B.R. Wells

RICE RESEARCH STUDIES 1998

R.J. Norman and
T.H. Johnston, editors

ARKANSAS AGRICULTURAL EXPERIMENT STATION
Division of Agriculture | University of Arkansas
August 1999 | Research Series 468

Editing and cover design by Karen Eskew

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. PS1.2899PM65.The Arkansas Agricultural Experiment Station follows a nondiscriminatory policy in programs and employment.

ISSN:0099-5010 CODEN:AKAMA6

B.R. Wells
Rice Research Series

R.J. Norman and T.H. Johnston, editors

Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72701

DEDICATED IN MEMORY OF BOBBY R. WELLS

Dr. Bobby R. Wells was born July 30, 1934, at Wickliffe, Kentucky. 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. E. (Elza) M. (Monroe) "Monty" Cralley
November 20, 1905 - April 19, 1999

Dr. Monty Cralley was born at Carmi, White County, in southern Illinois, in 1905. He grew up one of three brothers on a family livestock and crops farm. Following high school, he obtained a B.S. in Liberal Arts in 1928 at McKendree College in Lebanon, Illinois, majoring in Biology, History, and English. He obtained a Ph.D. in Plant Physiology and Plant Pathology in 1931 from the University of Wisconsin.

Cralley joined the University of Arkansas' Plant Pathology Department in 1931 as an instructor and was promoted over the years to full professor in 1947. He served as Department Head from 1953 to 1959, and as Director of the Arkansas Agricultural Experiment Station from 1959 until he retired in 1973.

While Cralley worked with many Arkansas crops during the 1930s and 1940s, he specialized in rice research and identified a yellow coloration of the rice plant foliage as being caused by a deficiency of available soil potassium. He was recognized in the late 1940s and 1950s as being one of the great rice scientists of the developed world. This led to his demand as a rice culture scientist in a number of rice-growing developing countries such as Cuba, Central America, and South Korea and with the Ford Foundation in India.

One of his prized, but rarely shown, possessions is a photo of him in a private discussion with Jawaharlar Nehru, India's first prime minister.

Ever active in campus and southern experimentation affairs, Cralley served on faculty senate committees that recommended President John Tyler Caldwell and other campus administrators to the Board of Trustees. In 1970, he was chosen as "Man of the Year in Service to Arkansas Agriculture". For a six-year period in the 1950s he served as secretary of the Arkansas State Plant Board.

In 1997, the Virology / Biocontrol Laboratory at the Arkansas Agricultural Experiment Station was renamed the Cralley / Warren Research Laboratory.

Following a 42-year career at the University of Arkansas, Cralley retired in 1973 and took up painting, taught by his wife, Ann, who was well-known as an artist locally and regionally. He enjoyed and continued painting well into his 90s, even though age had diminished his vision. He sold and gave his paintings to friends and exhibited them in local banks and elsewhere.

In 1983, he wrote a small book entitled "Distant Horizons", a book of philosophical comments. His wife illustrated the book. In 1998, he revised and republished the book which included prints of some of his favorite paintings.

Cralley continued to have a verve for life 25 years following his retirement, and he kept in contact and attended meetings with former campus colleagues.

FOREWORD

The research reports in this publication 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, 1998, Arkansas Agricultural Experiment Station Research Series 463. 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 funds.

Use of products and trade names in any of the research reports in 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. This publication is available online at http://www.uark.edu/depts/agripub/Publications/researchseries/. Additional printed copies of this publication can be obtained free of charge from Communication Services, 110 Agriculture Building, University of Arkansas, Fayetteville, AR 72701.

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 at (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.

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COMPLETED STUDIES

AN ADAPTIVE, OBJECTIVE RICE GROWTH STAGING SYSTEM

Paul A. Counce, Terry C. Keisling, and Andrew J. Mitchell

ABSTRACT

Undefined and conflicting descriptions of rice developmental stages make application of research results to farm management practices difficult. The use of time (days after emergence, days after seeding, days after flooding, days after anthesis) in lieu of developmental stage descriptions is not very meaningful for field conditions. Consequently, an objective growth staging system with enumeration adapted to the development of the plant would improve communication among scientists, farmers, and educators. We propose a rice growth staging system with four growth stages (S0 to S3) during seedling development (unimbibed seed, radicle, coleoptile emergence from the seed, and prophyll emergence from the coleoptile), the number of vegetative stages (V1 to V_F) equal to the number of completely expanded leaves (excluding the prophyll) on the main stem, and nine reproductive growth stages (R0 to R9) based on discrete morphological criteria (panicle initiation and differentiation, boot stage, panicle exertion, anthesis, grain expansion, grain filling, grain dry down, and grain maturity). Assigning rice growth stages based on discrete morphological criteria will result in unambiguous growth stage determination (i.e., two people staging the same plant will, using this system, arrive at the same growth stage). This system takes advantage of the presence or absence of distinct morphological criteria in a framework which only permits 'yes' or 'no' answers. Consequently, an unequivocal rice growth staging system is presented which allows improved communication and application of rice research results to production practices.

INTRODUCTION

Crop growth staging systems are meant to be an aid in information transfer for crop management. They can also aid scientists and others in observing, recording, and communicating critical crop growth data. Yet for rice (*Oryza sativa*, L.), the most important single plant species for human nutrition, there is not a widely used growth staging system. There are two published systems for staging rice: IRRI (1980) and the BBCH system (Lancashire *et al.*, 1991). The IRRI scale is a 10-point system (0 to 9). The BBCH is an adaptation of the Feeks (1941) scale but broken in 10-point subdivisions. Consequently, the BBCH is a 99-point system with both discrete and continuous criteria for plant growth stage. The very nature of arbitrarily assigning crop growth stages makes them subject to individual judgements rather than discrete and objective criteria.

The growth staging system with the most long-lived usefulness and employment is the system presented by Fehr and Caviness (1979) for soybean (*Glycine max*, L. [Merr.]). They recognized the basic developmental pattern for soybeans as being leaf age. They also allowed the enumeration of the vegetative growth stages to be determined by the plant rather than being imposed arbitrarily upon it. Their system uses objective, determinable morphological criteria for soybean development. Consequently, two people independently examining one plant for soybean growth stage will arrive at the same answer.

A crop growth staging system based on plant development, with each stage differentiated from another dichotomously, would remove the major limitation of other systems. Only discrete criteria are employed because criteria determined by quantitative measurement (length, width, height, etc.) are plastic and consequently produce conflicting growth stage determinations. An objective morphological criterion is either present or absent, thus for the question of whether a plant is at a given growth stage, the answer is either yes or no.

The primary value of an objective and adaptive crop growth staging system is better communication among farmers, scientists, teachers, and extension personnel. The central feature that allows meaningful communication is the ability to objectively determine the growth stage. The dichotomous feature assures that different people staging the same rice plant will obtain the same crop growth stage. Visibility of criteria is also critical to the system. It is more convenient in the field to observe things visible, at most, with a small hand lens (10X magnification) rather than requiring a microscope. Consequently, plant structures visible with 10X or less magnification were selected as growth stage criteria. A crop growth system based on objective, visible, and discrete morphological developmental criteria, with enumeration derived from the plant rather than being imposed upon it, can replace the vagaries of time and temperature time units with precise leaf age time units.

Rice morphological development can be divided into three stages: seedling, vegetative, and reproductive. These three stages are described in detail below. The late vegetative stage and the early reproductive stages occur simultaneously. The seedling and reproductive stages progress through a series of unique (occurring only once during development) events whereas the vegetative stages progress through an iterative sequence of leaf developmental events.

To germinate, a dry rice seed must imbibe water. A germinating seed produces a coleoptile and a radicle. A prophyll (rudimentary leaf) emerges from the coleoptile. This is followed by the emergence of the first true leaf (one with a blade and sheath) above the prophyll.

Vegetative growth occurs in distinct, biological units of development time. Terms that have been used to describe this developmental time include 'leaf age' and phyllochron. Leaf age is a somewhat loose term used to refer to leaf number on a rice culm. A phyllochron is the time interval between successive leaf developmental events

(Rickman and Klepper, 1995; Wilhelm and McMaster, 1995; Nemoto *et al*., 1995). The period between successive leaf collar formations is one measure of a phyllochron that is easily determined without magnification.

Reproductive development begins when the panicle on the main stem initiates growth. Subsequently, the panicle differentiates, the panicle enlarges concurrently with the rest of the plant stem, the panicle emerges, anthesis occurs, the caryopsis (i.e., developing kernel) elongates, the grain fills, the grain ceases to fill, and the grain dries down.

Our purpose is to present an objective, adaptive rice growth staging system.

PROCEDURES

The primary methods leading to the development of the system were (1) observing rice plants as they developed, (2) studying the literature on plant development and growth staging and (3) reflectively analyzing these. Discussions were held with scientists from several disciplines to elucidate rice growth stages that were important to their discipline. Literature searches were made and an objective, adaptive rice growth staging system was presented and discussed on 4 March 1998 at the Rice Technical Working Group in Reno, Nevada (Counce, 1998). A workshop was held on 3 September 1998 in Stuttgart to demonstrate the system and to get feedback from participants about the system. Questions raised in the discussion session were addressed either by literature searches or through experimental observations.

RESULTS AND DISCUSSION

The seedling growth stages, illustrations, and morphological criteria for each growth stage are presented in Fig. 1. The stages outline the development described above.

The vegetative growth stages, illustrations, and morphological criteria for each growth stage are presented in Figs. 2 and 3. Each leaf is succeeded by an additional leaf until the formation of the final leaf on a culm, the flag leaf. A rice phyllochron usually varies from three to eight days. Late vegetative development (V_{F-4} to V_F) and early reproductive development (R0 to R2) occur simultaneously.

The reproductive growth stages, illustrations, and the morphological criteria for each growth stage are presented in Fig. 4. Stages R0 through R3 refer to the developing panicle while Growth Stages R4 through R8 refer to the individual florets or grains on a panicle. If any florets or grains on a main stem panicle have passed into the next R-stage then the plant is determined to be at that R-stage. That is, if one grain on a panicle has a caryopsis filling the cavity of the lemma and palea (the “hull”) then the growth stage is R-6. Usually, the first grains to be at the criteria stages of development will be the grains at the top of the panicle.

The growth stages refer to individual plants, main stems, or grains. It is useful to have a way to quantitatively express the stage of development for a field. Fehr and Caviness (1979) and others suggested enumeration of individuals in a population and if more than 50% had advanced into the next growth stage, then the crop was considered to be in the next growth stage. To enumerate a field within seedling, vegetative, or reproductive growth stages--take the average of the growth stages for the individual plants. (Field enumeration cannot be averaged across growth stage divisions, i.e., seedling, vegetative, or reproductive.) For example, if three plants from a field were at V5, V7, and V8, the field growth stage would be V6.7.

SIGNIFICANCE OF FINDINGS

The rice growth staging system allows improved communication about rice stages of growth among farmers, researchers, and extension personnel.

ACKNOWLEDGMENTS

We thank Arkansas rice producers for support through checkoff funds administered by the Arkansas Rice Research and Promotion Board. We thank Angela Rosencrantz for the excellent illustrations. We thank Bobby Kelly and Mark Poag for notes and observations.

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Growth Stage	S0	S1	S2	S3
Morphological Marker	Dry, unimbibed seed	Emergence of coleoptile[z]	Emergence of radicle[z]	Emergence of prophyll leaf from coleoptile[y]

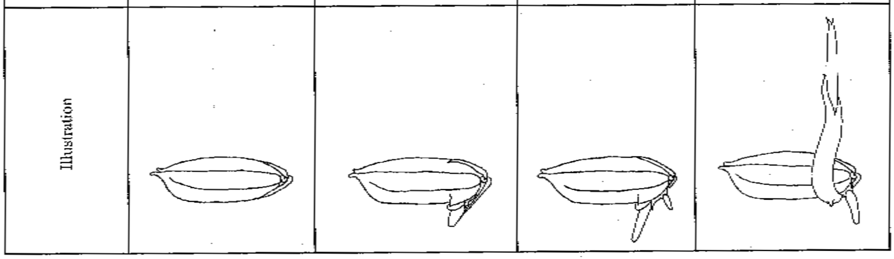

Fig. 1. Rice seedling growth stages and morphological markers.

[z] The sequence of seedling growth stages normally encountered in aerobic seedbed conditions (whether direct-seeded or transplanted rice culture) may change under anaerobic (such as under water-seeded culture) conditions. Under anaerobic conditions, the coleoptile emerges first.This table is for aerobic conditions only which applies to most of the rice grown in the world.

[y] The prophyll leaf is the first leaf to emerge, but it lacks a blade and consists only of the leaf sheath.

Growth Stage	V1	V2	V3	V4	V5
Morphological Marker	Collar formation on first complete leaf (Leaf 1) on main stem	Collar formation on Leaf 2 on main stem	Collar formation on Leaf 3 on main stem	Collar formation on Leaf 4 on main stem	Collar formation on Leaf 5 on main stem

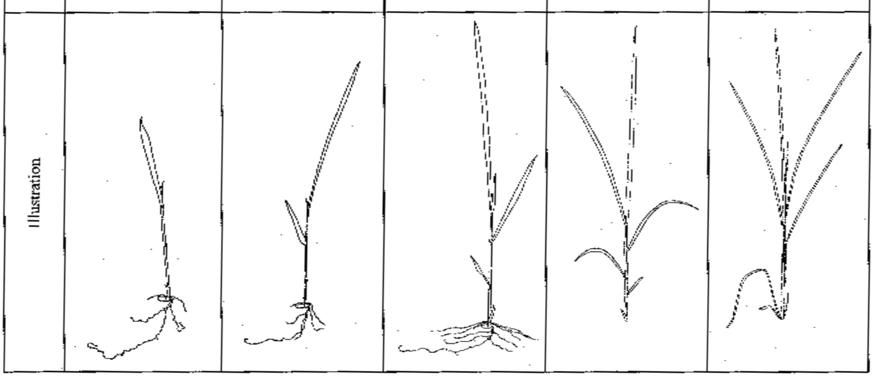

Fig. 2. Early rice vegetative growth stages and morphological markers for a rice cultivar with 13 true leaves on the main stem[z].

