.03	19.82
Toothpull	1	7, 4, 2, 1	0.941	0.263	0.979	0.124	2.12	3.68	26.12
	2	8, 4, 2, 1	0.930	0.277	0.925	0.230	1.20	3.49	22.19
	3	4, 3, 2, 1	0.934	0.269	0.922	0.237	1.14	3.60	24.44
Particle size	1 & 2	2, 4, 2, 1	0.674	0.079	0.662	0.071	1.11	3.70	13.19
	3	4, 3, 2, 1	0.610	0.086	0.721	0.066	1.30	3.40	5.49
Toothpack	1	5, 4, 2, 1	0.841	0.340	0.961	0.137	2.48	2.70	22.37
	2	7, 4, 2, 1	0.823	0.350	0.975	0.109	3.21	2.62	20.09
	3	4, 3, 2, 1	0.821	0.342	0.943	0.163	2.10	2.68	21.92
Loose particles	1	8, 4, 2, 1	0.894	0.380	0.901	0.377	1.01	3.37	13.04
	2	7, 4, 2, 1	0.911	0.353	0.946	0.291	1.21	3.63	19.22
	3	4, 3, 2, 1	0.868	0.423	0.892	0.390	1.08	3.03	3.20

continued

Table 4. Continued.

[z] Design 1: Number of inputs was equal to number of PCs suggested in PLS Regression (test set method); Design 2: Number of inputs was equal to number of PCs suggested in PLS Regression for full cross validation; and Design 3: Number of inputs was equal to four.
[y] Correlation for the prediction model.
[x] Root Mean Square Error of Prediction.
[w] Correlation for the calibration (training) model.
[v] Root Mean Square Error of Calibration.
[u] Standard deviation of a sensory attribute
[t] $\% \text{ improvement} = \frac{\text{RMSEP pls (test set)} - \text{RMSEP ann}}{\text{RMSEP pls (test set)}} \times 100$

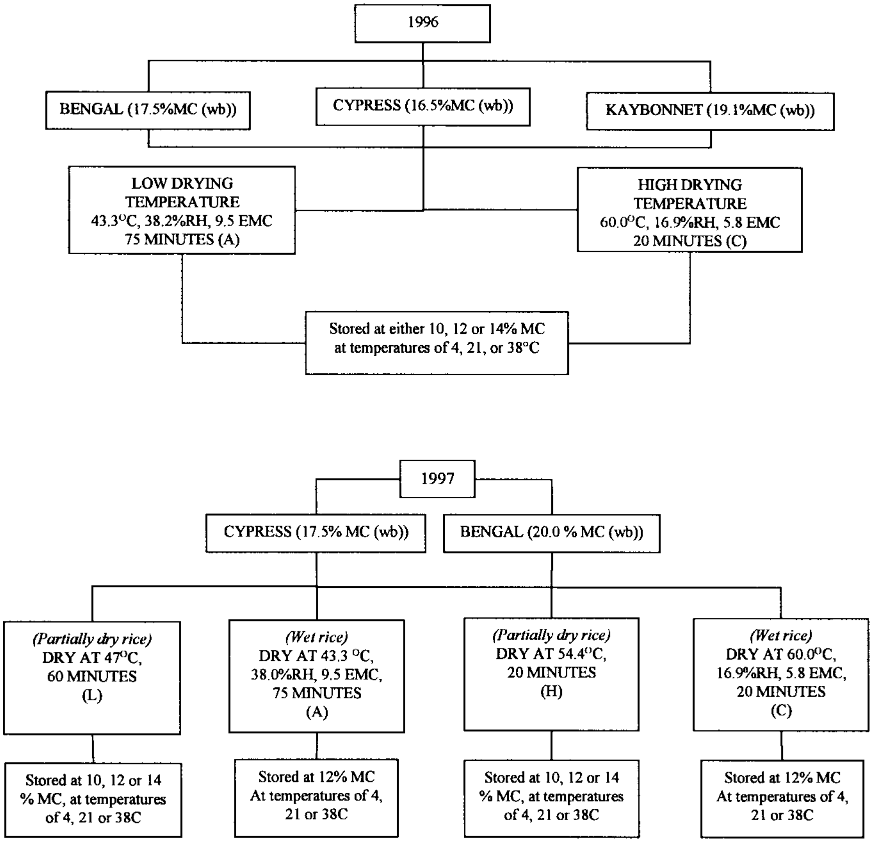


Fig. 1. Processing conditions of samples harvested in 1996 and 1997.