[z] The number of vegetative growth stages varies with the number of true leaves on the main stem.

Growth Stage	V9 (V_{F-4})[y]	V10 (V_{F-3})	V11 (V_{F-2})	V12 (V_{F-1})	V13 (V_F)
Morphological Marker	Collar formation on Leaf 9 on main stem	Collar formation on Leaf 10 on main stem	Collar formation on Leaf 11 on main stem	Collar formation on Leaf 12 on main stem	Collar formation on Leaf 13 (flag leaf) on main stem
Illustration					

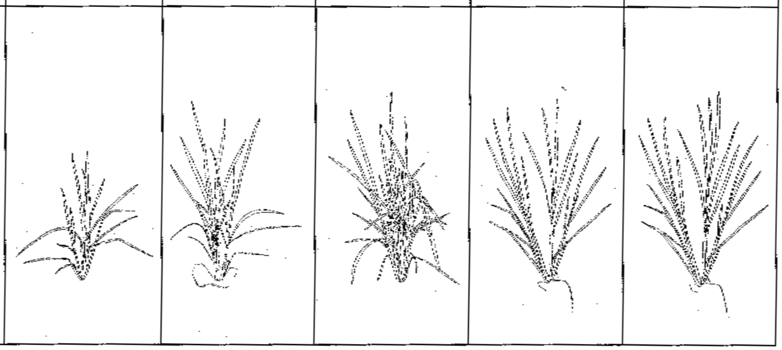

Fig. 3. The final five rice vegetative growth stages and morphological markers for a rice cultivar with 13 leaves on the main stem[z].

[z] The number of vegetative growth stages varies with the number of true leaves on the main stem.
[y] V_F denotes flag leaf and it follows that V_{F-n} denotes the n^{th} node before the flag leaf.

Growth Stage	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
Morphological Marker	Panicle initiation	Panicle differentiation	Panicle enlargement (boot)	Panicle exertion from boot	One or more florets on the main stem panicle has reached anthesis	At least one caryopsis on the main stem panicle is elongating to the end of the hull	At least one caryopsis on the main stem panicle has elongated to the end of the hull	At least one grain on the main stem panicle has a yellow hull and panicle branch	At least one grain on the main stem panicle has a brown hull z	All grains which reached R6 have a brown hull y
Illustration										

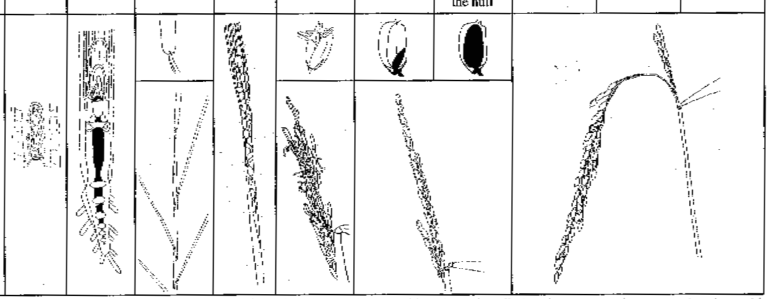

Fig. 4. Rice reproductive growth stages and morphological markers.

[z] The grain turning yellow along the panicle branch indicates the branching tissue has died and transport of sugars and amino acids through the phloem is no longer possible. Other authors have chosen to use terms physiological maturity or cessation of dry matter accumulation. We avoid these terms because, except for grains with black layer formation, such determination is difficult or impossible to make with any known morphological marker.
[y] The brown hull indicates the grain has dried enough to be harvestable.

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, R.H. Dilday, J.N. Rutger, M.M. Blocker, and A.C. Tolbert

ABSTRACT

The Arkansas rice breeding program is an ongoing program involving the development of new varieties, the testing of these varieties, and the identification of important characteristics for further improvement. Pest resistance as well as high-yield potential, excellent milling yields, improved plant type (i.e. short stature, semidwarf, earliness, erect leaves), and superior quality (i.e. cooking, processing, and eating) are all important components in this program. Currently, there are several promising lines in all stages of this program. They are lines with improved plant type, high grain and milling yields, disease resistance, and acceptable cooking quality. New cultivars 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 U.S. 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 in the Temperate Rice Conference in Australia (Moldenhauer *et al.*, 1994). As interest in specialty rices has increased, the program has taken on the added task of developing agronomically acceptable rice cultivars which are aromatic or have Japanese quality. Significant yield increases have been realized with the release of the latest four long-grain cultivars 'LaGrue', Kaybonnet, Drew, and 'Wells' developed in this program. Other lines currently in the program have potential to be new cultivars which will offer even further increases in yield potential.

PROCEDURES

The rice breeding program continues to use the best available parental material from all sources including other breeding programs in the United States, the USDA World Collection, and International programs like CIAT, IRRI, and WARDA. Crosses are made each year to incorporate genes for broad-based disease resistance, improved plant type (i.e. short-stature and semidwarf, earliness, erect leaves), superior quality (i.e. cooking, processing, and eating), and nitrogen (N) fertilizer use efficiency, into highly productive, well-adapted lines. Early generation selections are chosen from the various crosses each year and advanced a generation at the winter nursery in Puerto Rico. As outstanding lines are selected and advanced, they are evaluated extensively for yield, milling, and cooking characteristics, insect tolerance by entomologists, and disease resistance by plant pathologists. The advanced lines are extensively evaluated for proper N-fertilization practices and DD50 thermal units required to reach critical growth stage by soil fertility scientists, as well as response to recommended weed control practices by weed scientists. The rice breeding program uses all feasible breeding techniques and methods including hybridization, backcrossing, mutation breeding, and biotechnology to produce breeding material and new cultivars. Segregating populations and advanced lines are evaluated for grain and milling yields, quality traits, maturity, plant height and type, and disease and insect resistance as appropriate. The winter nursery in Puerto Rico is used to accelerate generation advance as well as increase seed for breeders 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.

RESULTS AND DISCUSSION

Drew, the blast resistant, high-yielding, long-grain rice cultivar developed in this project was grown as certified seed for the first time in 1998 on 37% of the Arkansas rice acreage. Wells, (RU9601053) a very high-yielding, long-grain cultivar originating from the cross 'Newbonnet'/3/'Lebonnet'/CI 9902//'Labelle' (cross no. 890481), made in 1989 at the Rice Research and Extension Center, Stuttgart, will be released to seed growers for the 1999 growing season. Wells has performed very well in both the Arkansas Rice Performance Trials (ARPT) (Table 1) and the Uniform Rice Regional Nursery (URRN) 1996-1998, being either at the top or close to the top of the test all three years at all locations. Like LaGrue, this line may be susceptible to the common blast races, but blast has not been a problem for this line in the field for the last two years across the southern growing region. Data were presented on Wells in the 1998 Rice Research Series (Moldenhauer *et al.*, 1999).

Two of the short-grain lines (RU9601096, and RU9601099) from the cross 'Koshihikari'/'Mars' which performed well in 1996 and 1997 were also in the ARPT (Table 2) and URRN in 1998. Again, these lines were high-yielding, excellent milling lines with improved texture and taste for the Oriental market when compared to typical southern U.S. medium-grain rice cultivars. Initial sensory evaluation suggests that the quality of these lines is closer to that of the Japanese type of rice than are Mars and 'Bengal'. Currently, these lines are being re-screened for quality characteristics. A possible seed increase of RU9601096 and RU9601099 will be grown in 1999. Through this program we hope to develop a high-yielding, agronomically adapted, short-grain rice which will be acceptable to the Japanese market.

Currently, there are several promising lines in the breeding program. They have come from all phases (short-stature or semidwarf crosses, crosses for blast resistance and recurrent selection for sheath blight, speciality crosses, and earliness crosses). Two lines are being considered for new foundation seed fields for 1999. One, Line D (Table 3), is a semidwarf line from the cross 'Lemont'//82CAY21/'Cica 8'/3/Mars/'Tebonnet', which has improved sheath blight tolerance, good milling yields, and high rough rice yield potential. The other, Line E (Table 3) is from the cross PI338046/Katy which is a high-yielding, good milling, long-grain rice. This line has been derived from germplasm (PI338064) identified by Dr. Dilday to have potential allelopathic activity. In 1999, head rows will be grown of Line A (Table 1), which is from the recurrent selection program and had extremely high yields in the 1998 ARPT.

Three high-yielding, large-kerneled, medium-grain lines were grown in the ARPT and URRN in 1998. They were from the cross 'Brazos'/Tebonnet/32/PI164986-4/'Nova' 66//'Nortai'/4/Bengal, made in 1992 at Stuttgart. Two of these lines will be tested again in 1999. One, a very-short-season line, Line C (Table 2), headed in 77 days, the other which is a short-season line, Line B (Table 1), headed in 81 days. Both of these lines had the highest yields in their respective groups in the ARPT in 1998.

There are many lines in the Stuttgart Initial Test (SIT) with outstanding yield potential. Two impressive lines from the cross IRGA409/Rexmont (930944) made in 1993 at Stuttgart are very high-yielding (200 bu/acre), long-grain cultivars, which will be in the ARPT for the first time in 1999. Twelve very-short-season sister lines from the cross 'Lebonnet'/CI9902/3/'Dawn'/ CI9695//'Starbonnet'/4/LaGrue had extremely high yield potential with plot yield approaching 200 bu/acre. In the SIT there were also five extremely early, long-grain lines which had improved yield potential over RU9101001 and exhibited blast resistance. The best of these lines will be advanced into the ARPT in 1999.

Rice blast (*Pyricularia grisea*) can be a devastating disease in Arkansas. Races IB-49 and IC-17 are currently the major races in Arkansas. Studies are being conducted to look at the inheritance of resistance to rice blast races. Two races of the pathogen, IE-1k and IB-33, could become a problem in the future, therefore, we are studying the inheritance of resistance to these blast races, and collecting lines which have resistance to these races. A program is also underway to incorporate the genes for blast resistance from Raminad Strain #3 an international rice blast differential which has resistance to all of the southern U.S. races. The second cross to agronomically acceptable material was made in 1997. F_3 material is being screened for blast resistance in the greenhouse. Several of the lines grown in 1998 had improved semidwarf plant type and resistance to our major blast races. The resistant lines from this approach will be used as parental material, and desirable phenotypes will be included in the breeding program and evaluated for cooking quality and agronomic characteristics.

Table 4 shows the number of lines that were in the different phases of this breeding project for the 1998 growing season.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum yielding cultivars with good levels of disease resistance for release to Arkansas rice producers. The release of Wells to qualified seed growers for the 1999 growing season and the existence of other high yielding semidwarf potential releases and Japanese quality lines are examples of the continued improvement being realized through this program. Improved lines from this program will continue to be released in the future. They will have the characteristics of improved disease resistance, plant type, and grain and milling yields. In the future new rice cultivars will be released not only for the traditional southern U.S. long- and medium-grain markets but also for specialty markets as they arise.

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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 1996 to 1998 Arkansas Rice Performance Trials for Wells, experimental lines, and check cultivars.

	Grain	Yield[z]					Maturity	Kernel	Milling
Cultivar	type	1996	1997	1998	Mean[y]	Height	50% HD	weight	HR:TOT
		---------- (bu/acre) ----------				(inches)	(days)	(mg)	(%)
Wells	L	178	171	151	168	40	84	18.80	62-73
Line A[x]	L	–	–	165	165	41	80	16.60	63-68
LaGrue	L	177	167	158	169	45	84	18.30	63-71
Kaybonnet	L	136	146	138	140	44	84	15.20	64-72
Line B[w]	M	–	–	171	171	38	81	18.00	67-70
Bengal	M	187	171	161	175	36	84	20.00	68-74

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

[y] 1996 data are from six locations, Rice Research and Extension Center (RREC), Stuttgart; Pine Tree Branch Experiment Station (PTBES), Colt; Northeast Research and Extension Center (NEREC), Keiser; Southeast Branch Experiment Station (SEBES), Rowher; Jackson County Farmer Field, Tupelo; and Campbell, Missouri. 1997 data are from the five locations in Arkansas. 1998 data are from RREC, PTBES, NEREC, and SEBES. Lines A and B data are from 1998 only.

[x] Line A is from the recurrent selection program for sheath blight tolerance.

[w] Line B is a short-season, medium-grain line from the cross Brazos/Tebonnet/3/PI164986-4/Nova 66//Nortai/4/Bengal.

Table 2. Data from the 1996 to 1997 Arkansas Rice Performance Trials comparing two experimental lines from Koshihikari crosses with the medium-grain check cultivar M-202.

Cultivar or line	Grain type	Yield[z] 1996	Yield[z] 1997	Yield[z] 1998	Yield[z] Mean[y]	Height	Maturity 50%HD	Kernel weight	Milling HR:TOT
		(bu/acre)				(inches)	(days)	(mg)	(%)
M202	M	151	135	135	141	39	74	20.80	64-72
RU9601099	S	173	160	133	158	39	78	18.40	65-74
RU9601096	S	169	161	138	158	36	76	18.70	61-73
Line C[x]	M	--	--	159	159	33	77	18.90	64-70

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

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

[x] Line C is a very-short-season, medium-grain line from the cross Brazos/Tebonnet/3/PI164986-4/Nova/66//Nortai/4/Bengal, with only 1998 data.

Table 3. Data from the 1997 to 1998 Arkansas Rice Performance Trials for two experimental lines and three check cultivars.

Cultivar or line	Grain type	Yield[z] 1997[y]	Yield[z] 1998	Yield[z] Mean[y]	Height	Maturity 50% HD	Kernel weight	Milling HR:TOT
		(bu/acre)			(inches)	(days)	(mg)	(%)
Line D[x]	L	155	156	155	35	91	17.20	66-71
Line E[w]	L	165	161	163	44	86	19.30	64-71
Madison[v]	L	--	141	141	34	87	16.20	64-68
Drew	L	159	157	158	45	89	15.90	65-72
Cypress	L	148	147	148	38	88	17.00	67-72

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

[y] 1997 data are from five locations, Rice Research and Extension Center (RREC), Stuttgart; Pine Tree Branch Experiment Station (PTBES), Colt; Northeast Research and Extension Center (NEREC), Keiser; Southeast Branch Experiment Station (SEBES), Rowher; and Jackson County Farmer Field, Tupelo. 1998 data are from RREC, PTBES, NEREC, and SEBES.

[x] Line D is from the cross Lemont//82CAY21/Cica 8/3/Lebonnet/CI9902//Newbonnet.

[w] Line E is from the cross PI338046/Katy.

[v] Madison data is from 1998 only.

Table 4. Number of lines in each phase for project ARK01387 in 1997.

Evaluation phase	Number of lines
Crosses	90
F_2 Space Plants	45,000
F_3 Panicle Rows Puerto Rico	8300
F_4 P Panicle Rows	3200
L & M Panicle Rows	4140
Preliminary Trials	960
Stuttgart Initial Test & Quality test	352
Uniform Regional Nursery	200
Arkansas Rice Performance Trials	72
Preliminary Seed Increases	8
Breeder Head Rows	7

FENOXAPROP + SAFENER (AEF046360) FOR WEED CONTROL IN RICE

F.L. Baldwin, T.L. Dillon, R.E. Talbert, and L.A. Schmidt

ABSTRACT

A study was conducted at Lonoke to compare crop injury from applications of AEF046360 (safened Whip) to that of Whip 360 and propanil. Blanket herbicide treatments were used to maintain the test area weed free. 'Bengal' rice, a cultivar known to be susceptible to fenoxaprop, was seeded. Water management, nitrogen (N) application practices, and rice growth stages known to increase fenoxaprop injury were used where possible. Rice grain yields were 146, 192, and 190 bu / acre for labeled rates of Whip 360, AEF046360, and propanil respectively. Also in the study, 2X rates of the two herbicides were compared. Where Whip 360 was applied at 0.08 lb / acre to 2- to 3-leaf (lf) rice, followed by 0.133 lb / acre applied preflood, the rice yield was 67 bu / acre. Where the same equivalent rates of fenoxaprop were applied, at the same timings as AEF046360, rice yield was 186 bu / acre, which was equivalent to that of the propanil standard.

A weed control study also was conducted at Stuttgart to determine if there were any differences in weed control between applications of Whip 360 and AEF046360. At 42 days after treatment (DAT), percent barnyardgrass (ECHCG) control was 95 and 90 for Whip 360 and AEF046360, respectively. Also at 42 DAT, percent control of bearded sprangletop (LEPFA) was 95 and 95 for Whip 360 and AEF046360, respectively. The AEF046360 will be marketed under the trade name of "Ricestar". These studies indicate that Ricestar has the same weed control potential as Whip 360 but without the potential crop injury.

INTRODUCTION

Fenoxaprop was found to be an effective herbicide for controlling grass weeds in rice by R.J. Smith, Jr., and others in the 1980s. In Dr. Smith's research at that time, an early application of propanil followed by a preflood application of fenoxaprop, became the standard for comparing annual grass control programs. It was also found that several factors could influence the selectivity of fenoxaprop to rice. These included: rice cultivar, growth stage, nitrogen fertilization, how early the flood was applied, amount of sunlight, and temperature. While research was promising, combinations of these factors often led to severe rice injury in grower fields after fenoxaprop became a commercial product. Lawsuits often resulted, and fenoxaprop (Whip 360) became a very limited herbicide used primarily for salvage control of sprangletop. In 1997, AgrEvo introduced a "safener" for Whip 360, HOE 122006, which was tested on a very limited basis in university research programs. Preliminary results with Whip 360 + HOE 122006 indicated a remarkable reduction in rice injury, with little or no loss in weed control, compared to Whip 360 alone. Research was expanded in Arkansas in 1998. For 1998, the HOE 122006 "safener" was formulated with Whip 360 as AEF046360.

PROCEDURES

In 1998, an experiment was conducted at the University of Arkansas - Pine Bluff farm near Lonoke to compare the effects of the safened and standard formulation of Whip 360 on rice injury and yield. The experiment was a randomized complete block with four replications. The plot size was 10 ft x 20 ft. Standard seedbed preparation practices had been used in the spring and the soil left hard packed by land planing and rainfall. The final seedbed was prepared making two passes with a field cultivator. Bengal, a rice cultivar known to be susceptible to fenoxaprop, was drill-seeded into each plot with a four-foot-wide experimental plot drill. Only four feet of rice was seeded in each 10-ft plot. Mixed fertilizer, 0-26-26 (i.e., % N-% phosphorus $[P]_2$oxygen $[O]_5$-% potassium $[K]_2O$) and ammonium sulfate at 300 lb / acre and 100 lb / acre, respectively, was applied prior to final seedbed preparation. An application of 18-46-0 at 100 lb / acre was applied and flushed in prior to applying any postemergence herbicide treatments. Urea was applied preflood and at midseason. Facet at 0.25 lb active ingredient (ai)/ acre was applied as a delayed preemergence treatment for grass control. The test was maintained weed free so that only the effects on the rice would be studied. Herbicide treatments were applied with a carbon dioxide (CO_2) backpack sprayer delivering 10 gallons per acre (GPA). Treatments included two applications of propanil (Super Wham) as a standard, Super Wham applied to 2- to 3-lf rice followed by the Whip formulation applied preflood, and two rates of the two Whip formulations applied to 2- to 3-lf rice and repeated preflood. Rice injury was estimated visually and yields were taken with a JD 4435 combine modified for plot harvesting.

A study at Stuttgart was conducted to compare the activity of equivalent rates of the two Whip formulations on barnyardgrass (ECHCG), including propanil resistant barnyardgrass, and bearded sprangletop (LEPFA). Normal seedbed preparation practices were used. The experiment was a randomized complete block with four replications. Plot size was 6 ft x 20 ft. 'Drew' rice was drill-seeded (7-inch row spacing). Treatments were applied with a CO_2 backpack sprayer delivering 15 GPA. The two treatments compared were Whip 360 at 0.04 lb ai / acre applied to 2- to 3-lf rice followed by Whip 360 at 0.067 lb ai / acre applied preflood; and AEF046360 at 0.08 lb ai / acre applied to 2- to 3-lf rice followed by AEF046360 at 0.133 lb / acre applied preflood. The AEF046360 rates appear to be twice those of the Whip 360. However, 50% of the AEF046360 is Whip 360, and 50% is safener. Therefore, the same active rates of fenoxaprop (as Whip 360) are being compared in each case. A propanil treatment followed by propanil standard was also included.

RESULTS AND DISCUSSION

Data for the study at Lonoke are presented in Table 1. There was little to no visual injury in the Super Wham and Super Wham followed by Whip 360 and AEF046360 treatments. However, rice yields were significantly higher where Super Wham was followed by AEF046360 compared to the same treatments with Whip 360. In other research with Whip 360 through the years, yield decreases have been reported where no visual injury could be observed. Comparing the split applications of the two formulations where 0.04 lb active fenoxaprop was applied to 2- to 3-lf rice followed by 0.067 lb ai/acre preflood, early visual injury was 25% with the Whip 360 vs. 0 for the AEF046360. Rice yields were 146 bu/acre from plots receiving Whip 360 vs. 192 bu/acre where only the AEF046360 was used. The most dramatic differences were with the 2X rates. Initial rice injury ratings after the second Whip 360 application was 91% injury vs. 0 injury where AEF046360 was used. Rice yields were 61 bu/acre in the Whip 360 plots vs. 186 bu/acre in the AEF046360 plots. In this study, using a known susceptible cultivar (Bengal) and making applications earlier, and under fertility and moisture conditions known to enhance Whip injury, no injury or yield reductions occurred in any of the AEF046360 plots.

In the weed control study at Stuttgart (Table 2), equal weed control was observed with both formulations. This was also noted in some observation plots at Lonoke that are not reported in detail here. The large increases in rice yields, with no reduction in weed control with the AEF046360 formulation vs. Whip 360 observed in the research reported here, is consistent with results reported by Dr. Bill Williams at the Louisiana State University Northeast Experiment Station.

SIGNIFICANCE OF FINDINGS

This research was funded primarily by the Rice Promotion Board. AgrEvo also supported the project, however, it is the Rice Promotion Board funds that make the overall program possible. AEF046360 will be sold under the trade name of Ricestar. Based upon the results of these studies, the State of Arkansas applied for a Section 18 exemption for Ricestar to be used on rice in 1999. A federal label is anticipated for the year 2000. Whip has always had excellent potential as a grass herbicide in rice, however, the excessive injury potential has caused it not to be used. The Ricestar formulation has the potential to be used on large acreages of rice for grass control, especially around susceptible crops such as cotton, soybeans, and tomatoes. It provides excellent control of broadleaf signalgrass, barnyardgrass, and sprangletop, yet has no activity on any broadleaf crop plants. Ricestar will need to be used in a program with other herbicides for broadleaf weed and sedge control.

Table 1. A comparison of various treatments with Whip 360 and AEF046360 on rice injury and yield at Lonoke in 1998.

Treatment	Rice injury[z]	Rice injury[y]	Rice injury[x]	Rice injury[w]	Rice yield
(lb ai/acre)	(%)				(bu/acre)[v]
Super Wham, 4.0, 2-3 lf fb Super Wham, 4.0, preflood	0	0	0	1	190
Super Wham, 4.0, 2-3 lf fb Whip 360, 0.067, preflood	0	1	0	9	167
Super Wham, 4.0 2-3 lf fb AEF046360, 0.133, preflood	0	0	0	0	187
Whip 360, 0.04, 2-3 lf fb Whip 360, 0.067, preflood	28	25	15	15	146
AEF046360, 0.08, 2-3 lf fb AEF046360, 0.133, preflood	0	0	0	0	192
Whip 360, 0.08, 2-3 lf fb Whip 360, 0.133, preflood	50	91	85	66	61
AEF046360, 0.16, 2-3 lf fb AEF046360, 0.27, preflood	3	0	0	0	186
LSD$_{(0.05)}$					20

[z] 10 days after 2-3 lf timing application.
[y] 14 days after preflood application.
[x] 30 days after preflood application.
[w] 55 days after preflood application.
[v] A bushel of rice weighs 45 lb.

Table 2. A comparison of various treatments with Whip 360 and AEF046360 on barnyardgrass and bearded sprangletop control.

Treatment	ECHCG control[z]	ECHCG control[y]	LEPFA control[x]	LEPFA control[y]	Rice yield
	(%)				(bu/acre)[w]
Whip 360, 0.04, 2-3 lf fb Whip 360, 0.07, preflood	97	95	99	95	144.5
AEF046360, 0.08, 2-3 lf fb AEF046360, 0.13, preflood	94	90	98	95	142.3
Propanil, 4.0, 2-3 lf fb propanil, 4.0, preflood	75	41	92	90	98.0
LSD$_{(0.05)}$					93

[z] 9 days after 2-3 lf timing application.
[y] 42 days after preflood application.
[x] 17 days after preflood application.
[w] A bushel of rice weighs 45 lb.

RESPONSE OF SOYBEAN, COTTON, GRAIN SORGHUM, AND TOMATO TO SIMULATED DRIFT OF BISPYRIBAC

R. Bevitori and R. Talbert

ABSTRACT

Comparisons were made on the response of soybean, cotton, grain sorghum, and tomato to simulated drift rates of bispyribac (0.22, 2.2, and 22 g active ingredient [ai]/ha). Plant response to this herbicide was evaluated in the greenhouse at the Arkansas Agricultural Research and Extension Center, Fayetteville. Tomato was very sensitive to herbicide drift; soybean showed some recovery after three weeks (wk); and sorghum and cotton were less affected by bispyribac drift. There was very little response by even the most sensitive crops, tomato and soybean, to the lowest rate of 0.22 g/ha (100X the proposed labeled rate).

INTRODUCTION

Herbicide drift is a problem in many areas, especially when herbicides are applied with airplanes under windy conditions or other environmental conditions that favor redeposition. This off-target herbicide drift can damage surrounding crops. Damage to crops from drift depends on many factors including plant species, growth stage, environmental conditions, herbicide formulation, droplet size, and the spray height above the ground (Miller, 1993). Recent developments of drift retardants have helped to reduce the potential for the herbicide drift, but it may still occur (Wolf *et al.*, 1992).

Bispyribac-sodium (sodium 2,6-bis [4,6-dimethoxypyrimidim 2-yl]) benzoate is a postemergence herbicide being developed for rice at the proposed rate of 22 g ai/ha. The trade name is "Regiment". It can control barnyardgrass (*Echinochloa crus-galli*), junglerice (*Echinochloa colonum*), watergrass (*Echinochloa oryzoides*), hemp sesbania (*Sesbania exaltata*), Indian (*Aeschynomene indica*) and northern jointvetch (*Aeschynomene virginica*), purple ammannia (*Ammannia coccinea*), waterhyssop (*Bacopa rotundifolia*), alligatorweed (*Alternanthera philoxeroides*), riceflatsedge (*Cyperus iria*), gooseweed (*Sphenoclea zeylandica*), ricefield bulrush (*Scirpus mucronatus*), prickly sida (*Sida spinosa*), dayflower, purslane (*Portulaca oleracea*), and falsepimpernel (*Lindernia anagallidea*). In Arkansas, soybean, cotton, grain sorghum, and tomato are grown in close proximity to rice fields. Application of bispyribac will be done aerially and will usually coincide with early growth of these crops.

The objective of this research was to investigate the response of soybean, cotton, grain sorghum, and tomato to labeled and simulated drift rates of bispyribac.

PROCEDURES

The experiment was conducted in a greenhouse. Eight seeds of each crop were planted in a flat tray (14x25x8 cm) containing Sunshine Mix and then watered. After germination, each crop was thinned to four plants. Herbicide treatments were made on 28 September 1998 when the seedlings were in the 3- to 4-leaf (lf) stage. Plants were treated with bispyribac in a spray chamber using low volume (94 l/ha). The herbicide rates were 0, 0.22, 2.2, and 22 g ai/ha, corresponding to 0, 1/100th, 1/10th, and 1X the proposed label rate for bispyribac. Crop injury symptoms were evaluated one, two, and three wk after application using a 0 to 100% injury rating scale, where 0 = no visible effect, and 100 = complete crop kill. The treatments were arranged in a split plot as randomized complete block with four replications for each treatment. The main plot was the dosage, and the subplots were the plant species. Statistical analysis was performed using SAS.

RESULTS AND DISCUSSION

Tomato was most affected by bispyribac at drift rates. Herbicide injury on tomato increased with increasing rate of application (Fig. 1). In the first week, tomato had slight leaf discoloration. In the second week, the rate of 0.22 g/ha caused wilted tomato leaves, however, plants treated at the lowest rate (0.22 g/ha) successfully recovered from injury. At the highest rate (22 g/ha), tomato showed necrosis in the leaves. By the third week, tomato showed moderate to severe stunting and necrosis injury, depending on herbicide rate. Tomato had not recovered from the high rate after three wk. At the 2.2 g/ha rate, tomato showed reduction in growth and necrotic leaves and recovery of tomato was doubtful. The highest rate (22 g/ha) caused necrosis on the tomato leaves. Terminal and lateral growth ceased and death of shoot tips and young leaves occurred at this rate.

Herbicide injury on soybean increased with increasing rate of application (Fig. 2). The highest rate (22 g/ha) caused necrosis in the veins of soybean. At the first week, soybean leaves had some discoloration. Leaves were chlorotic, crinkled, stunted, and distorted and necrotic in the veins at the 2.2 g/ha rate. The yellow leaves were more intense at higher than the lowest rate. Also, there was some necrosis in the stem that subsequently caused the stem to become brittle. At two wk, the plants continued to show significant herbicide injury. However, soybean was recovering by three wk after being treated with 2.2 g/ha.

The lowest rate (0.22 g/ha), caused some slight leaf chlorosis to cotton (Fig. 3). There was not a significant increase in injury to cotton with increasing rate of application, nor was there increasing injury to cotton over a three-wk period.

Sorghum was not affected by the lowest rate (Fig. 4). At the rate of 2.2 g/ha, bispyribac caused slight chlorotic leaves in the sorghum. Over a three-wk period, there was an increase in injury to sorghum only at the full rate (22 g ai/ha), however, at lower doses there was little or no effect.

The most sensitive crops to bispyribac were tomato and soybean. Sorghum was slightly affected and cotton was fairly tolerant. This study demonstrated that bispyribac spray drift may cause injury in tomato and soybean. There were no severe symptoms in sorghum and cotton.

SIGNIFICANCE OF FINDINGS

Bispyribac spray drift may cause injury in tomato and soybean. This finding should be considered when applying bispyribac where tomato and soybeans are growing nearby. Further field studies on the response of crops to bispyribac drift rates are planned for 1999.

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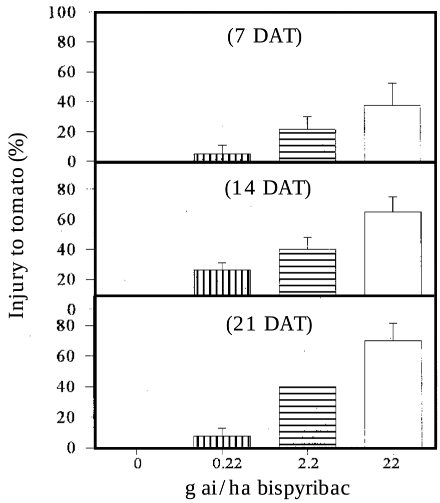

Fig. 1. Injury to tomato as affected by drift rates of bispyribac at 7,14, and 21 days after treatment (DAT). Error bar represents standard deviation.

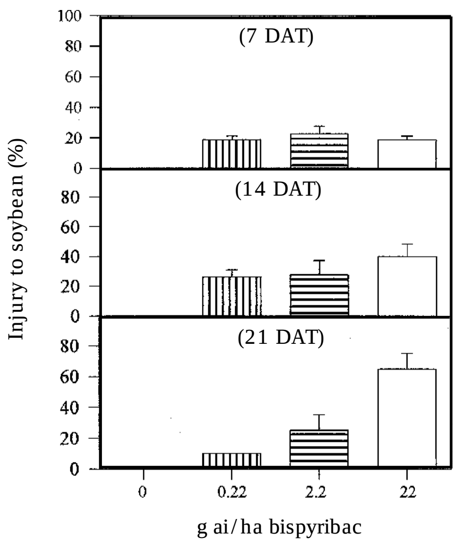

Fig. 2. Injury to soybean as affected by drift rates of bispyribac at 7,14, and 21 days after treatment (DAT). Error bar represents standard deviation.

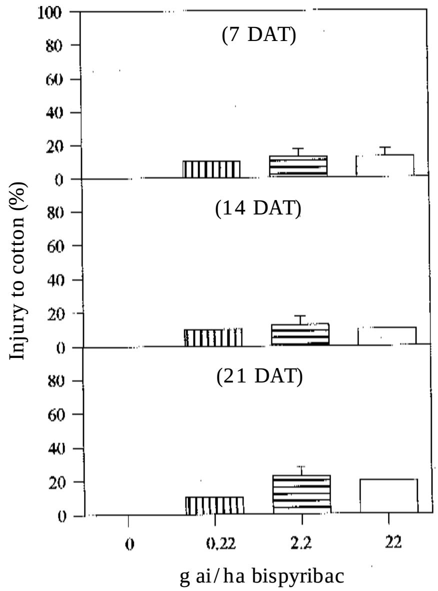

Fig. 3. Injury to cotton as affected by drift rates of bispyribac at 7,14, and 21 days after treatment (DAT). Error bar represents standard deviation.

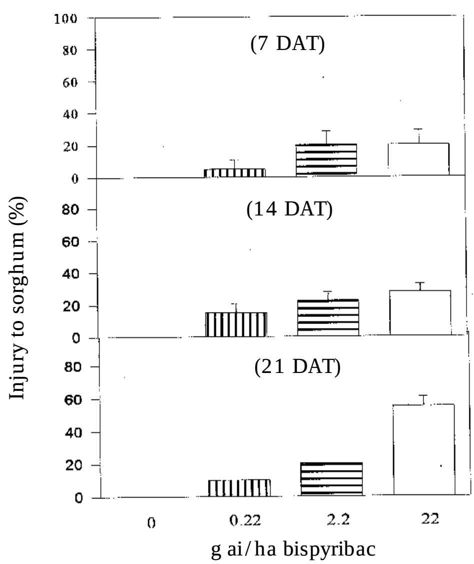

Fig. 4. Injury to sorghum as affected by drift rates of bispyribac at 7,14, and 21 days after treatment (DAT). Error bar represents standard deviation.

RESPONSE OF BARNYARDGRASS TO SELECTED SUPPRESSIVE RICE CULTIVARS IN A REPLACEMENT SERIES STUDY

R.S.C. Chavez and D.R. Gealy

ABSTRACT

A replacement series was established using T65*2 / TN 1 (PI312777), PI312777 x Lemont (2884-30-11), and 'Lemont' rice cultivars / lines. The different rice types did not affect individual plant height and tiller number of barnyardgrass during the first 30 days after emergence (DAE). At 45 DAE and onwards, PI 312777 significantly reduced barnyardgrass tiller number. Relative shoot (vegetative) yield curves based on dry weight indicated that PI312777 suppressed barnyardgrass growth to a greater extent than did the other rice types. Lemont was not suppressive to barnyardgrass. The cross between Lemont and PI312777 showed an intermediate response between the two parents.

INTRODUCTION

The rice variety PI312777 (T65*2 / TN 1) has been reported to naturally suppress ducksalad (*Heteranthera limosa* [Sw.] Willd.) (Dilday *et al.*, 1991, 1994) and barnyardgrass (*Echinochloa crus-galli* [L.] Beauv.) in drill-seeded rice field studies (Gealy *et al.*, 1996, 1998a, 1998b). In all these studies, suppression was attributed to allelopathic interaction but the necessary validation of an allelopathic interference is still lacking (Fuerst and Putnam, 1983; Olofsdotter *et al.*, 1995). Elucidation of the mechanism(s) by which this variety suppresses barnyardgrass is important in the use of rice germplasm as an additional tool in controlling economically important weeds in drill-seeded rice.

Even though the method has some shortcomings, the replacement series has been extensively used in characterizing interactions in many plant interference studies. This method does not validate the existence of an allelopathic interaction, but it could provide a glimpse of the extent of interference occurring between two species in a mixture. This preliminary study was conducted to determine how a naturally suppressive rice variety and its cross with a non-suppressive cultivar would affect the interactions between rice and barnyardgrass in a replacement series.

PROCEDURES

A replacement series consisting of 0:4, 1:3, 2:2, 3:1, and 4:0, rice:barnyardgrass plants per pot, was established using PI312777, PI312777 x Lemont (2884-30-11), and the rice cultivar Lemont. Pots (32.5 cm diameter) were laid out in a randomized complete block design with treatments factorially arranged and replicated three times. A total rate of 150 kg nitrogen (N) (as urea)/ ha was split-applied in each pot. Plant heights and tiller counts were determined at 15, 30, 45, 60, and 108 DAE. At harvest, all the plants were cut at the soil surface, separated by species, and oven dried for 96 hours at 50°C. Shoot dry weights were taken and used for calculations of relative vegetative yields. Relative yield for each species at each mixture proportion was expressed as the shoot dry weight per pot of the species in mixture divided by the shoot dry weight per pot of the species in monoculture.

RESULTS AND DISCUSSION

The different rice types did not affect individual plant height (Fig. 1) and tiller number (Table 1) of barnyardgrass during the first 30 DAE. Plant height was not as sensitive to competition as were the other growth parameters. Only a slight reduction in barnyardgrass plant height (7 to 10%) occurred when it was grown with the PI312777 x Lemont cross. Since the pots were placed 1 m apart, light resource capture was not a determining factor in this study. At 45 DAE and onwards, PI 312777 significantly reduced barnyardgrass tiller number. Averaged across the density combinations, barnyardgrass tillering was reduced 14 to 30% by PI312777 and 10 to 18% by the PI312777 x Lemont cross, compared to competition with Lemont plants. The adverse effect of PI312777 on barnyardgrass growth was apparent only after 30 days of growing in association with each other. This lag time is important in characterizing the nature of this suppression and should be explored further.

On an individual plant basis, barnyardgrass plants growing in association with Lemont were able to accumulate an average of 58% higher dry matter weight than when barnyardgrass was grown in monoculture. When grown in association with the cross (PI312777 x Lemont), 10% more dry matter was accumulated. On the other hand, when barnyardgrass was grown in association with PI312777, 19% reduction in total plant weight occurred.

Regression analysis indicates that there was a significant quadratic relationship between density and shoot dry weight for both rice and barnyardgrass (Fig. 2). The shape of the curve has been used as an indicator of the extent of interference between the two associated species. Two straight lines indicate equivalency of interference (i.e. both species are equally 'competitive') while concave and convex lines indicate that one species gained more resources at the expense of the other. When barnyardgrass was grown together with Lemont, resource capture favored barnyardgrass growth at the expense of rice growth. In contrast, when barnyardgrass was grown with PI312777, rice growth was favored at the expense of barnyardgrass. Barnyardgrass growth suppression was evident with PI312777. The cross between PI312777 and Lemont showed an almost equivalent interference which was an intermediate response between the two parents. The relative total shoot yield curves (Fig. 3) depicted the same trends. The non-suppressive rice cultivar Lemont shifted the intersection between the two lines to the right of the intersection of the linear lines of equivalency. This indicated that even at the ratio where rice density is three times greater than barnyardgrass, the Lemont plants were not able to capture resources to favor rice growth. On the other hand, the suppressive variety PI312777 shifted the intersection to the left of the linear lines of equivalency. This implies that with a density as low as 1 rice to 3 barnyardgrass, PI312777 suppressed barnyardgrass growth.

SIGNIFICANCE OF FINDINGS

Although these graphic illustrations do not confirm the mechanism of interference, they show that rice germplasm can be exploited to provide weed suppression. Another implication is that some or all of the characteristics that enabled PI312777 to suppress barnyardgrass growth, were genetically transferred to the PI312777 x Lemont cross. Our findings suggest that there is strong justification for increased effort in breeding and selection for development of weed suppressive rice cultivars, and for further investigation into elucidation and characterization of the nature of suppression by these cultivars against major weeds in rice.

ACKNOWLEDGMENT

This research was partially funded by the rice producers' check-off funds through the Arkansas Rice Research and Promotion Board.

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Table 1. Barnyardgrass tiller production as affected by different rice cultivar/varieties (averaged across density combinations).

Rice cultivar/variety	Days after planting 15	30	45	60	108
	------------- (no. tillers per barnyardgrass plant) ----------------				
Lemont	3.4	23.2	18.5	25.0	26.0
PI312777 x Lemont	2.8	19.9	16.6	22.5	23.6
PI312777	2.9	19.1	14.3	17.5	16.0
LSD $_{(0.05)}$	NS[z]	NS	3.2	3.3	5.0

[z]Not significant.

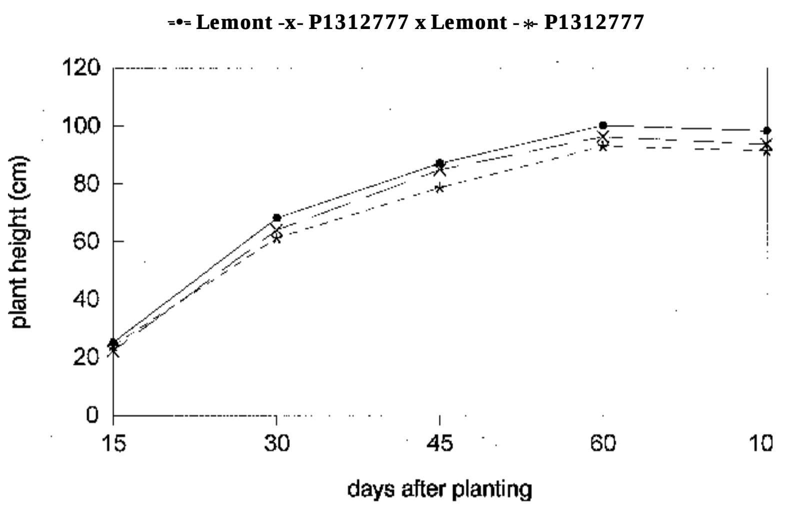

Fig. 1. Barnyardgrass plant height as affected by different rice cultivar/varieties (averaged across density combinations, LSD [0.05] = 6.3, 7.0, and 5.9 at 45,60, and 108 days after planting, respectively). To convert height values to inches, divide number by 2.54.

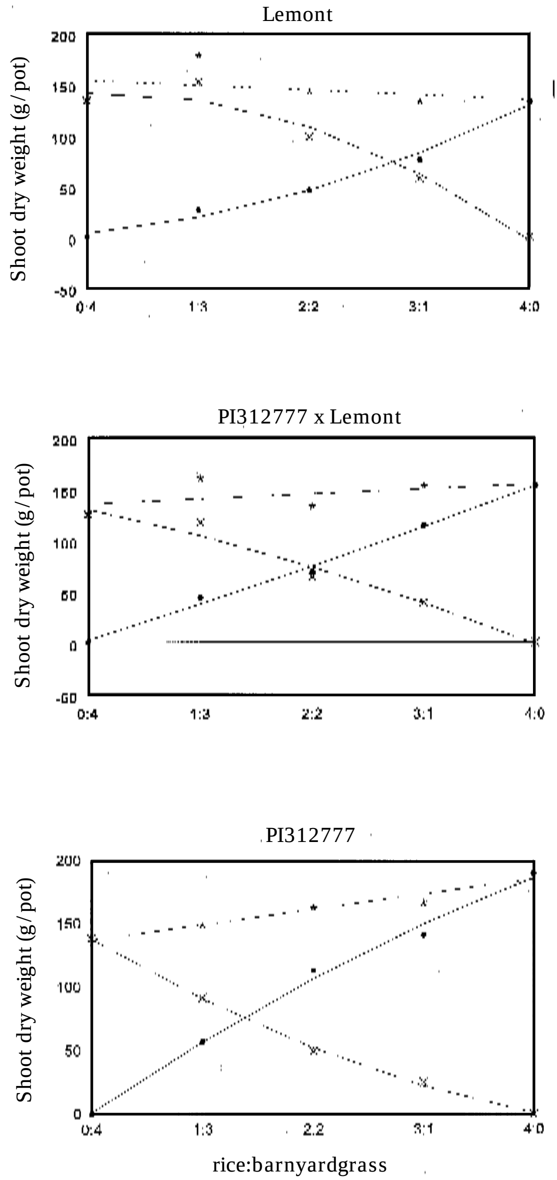

Fig. 2. Shoot dry weight (g/pot) of rice types and barnyardgrass in a replacement series (where x = density of species in the combination).

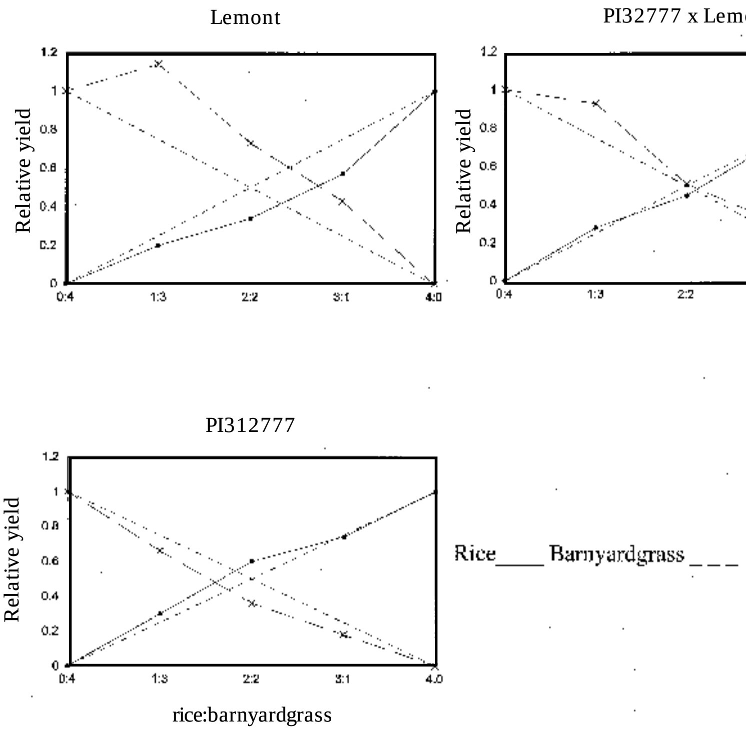

Fig. 3. Relative shoot yield of rice and barnyardgrass as affected by different rice cultivars/varieties. Small dashed diagonal lines for each species between 0 and 1.0 intersecting at 2:2 depict the linear lines of equivalency.

REDUCED PROPANIL RATES AND NATURALLY SUPPRESSIVE CULTIVAR/ VARIETIES FOR BARNYARDGRASS CONTROL IN DRILL-SEEDED RICE

R.S.C. Chavez, D.R. Gealy, and H.L. Black

ABSTRACT

Field studies were conducted to evaluate the weed suppressive abilities of four U.S. cultivars and three foreign rice cultivar/varieties, and to analyze the economic benefit of reduced propanil rates. Yields generally increased, and weed biomass at harvest decreased with increasing propanil rate. PI312777 consistently suppressed barnyardgrass and consequently produced higher grain yield with or without propanil application. Economic benefit of using propanil on PI312777 was marginal. Grain yields of 'Starbonnet', 'Lemont', 'Cypress', 'Kaybonnet', and 'Guichow' quadratically decreased with increasing weed biomass at harvest. In all types, except PI312777, propanil application (regardless of rate) resulted in a marginal benefit cost return (MBCR) of 4.4 or more, indicating that propanil application was beneficial. Marginal returns decreased as propanil rate increased for Lemont, Starbonnet, and Guichow. The naturally weed suppressive PI312777, 'Teqing', and Guichow produced higher grain yields than cultivars Starbonnet, Kaybonnet, Lemont, and Cypress.

INTRODUCTION

Propanil is the standard herbicide used for the control of a wide array of grasses, and broadleaf and aquatic weeds in southern U.S. rice production, and is usually applied at 3 to 5 lb active ingredient (ai)/acre. Propanil does not provide residual control, and weed reinfestation may occur (Smith, 1988a) which may necessitate a second application. At least one application of propanil is applied to about 98% of the rice acreage in Arkansas (Carey *et al*., 1995). Barnyardgrass (*Echinochloa crus-galli* [L.] Beauv.) is the most common and troublesome of the 70 weed species that infest direct-seeded rice (Chandler, 1981; Smith, 1988b; Smith *et al*., 1977). The development of propanil resistant populations in Arkansas rice farms (Baltazar and Smith, 1994; Carey *et al*., 1995) prompted studies on alternative methods of controlling barnyardgrass. Previous work with naturally suppressive varieties indicate that certain rice accessions in the U.S. rice germplasm World Collection can reduce the number and partially inhibit the growth of barnyardgrass (Dilday *et al*., 1998). This inhibition resulted in about 20% increase in grain yield among varieties that were reported to be suppressive in contrast to non-suppressive cultivars (Dilday *et al*., 1998). This study was conducted to evaluate the weed suppressive abilities of four U.S. cultivars and three foreign rice varieties, and analyze the economic benefit of reduced propanil rates in conjunction with suppressive types.

PROCEDURES

Field studies were conducted in 1995, 1996, and 1998 at the University of Arkansas Rice Research and Extension Center, Stuttgart. Inherent suppressive abilities of four U.S. rice cultivars (Lemont, Cypress, Kaybonnet, and Starbonnet) and three foreign varieties (Teqing and Guichow from China and T65*2/TN 1 [PI312777] from the Philippines) were evaluated. All of these were included in the 1995 and 1996 trials, but only Lemont, Kaybonnet, and PI312777 were evaluated in 1998. Single postemergence applications of propanil at 1.12 (1/4 X), 2.24 (1/2 X), or 4.48 (1X) kg ai/ha were applied in 1995 and 1996. These rates correspond to 1, 2, and 4 lb ai/acre, respectively. In 1998, 3.36 (X) and 5.6 (1X) kg ai/ha were also evaluated. These rates correspond to 3 and 5 lb ai/acre, respectively. Untreated and unseeded (no rice) plots were included for comparison. A split-plot design with propanil rates as main plots and rice cultivar/varieties as subplots, was used in this study. Each treatment was replicated four times. Rice was drill-seeded in nine rows (18 cm apart) by 3 m long. The middle five rows x 2 m were harvested for grain yield. Standard cultural practices for the area were adopted. Plots were fertilized with a one time preflood application of 112 nitrogen (N) kg/ha as urea. The plots were over-seeded with barnyardgrass after the rice was seeded. Bentazon was applied at 1.12 kg ai/ha for general broadleaf weed control on an as needed basis. MBCR analysis was also done to evaluate the benefit of reduced propanil rates in conjunction with weed suppressive varieties. The MBCR was computed as the incremental value divided by the incremental cost. Incremental value was the difference in value of the average grain yield for a given propanil rate and the value of the average grain yield in the untreated plots. Incremental cost was the difference in the cost between a given propanil rate and the cost without propanil application. The cost of producing rice without propanil application was assumed to be $734.25 per ha ($297.15/acre) for silt loam soils of Arkansas. This was based on the 1999 budget estimates for cost of production as put forth by the Arkansas Cooperative Extension Service. The price of propanil was assumed at $19 per gallon. The price of rough rice was assumed at $ 9.31/cwt based on the average national price from 1995 to 1998.

RESULTS AND DISCUSSION

Problems with establishing a consistent uniform population of barnyardgrass occurred across years even though the area was overseeded with barnyardgrass. Generally, in untreated plots there were fewer weeds at harvest in 1996 and 1998 than in 1995 (Fig. 1). In unseeded plots, primary species also included bearded sprangletop (*Leptochloa fascicularis* [Lam.] Gray) which dominated the weed population at rice harvest. Averaged across years, grain yields generally increased (Table 1) and weed biomass at harvest decreased with increasing propanil rate on the two rice cultivars. Averaged across propanil rates, grain yields were generally higher in 1996 and 1998 than in 1995 (Table 2). Without propanil application, rough rice yields decreased in the following order: PI312777 > Guichow > Teqing > Kaybonnet > Lemont > Cypress > Starbonnet (data not shown). Grain yields of Starbonnet, Lemont, Cypress, Kaybonnet, and Guichow quadratically decreased with increasing weed biomass at harvest (Fig. 2). Excellent weed control throughout the season for these cultivars is essential in achieving maximum yield potential. PI312777 and Teqing did not exhibit this quadratic relationship indicating that these two types suppressed weeds throughout the season and maintained high grain yields even in untreated plots.

Economic analysis (Table 3) showed that all entries (except PI312777) had a MBCR of 4.4 or more indicating that propanil application was beneficial for these cultivars. With the naturally suppressive variety PI312777, marginal returns were negative at 1/4 and 1/2X rates of propanil, indicating that no additional yield benefit was realized with the application of these rates of propanil. PI312777 consistently suppressed barnyardgrass and consequently produced higher grain yield with or without propanil application. Economic benefit of using propanil on PI312777 was marginal, and propanil probably was not needed depending on the initial weed pressure early in the season.

Highest actual and marginal returns differed among cultivars. Application of 2.24 kg ai (1/2X) propanil/ha resulted in the highest marginal and actual returns for Kaybonnet and Teqing. Marginal returns decreased as propanil rate increased for Lemont, Starbonnet and Guichow. Lemont, Starbonnet and Guichow were very responsive to propanil application and the highest MBCR for these cultivars was observed at the 1/4X rate of propanil. However, high values of marginal return do not always translate to higher actual returns. The naturally suppressive foreign varieties, such as PI312777, Teqing, and Guichow, produced higher yields thereby resulting in higher actual returns compared to the cultivars Starbonnet, Kaybonnet, Lemont, and Cypress. However, grain quality characteristics of the foreign types tested generally are unacceptable for the U.S. rice industry at the present time, and actual value per unit of yield would be considerably less. Unless grain quality can be improved substantially, the true actual returns from growing these foreign types in Arkansas would be somewhat less than we have indicated.

SIGNIFICANCE OF FINDINGS

Results indicate that the choice of cultivar is critical in achieving maximum returns from use of propanil. MBCR can be a useful tool in evaluating the optimum rate of propanil to apply, once the choice of cultivar has been made. The use of weed suppressive rice varieties coupled with reduced herbicide rates could be an economically profitable and an environmentally sound weed management strategy if suitable types can be developed.

ACKNOWLEDGMENT

This research was partially funded by rice producers' check-off funds through the Arkansas Rice Research and Promotion Board.

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Table 1. Grain yield (kg/ha)[z] of different rice cultivar/varieties as affected by propanil rate (averaged across years).

Propanil rate	Grain yield Kaybonnet	Lemont	PI312777
	----- (kg/ha) -----		
0X	5357	4784	7320
1/4X	5741	5805	7263
1/2X	6603	5715	7117
1X	6448	6309	7610

[z] To convert grain yields to lb/acre, divide numbers by 1.12.

Table 2. Grain yield (kg/ha)[z] of different rice cultivar/varieties averaged across propanil rates.

Cultivar/variety	Grain yield 1995	1996	1998
	----- (kg/ha) -----		
Starbonnet	3291	5520	-
Cypress	3900	6679	-
Teqing	5415	7949	-
Guichow	6221	8972	-
Lemont	2733	7178	7151
Kaybonnet	3451	6744	7790
PI312777	6090	7410	8509
$LSD_{(0.05)}$		318.7	

[z] To convert grain yields to lb/acre, divide numbers by 1.12.

Table 3. Economic analysis of reduced propanil rates in conjunction with weed suppressive rice varieties.

Cultivar	Propanil rate	Cost/ha	Yield	Yield	Cost increase	Value increase	MBCR	Returns
		($)	(kg/ha)	-------------------- ($/ha) --------------------				($/ha)
Lemont	0X	734.25	4784	980.12				245.86
Lemont	1/4X	745.98	5805	1189.30	11.72	209.18	17.84	443.32
Lemont	1/2X	757.71	5715	1170.86	23.45	190.74	8.13	413.15
Lemont	1X	785.03	6309	1292.56	50.77	312.43	6.15	507.53
Kaybonnet	0X	734.25	5357	1097.52				363.26
Kaybonnet	1/4X	745.98	5741	1176.19	11.72	78.67	6.71	430.21
Kaybonnet	1/2X	757.71	6603	1352.79	23.45	255.27	10.89	595.08
Kaybonnet	1X	785.03	6448	1321.03	50.77	223.52	4.40	536.01
PI312777	0X	734.25	7320	1499.69				765.43
PI312777	1/4X	745.98	7263	1488.01	11.72	-11.68	-1.00	742.03
PI312777	1/2X	757.71	7117	1458.10	23.45	-41.59	-1.77	700.39
PI312777	1X	785.03	7610	1559.10	50.77	59.41	1.17	774.07
Guichow	0X	734.25	6773	1387.62				653.36
Guichow	1/4X	745.98	7877	1613.80	11.72	226.18	19.29	867.82
Guichow	1/2X	757.71	7512	1539.02	23.45	151.40	6.46	781.31
Guichow	1X	785.03	8223	1684.69	50.77	297.07	5.85	899.66
Teqing	0X	734.25	5928	1214.50				480.24
Teqing	1/4X	745.98	6337	1298.29	11.72	83.79	7.15	552.31
Teqing	1/2X	757.71	7403	1516.69	23.45	302.19	12.89	758.98
Teqing	1X	785.03	7311	1497.84	50.77	283.34	5.58	712.81
Starbonnet	0X	734.25	3519	720.96				-13.3
Starbonnet	1/4X	745.98	4464	914.56	11.72	193.61	16.51	168.58
Starbonnet	1/2X	757.71	4769	977.05	23.45	256.09	10.92	219.34
Starbonnet	1X	785.03	4870	997.74	50.77	276.79	5.45	212.71
Cypress	0X	734.25	4727	968.44				234.19
Cypress	1/4X	745.98	5034	1031.34	11.72	62.90	5.36	285.36
Cypress	1/2X	757.71	5402	1106.73	23.45	138.29	5.90	349.03
Cypress	1X	785.03	5995	1228.23	50.77	259.78	5.12	443.20

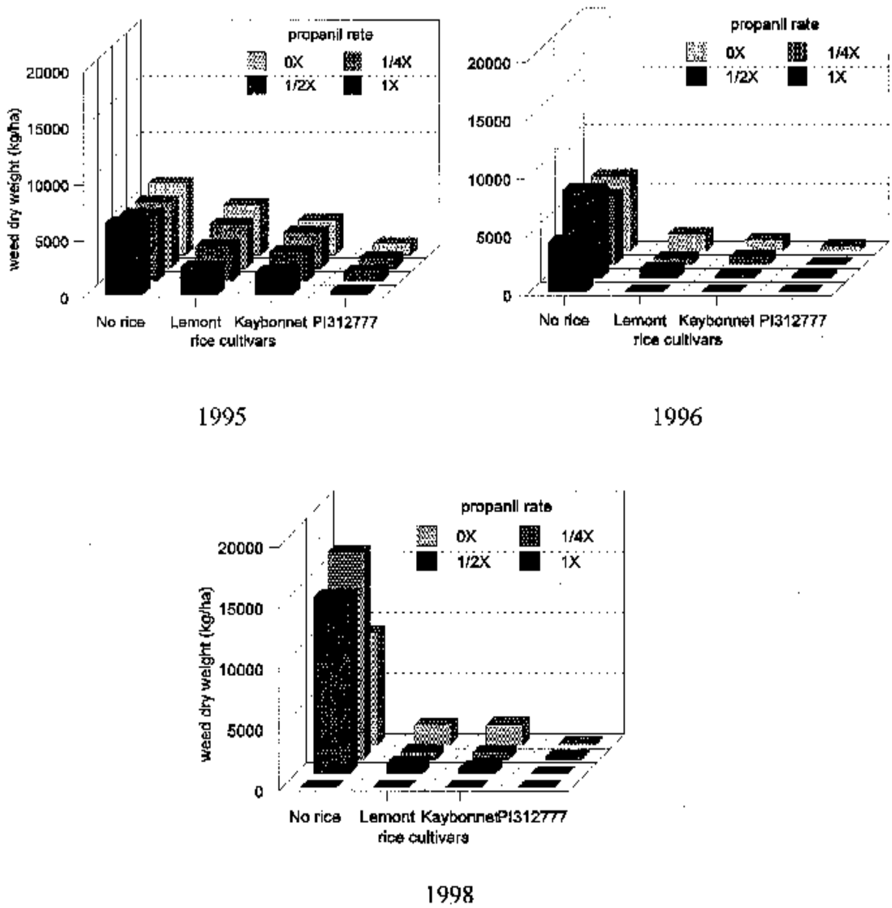
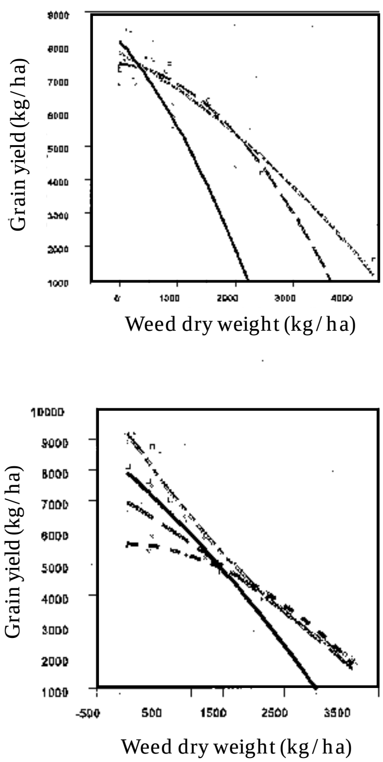


Fig. 1. Total weed dry weight (kg/ha) at harvest as affected by propanil rates and rice cultivars. To convert weed dry weights to lb/acre, divide numbers by 1.12.



Kaybonnet __ $Y=7496-0.8x-.0004x^2$, $R^2 = 0.9$
Lemont ------ $Y=7810-.96x-.0001x^2$, $R^2=0.96$
PI312777___ $Y=8166-2.02x-.0005x^2$, $R^2=0.79$

Cypress __ $Y=6995-1.24x-.0007x^2$, $R^2 = 0.95$
Starbonnet ------ $Y=5683-0.13x-.00026x^2$, $R^2=0.98$
Guichow____ $Y=89234-2.97x-0.00026x^2$, $R^2=0.93$
Teqing___ $Y=7491-1.82x-0.00016x^2$, $R^2=0.59$

Fig. 2. Relationship between grain yield and total weed dry weight at harvest as affected by rice cultivars. Data in the top graph are averages from 1995, 1996, and 1998. Data from the bottom graph are averaged from 1995 and 1996 only. To convert grain yields and weed dry weights to lb/acre, divide numbers by 1.12.

CONTROL OF YELLOW NUTSEDGE AND OTHER DIFFICULT WEEDS IN IMIDAZOLINONE-TOLERANT RICE

T.L. Dillon, R.E. Talbert, and F.L. Baldwin

ABSTRACT

The ability to control yellow nutsedge in rice is becoming increasingly more difficult. With fewer producers rotating fields to other crops, the need to control difficult weeds in rice has become top priority. A solution to this problem could be herbicide tolerant rice cultivars that allow use of more effective herbicides that are not currently available in rice. A study using drill-seeded, imidazolinone-tolerant rice was conducted near Lodge Corner, which compared imazethapyr to several standard treatments for control of yellow nutsedge. Imazethapyr was shown to be very promising for yellow nutsedge control in rice. The 0.063 lb / acre sequential applications provided the most consistent control of yellow nutsedge. Red rice and other weeds at this site were also controlled. Imazethapyr was effective when applied at various application timings and tank-mixed with many popular rice herbicides.

INTRODUCTION

Yellow nutsedge (*Cypreus esculentus*) has become an increasing problem for Arkansas rice (*Orzya sativa*) producers over the past decade. Yellow nutsedge was cited as being the third most troublesome weed in Arkansas rice, following red rice and barnyardgrass in 1992 (Weed Science Society of America, 1992). Nutsedges are relatively short in height (10 to 80 cm) but can be very competitive and can reduce rice yields. Reported losses varied due to the density of yellow nutsedge, soil types and conditions, location, and / or duration of competition. However, it has been reported that 150 to 750 plants / m^2 can reduce rice yields from 2 to 59% (Keeley, 1987) by competing for nutrients, moisture, and light (Okafor and De Datta, 1976).

Although the yellow nutsedge plant produces seed, the primary means of propagation is through the production of an extensive network of underground tubers formed on rhizomes. A single yellow nutsedge plant can produce up to 300 tubers each year (Wright *et al.*, 1997). These tubers can remain dormant in the soil for several years before sprouting and producing new plants (Holt, 1997). Also, each yellow nutsedge tuber may sprout several times before exhausting its energy supply (Stroller, *et al.*, 1972; Thullen and Keeley, 1975; Patterson *et al.*, 1980). Since it is a marsh plant, yellow nutsedge also has the ability to withstand the rice flood, which is a common way of controlling many weeds in this crop. Few labeled herbicides are effective for control of yellow nutsedge in rice. This is why small patches of yellow nutsedge in some fields enlarge and often infest several acres or entire fields. With the new imidazolinone-tolerant rice cultivars becoming available, imazethapyr was evaluated for yellow nutsedge control. This study, conducted in 1998, evaluated various standard and experimental herbicides and herbicide combinations for yellow nutsedge control in rice.

PROCEDURES

A privately owned area near Lodge Corner has been made available for university and industry research purposes. This area is separate from the grower field and provides an excellent area for weed control studies. The plot area had been tilled and land planed early in the spring of 1998. A solid stand of emerged yellow nutsedge plants 3 inches tall was tilled prior to preplant herbicide application by making one pass with a field cultivator equipped with s-tine shanks and rolling baskets. Preplant incorporated (PPI) treatments were applied with a backpack carbon dioxide (CO_2) sprayer with a hand-held, six-nozzle wet boom calibrated to deliver 10 gallons of spray per acre. The experimental design was a randomized complete block with four replications and individual plot size was 10 ft by 20 ft. The preplant incorporated treatments were incorporated immediately following application by making two passes with a field cultivator set to operate 2 inches deep at a speed of 7 miles per hour.

Rice was seeded on 24 April 1998 with a Hege small plot drill with 7-inch row spacings. The total drill width of rice was 49 inches in the 10 ft plot. The imidazolinone-tolerant rice variety, 93AS3510, was drilled to a depth of 0.25 inches at a rate of 100 lb / acre and preemergence (PRE) treatments were applied. The soil was extremely dry in the seed zone, so the area was flushed with irrigation water later that same day. Rainfall of 2.0 inches occurred on 26 and 27 April. The study was flushed again 2 May. Rice was slow to germinate due to the prolonged period of saturated soil. Rice seedlings emerged 6 May. After the rain 26 April, no rain occurred until after harvest. The study was flushed again 13 May due to lack of adequate moisture. Early postemergence (POST) treatments were applied to 2- to 3-leaf (lf) rice 18 May and the area was flushed again 20 May. Preflood treatments were applied 28 May and were followed by a preflood fertilizer application (90 lb / acre nitrogen [N]) made 1 June. The permanent flood was established 3 June. The midseason fertilization consisted of a split application of 30 lb / acre nitrogen each, made 30 June and 7 July.

Visual ratings of percent control of the various weed species and percent crop injury were made throughout the rice growing season. The rice was harvested 11 August with a Yanmar CA 105 plot combine cutting a 28-inch swath from the center of each plot. Weights were recorded, grain samples from each plot were pooled by treatment across the replications and graded by Riceland Foods personnel located in Lonoke.

The standard treatment in this study was a sequential application of propanil plus bensulfuron applied at 2- to 3-lf rice stage and again at preflood. Comparison treatments also included clomazone preemergence followed by application of halosulfuron to 2- to 3-lf rice and also followed by several preflood treatments including halosulfuron, propanil plus bensulfuron, and molinate / propanil plus bentazon.

RESULTS AND DISCUSSION

Weed pressure was intense, with yellow nutsedge densities being 30 plants per square foot. Imazethapyr treatments were very effective in controlling yellow nutsedge (Table 1). Yellow nutsedge was flowering and easily observed in the rice canopy 11 days after the preflood treatment. The 0.063 lb / acre rate of imazethapyr PPI provided 85% control, as compared to the standard treatment of propanil 2 lb / acre + bensulfuron 0.5 oz / acre applied on 2- to 3-lf rice and repeated preflood, which provided 95% control. Clomazone PRE followed by halosulfuron applied at the 2- to 3-lf stage of rice also provided 95% control of yellow nutsedge. Imazethapyr 0.063 lb / acre PPI followed by halosulfuron preflood provided 98% control of yellow nutsedge. The sequential applications of the 0.063 lb / acre rate of imazethapyr provided 100% control of yellow nutsedge.

By 20 July the entire study area was overgrown in many other weed species including red rice (*Orzya sativa*), sprangletop (*Leptochloa* spp.), barnyardgrass (*Echinochloa crus-galli*), ducksalad (*Heteranthera limosa*), and roundleaf mudplantain (*Heternathera reniformis*). The imazethapyr plots remained relatively free of weeds, and were easily identified from a distance. Imazethapyr at 0.063 lb / acre applied to 2- to 3-lf rice and imazethapyr at 0.063 lb / acre applied sequentially were the only treatments that provided greater than 90% control of red rice and sprangletop. Both of these treatments provided 100% control of barnyardgrass and mudplantain, and 73% and 90% control of ducksalad, respectively (Table 2). The most consistent red rice control was achieved with the sequential applications of imazethapyr (Table 3).

The current imidazolinone tolerant rice variety, 93AS3510, is a short-season experimental variety and has a low yield potential. Due to bird damage and shattering, a delayed harvest caused rice yields to be low.

SIGNIFICANCE OF FINDINGS

Imazethapyr provided effective control of yellow nutsedge, as well as a variety of other weed species, in this study. Incorporation of imazethapyr could save a flushing to activate the herbicide. The residual control of imazethapyr may also allow a rice producer a wider window for timing the postemergence application. The PPI treatment followed by a postemergence application provided the most consistent control of yellow nutsedge. With two applications, the chance of misses or streaks in application can be reduced.

Imazethapyr has the potential to become a very important herbicide in rice weed control. The ability to control yellow nutsedge as well as red rice in rice will give the producers more flexibility in many aspects of farm management.

ACKNOWLEDGMENTS

Funding was provided by the Rice Research and Promotion Board and American Cyanamid Company.

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Table 1. Imazethapyr and standard treatments for yellow nutsedge control in imidazolinone-tolerant rice at Lodge Corner, 1998.

Treatment	Rate	Timing[z]	Yellow Nutsedge Control[y]
	(kg ai/ha)		(%)
Untreated check			0
Imazethapyr 2 EC	0.070	PPI	85
Imazethapyr 2 EC	0.070	PRE	44
Imazethapry 2 EC	0.070	2-3 lf rice	91
Imazethapyr 2 EC fb carfentrazone 40 DF	0.070 fb 0.022	PPI fb 2-3 lf rice	85
Imazethapyr 2 EC fb imazethapyr 2 EC	0.070 fb 0.070	PPI fb PREFLD	100
Imazethapyr 2 EC fb halosulfuron 75 WG	0.070 fb 0.053	PPI fb PREFLD	98
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb 2-3 lf rice	95
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb PREFLD	75
Clomazone 3 CS fb molinate/propanil 6 EC + bentazon	0.45 fb 6.72 + 0.84	PRE fb PREFLD	90
Clomazone 3 CS fb propanil + bensulfuron	0.45 fb 4.48 + 0.043	PRE fb PREFLD	84
Propanil 4 EC + bensulfuron 60 WG fb	3.36 + 0.021 fb	2-3 lf rice fb	
Propanil 4 EC + bensulfuron 60 WG	3.36 + 0.021	PREFLD	95

[z] PPI = preplant incorporated; PRE = preemergence; 2-3 lf rice = 2- to 3-leaf rice; PREFLD = preflood.
[y] Ratings 11 days after preflood treatments were applied.

Table 2. Imazethapyr and standard treatments for weed control in imidazolinone-tolerant rice at Lodge Corner, 1998.

			Weed control[z]				
Treatment	Rate	Timing[y]	Yellow nutsedge	Barnyard-grass	Sprangle-top	Mud-plantain	Duck-salad
	(kg ai/ha)		----	----	(%)	----	----
Untreated check			0	0	0	0	0
Imazethapyr 2 EC	0.070	PPI	96	73	98	98	66
Imazethapyr 2 EC	0.070	PRE	45	18	80	90	70
Imazethapry 2 EC	0.070	2-3 lf rice	100	100	90	100	73
Imazethapyr 2 EC fb carfentrazone 40 DF	0.070 fb 0.022	PPI fb 2-3 lf rice	98	84	91	91	84
Imazethapyr 2 EC fb imazethapyr 2 EC	0.070 fb 0.070	PPI fb PREFLD	100	100	100	100	90
Imazethapyr 2 EC fb halosulfuron 75 WG	0.070 fb 0.053	PPI fb PREFLD	100	73	93	65	70
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb 2-3 lf rice	100	59	90	18	33
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb PREFLD	100	63	89	85	63
Clomazone 3 CS fb molinate/propanil 6 EC + bentazon	0.45 fb 6.72 + 0.84	PRE fb PREFLD	100	100	100	48	30
Clomazone 3 CS fb propanil + bensulfuron	0.45 fb 4.48 + 0.043	PRE fb PREFLD	100	100	98	88	90
Propanil 4 EC + bensulfuron 60 WG fb propanil 4 EC + bensulfuron 60 WG	3.36 + 0.021 fb 3.36 + 0.021	2-3 lf rice fb PREFLD	84	91	84	75	58

[z] Ratings 43 days after preflood treatments were applied.

[y] PPI = preplant incorporated; PRE = preemergence; 2-3 lf rice = 2- to 3-leaf rice; PREFLD = preflood.

Table 3. Red rice control, rice yield, % red rice in a grain sample and grade of sample, Lodge Corner.

Treatment	Rate	Timing[z]	Red rice[y]	Yield	% Red rice	Grade[x]
	(kg ai/ha)		(%)	(lb/acre)	(% in sample)	
Untreated check			0	900	26	5
Imazethapyr 2 EC	0.070	PPI	81	1440	1	1
Imazethapyr 2 EC	0.070	PRE	20	960	18	5
Imazethapry 2 EC	0.070	2-3 lf rice	98	1860	1	1
Imazethapyr 2 EC fb carfentrazone 40 DF	0.070 fb 0.022	PPI fb 2-3 lf rice	70	1980	2	1
Imazethapyr 2 EC fb imazethapyr 2 EC	0.070 fb 0.070	PPI fb PREFLD	94	2160	0	1
Imazethapyr 2 EC fb halosulfuron 75 WG	0.070 fb 0.053	PPI fb PREFLD	65	2040	1	1
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb 2-3 lf rice	0	2220	11	5
Clomazone 3 CS fb halosulfuron 75 WG	0.45 fb 0.053	PRE fb PREFLD	0	1800	10	5
Clomazone 3 CS fb molinate/propanil 6 EC + bentazon	0.45 fb 6.72 + 0.84	PRE fb PREFLD	0	1980	34	5
Clomazone 3 CS fb propanil + bensulfuron	0.45 fb 4.48 + 0.043	PRE fb PREFLD	8	1800	16	5
Propanil 4 EC + bensulfuron 60 WG fb propanil 4 EC + bensulfuron 60 WG	3.36 + 0.021 fb 3.36 + 0.021	2-3 lf rice fb PREFLD	0	2040	13	5

[z] PPI = preplant incorporated; PRE = preemergence; 2-3 lf rice = 2- to 3-leaf rice; PREFLD = preflood.
[y] Ratings 43 days after preflood treatments were applied.
[x] Grade: scale of 1 (free of red rice seed) to 5 (unacceptable amounts of red rice seed).

ONGOING STUDIES: PEST MANGEMENT: WEEDS

RESPONSE OF RED RICE ECOTYPES AND RICE CULTIVARS TO DIFFERENT POPULATION DENSITIES

L.E. Estorninos, Jr., D.R. Gealy, and R.E. Talbert

ABSTRACT

In 1998, two field experiments were conducted at the Rice Research and Extension Center, Stuttgart, to evaluate the growth response of 1) the 'Kaybonnet' rice cultivar to four population densities of three red rice ecotypes, and 2) Stuttgart strawhull red rice to four seeding densities of three rice cultivars. In Experiment I, red rice leaf area index (LAI) at 70 days after emergence (DAE) was 36% higher at 36 lb / acre red rice seeding rate than at 23 lb / acre red rice. Also at 70 DAE, LAI of domestic rice was at least 29% lower when grown with 36 lb / acre red rice compared to when grown alone. Panicle density of Stuttgart strawhull and LA3 was higher than that of 'KatyRR' red rice. Yield of Kaybonnet was reduced by 76% when infested with Stuttgart strawhull and 94% when with LA3. KatyRR was less competitive than Stuttgart strawhull and LA3.

In Experiment II, red rice LAI was at least 29% higher when grown alone than when grown with domestic rice. Red rice panicle density decreased by 47% when grown with the rice cultivar and decreased by 28% as domestic rice seeding rate increased from 45 to 89 lb / acre. Stuttgart strawhull panicle density was lower by 21% when grown with PI 312777 as compared to being grown with Kaybonnet. When infested with red rice, yield of domestic rice was higher at the 134 lb / acre seeding rate than at the 45 lb / acre seeding rate of domestic rice, but did not differ among rice cultivars. Stuttgart strawhull red rice lodged at the flowering stage of domestic rice which also pulled down the rice. This probably contributed to the reduced yield of the three cultivars.

INTRODUCTION

Domestic rice and red rice are morphologically similar (Hoagland and Paul, 1978) and belong to the same species, *Oryza sativa* L. However, red rice is considered to be a weed because it generally grows taller and produces more tillers than domestic rice, most of its seeds shatter early, and it reduces the quality of commercial rice by contaminating the grains and milled rice (Diarra *et al.*, 1985a), and it contaminates the land with shattered grains (Smith, 1981).

Rice yield loss depends on the variety of domestic rice and the density and ecotype of red rice ecotypes. Diarra *et al.* (1985b) reported that five red rice plants / m^2 reduced grains / panicle of cultivated rice by 18% and 215 red rice plants / m^2 reduced this value by 70%. Kwon *et al.* (1992) found that yield of 'Lemont', a short-statured rice cultivar, was reduced by 90% with 35 red rice plants / m^2, while that of 'Newbonnet', a taller rice cultivar, was only reduced by 67% with 40 red rice plants / m^2. Despite the continuous effort to control red rice, problems continue to persist. There is a need, therefore, to fully understand the red rice biology and ecology to be able to adequately address this problem. The objectives of this study were to evaluate the growth response of 1) Kaybonnet rice cultivar to four population densities of three red rice ecotypes, and 2) Stuttgart strawhull red rice to four population densities of three rice cultivar / varieties.

MATERIALS AND METHODS

In 1998, two types of experiments were conducted at the Rice Research and Extension Center, Stuttgart. Each experiment was laid out in a split plot design with four replications. In Experiment I, main plots were the red rice ecotypes, Stuttgart strawhull (Stgstraw-a prominent, awnless red rice in Arkansas), 'Katy strawhull' (KatyRR-a short-statured, suspected hybrid of Katy rice and a red rice biotype), and LA3 (tall and awned ecotype from Louisiana). The subplots were red rice seeding rates of 0 (domestic rice alone), 12, 23, and 36 lb / acre. Kaybonnet was the standard rice cultivar and was sown at 89 lb / acre in plots nine 7-inch drill rows 20 ft in length. In Experiment II, the main plots were the rice cultivars, Kaybonnet (popular commercial cultivar), 'Guichow' (high yielding, Chinese cultivar with possible competitiveness against weeds), and PI 312777 (T65*2 / TNI; a possible allelopathic variety from the USDA World Rice Collection). Subplots were domestic rice seeding rates of 0, 45, 89, and 134 lb / acre. Stgstraw red rice was sown at 24 lb / acre. In both experiments, red rice was broadcast-seeded while domestic rice was drill-seeded with a commercial grain drill. A roller was pulled across plots parallel to drill rows immediately after seeding to bury the seeds and compact the soil.

Growth and development of red rice and domestic rice were determined in both studies. Panicle density was determined from two 2.7-ft^2 quadrants / plot at harvest. At 4, 7, 10, and 13 weeks after emergence (WAE), leaf area of 10 subsampled plants was measured and dry weight was determined for growth analyses. Domestic rice yield was determined by harvesting samples by hand from a 15.1-ft^2 area per plot. Fifteen red rice panicles from the 15.1 ft^2 were bagged at the hard dough stage to prevent losses from early shattering and to improve accuracy of red rice yield estimates. Red rice panicles were harvested by hand. Grain from panicles was weighed and adjusted to 12% moisture. This value was multiplied by the number of panicles counted from 15.1-ft^2 domestic rice sampling area and adjusted to red rice seed yield in lb / acre.

RESULTS AND DISCUSSION

Experiment I. Average leaf area index of red rice, when grown with Kaybonnet domestic rice increased with red rice seeding rate until 70 DAE but decreased after this time (Fig. 1). At 70 DAE, LAI of red rice seeded at 36 lb / acre was higher than when seeded at 12 lb / acre red rice. Leaf area index of Kaybonnet domestic rice increased over time until 70 DAE (Fig. 2). At 70 DAE, average LAI of domestic rice was lower when grown with red rice than when grown without red rice.

Panicle density of LA3 and Stgstraw was higher than that of KatyRR (Fig. 3). Panicle density of Sgtstraw was equal to that of LA3. There was a tremendous growth of LA3 and Sgtstraw such that the yield of Kaybonnet rice was reduced by 48% or more (Fig. 4). LA3 reduced the yield of Kaybonnet rice more than did Stgstraw. At 36 lb / acre red rice seeding rate, the yield of Kaybonnet rice was almost zero. KatyRR reduced the yield of Kaybonnet rice by 28 to 48% with 12 to 36 lb / acre red rice seeding rate.

Experiment II. There was a rapid vegetative growth and high tillering of red rice when planted alone such that LAI was 29 to 46% higher than when grown together with domestic rice (Fig. 5). At 70 DAE, red rice LAI was 50% higher when grown at the lowest seeding rate of domestic rice (45 lb / acre) compared to that from the highest seeding rate (134 lb / acre). However, LAI of domestic rice was not affected significantly until 70 DAE when infested with red rice (Fig. 6). At 91 DAE, leaf area index of domestic rice at the lowest rice seeding rate was 49% lower than that with the highest seeding rate. Red rice panicle density was highest when grown alone and was reduced by 47% when grown with domestic rice (Fig. 7). Panicle density of Stgstraw was higher when grown with Kaybonnet than when grown with PI 312777. Panicle density of Sgtstraw, when grown with Guichow, did not differ from that of Kaybonnet or PI 312777 at any of the seeding rates tested. Kaybonnet yield was generally low, probably due to more competition from red rice. Also, 95 to 100% of Stgstraw lodged at the flowering stage which also pulled down all the domestic rice plants. The yield did not differ significantly among the rice cultivars (Fig. 8). Yield of domestic rice was increased at the highest rice seeding rate as compared to the lowest rice seeding rate.

SIGNIFICANCE OF FINDINGS

The Kaybonnet rice cultivar and Stgstraw red rice behaved differently when planted alone and when in competition with each other. The LA3 red rice ecotype reduced the yield of Kaybonnet rice more than did Stgstraw. The red rice, KatyRR, was much less competitive compared to Kaybonnet than the more vigorous Sgtstraw and LA3 red rice ecotypes. Therefore, the strategy for dealing with each of these ecotypes would be somewhat different. PI 312777 reduced panicle density of Stgstraw more than did Kaybonnet, indicating that it interfered more with the growth of the red rice. This specific trait could help reduce red rice infestations and potentially could allow for reduced herbicide rates. There is a need to study further the possible allelopathic activity of PI 312777 against red rice.

ACKNOWLEDGMENT

This research was funded in part by rice producer's check-off contributions through the Arkansas Rice Research and Promotion Board. Special thanks are extended to Mr. Howard Black and Ms. Keena Taylor for their invaluable help.

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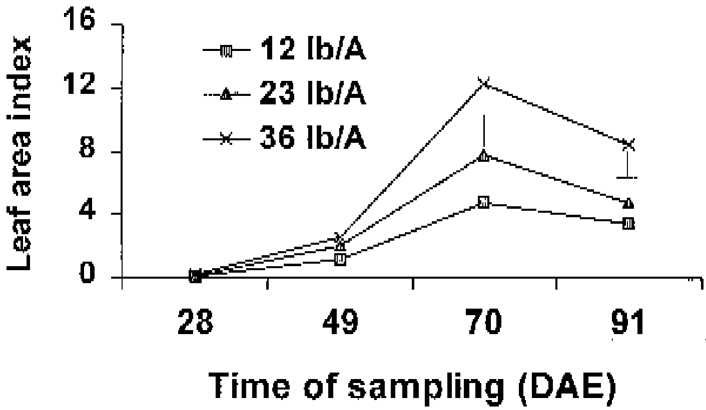

Fig. 1. Red rice LAI as influenced by red rice seeding rate, Stuttgart, 1998. (Average of three red rice ecotypes and four reps.)

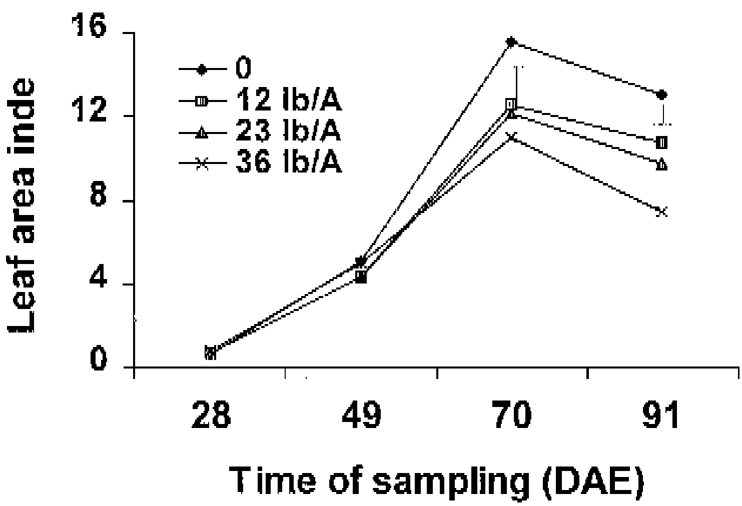

Fig. 2. Kaybonnet rice LAI as influenced by red rice seeding rate, Stuttgart, 1998. (Average of three red rice ecotypes and four reps.)

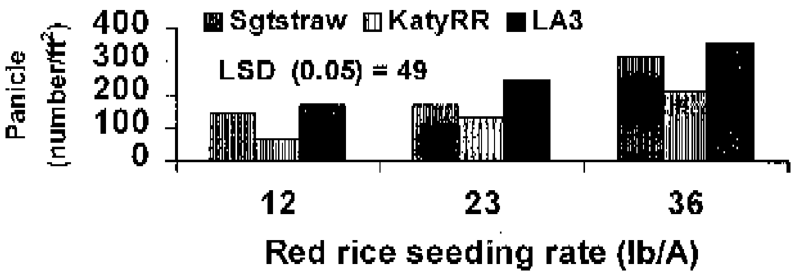

Fig. 3. Red rice panicle density as influenced by red rice seeding rate, Stuttgart, 1998. (Average of four reps.)

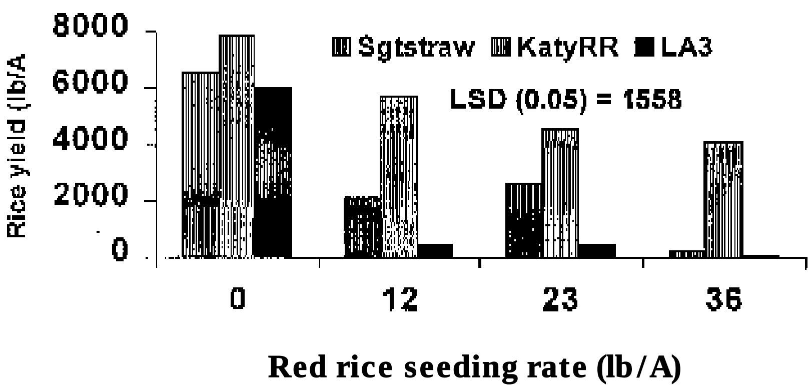

Fig. 4. Kaybonnet rice yield as influenced by red rice seeding rate, Stuttgart, 1998. (Average of four reps.)

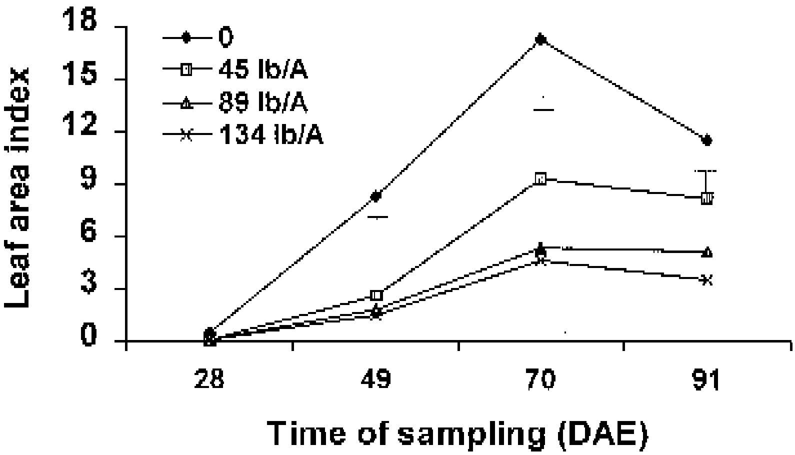

Fig. 5. Stgstraw red rice LAI as influenced by domestic rice seeding rate, Stuttgart, 1998. (Average of three rice cultivars and four reps.)

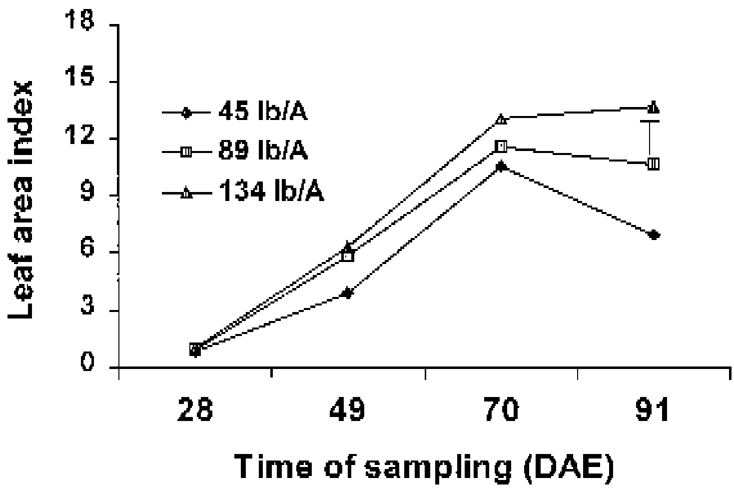

Fig. 6. Domestic rice LAI in competition with Sgtstraw red rice (23 lb/A) as influenced by rice seeding rate, Stuttgart, 1998. (Average of three rice cultivars and 4 reps.)

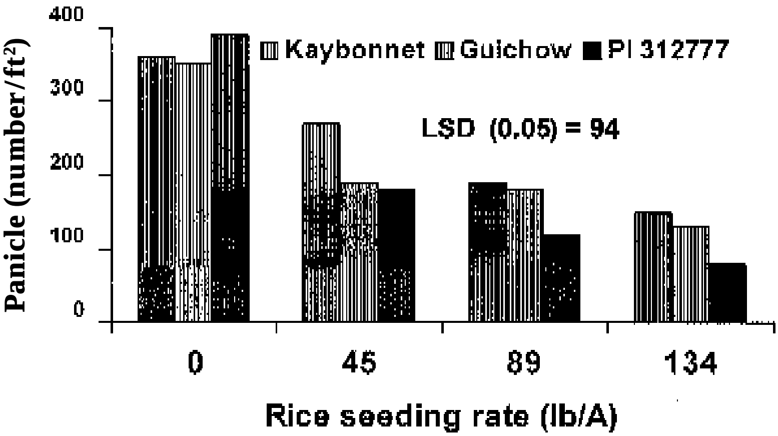

Fig. 7. Stgstraw red rice panicle density as influenced by domestic rice seeding rate, Stuttgart, 1998. (Averag of four reps.)

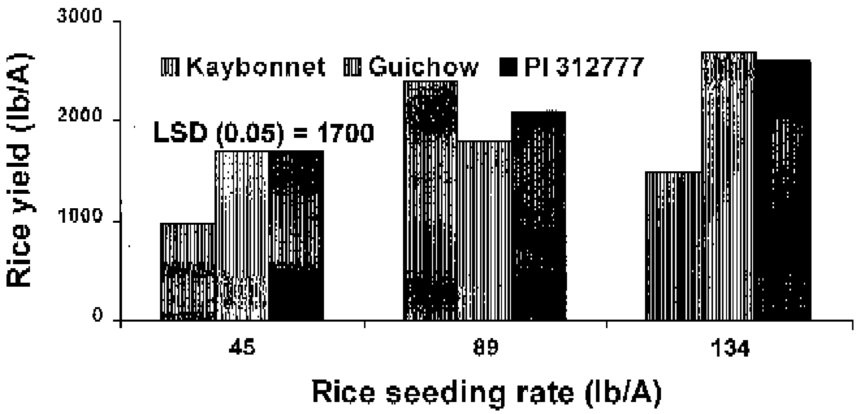

Fig. 8. Domestic rice yield in competition with Stgstraw red rice, Stuttgart, 1998. (Average of four reps.)

ONGOING STUDIES: PEST MANAGEMENT: WEEDS

GERMINATION, GROWTH, AND PHOTOSYNTHESIS RESPONSE OF RED RICE (*Oryza sativa* L.) BIOTYPES TO CHILLING TEMPERATURE

D.R. Gealy and H.L. Black

ABSTRACT

Experiments were conducted in growth chambers to assess tolerance of either chilling stress or flooding stress among a large number of red rice biotypes. In the first experiment, red rice germination was most dramatically inhibited at 13°C (55°F) and 15 cm (6 inch) water. Chilling generally inhibited germination of red rices more than white rices. The most cold-sensitive red rice biotypes were the strawhull (SH) types 4A and 20E, and the blackhull (BH) type, 5A. The least cold-sensitive biotypes were the SH types 16B and KatyRR (a rice-red rice hybrid), and the BH types 10A. In the second experiment, exposure of 3-leaf (lf) plants to 10°C (50°F) for seven days induced chlorosis in leaves and reduced growth and photosynthesis nearly to zero. A BH biotype (18E) developed the most chlorosis and an SH biotype (20E) developed the least chlorosis. Generally, BH biotypes developed more chlorosis than SH biotypes and white rice standards. Photosynthesis in chilled red rice plants was lower than in a chilling-tolerant cultivar, 'M202', but both red rice and white rice had recovered at least 50% of their optimum photosynthetic capacity within 24 hours after warming to 30/25°C (86/77°F). Overall, germination, growth, and photosynthesis of the various red rice biotypes varied greatly in response to environmental stresses, but none of the biotypes were consistently more tolerant than others to all stresses. Even so, diversity among these red rice biotypes may be enough to influence the interaction of a particular red rice biotype/management/environment setting.

INTRODUCTION

Red rice is a major problem in rice production in Arkansas and the southern United States (Deshaies, 1996), and increasingly, in temperate rice regions throughout South America and Asia. We have collected numerous biotypes of red rice from Arkansas rice fields and from other rice-producing states, and are systematically characterizing them at Stuttgart. Recent research indicated that a strawhull red rice biotype from Stuttgart emerged less vigorously than several other biotypes from soil and water in field studies (Saldain *et al.*, 1996 and 1997). Subsequently, we observed apparent differences in chilling tolerance among red rice biotypes growing in the field (Saldain *et al.*, unpublished data) and in growth chambers (Song and Gealy, unpublished data). Because chilling tolerance of a red rice biotype could be crucial to the success of that biotype under particular cultural conditions (especially deep flood water) and chilling tolerant genes from red rice could potentially be used to improve chilling tolerance in domestic rice germplasm lines, growth chamber experiments were conducted with a large number of red rice biotypes and domestic rice standards at Stuttgart to determine the effects of 1) water temperature and depth on germination of red rice and 2) chilling temperatures on growth, chlorosis, and photosynthesis of red rice.

PROCEDURES

Temperature – Water Depth Effect on Red Rice Germination

Twelve seeds each of 27 red rice biotypes (18 strawhull types and 9 blackhull types) and three domestic (white) rice standards (including 'Kaybonnet') were imbedded into the surface of Crowley silt loam soil, placed in 'cube' trays, covered to a depth of 0 (saturated) or 15 cm (6 inch) with water, and incubated in the dark at constant temperatures of 13, 18, 23, or 30°C (55, 64, 73, or 86°F). After 21 days of incubation, the number of germinated seeds was determined. The experiment was conducted as a split-plot design with depths as main plots and biotypes as subplots. The experiment was conducted two to four times at each temperature with three subsamples per experiment. Each experiment was considered to be a replication. An analysis of variance was conducted for each temperature and means were separated using least significant difference (LSD) at the 0.05 level of probability.

Chilling Temperature Effect on Growth, Chlorosis, and Photosynthesis of Red Rice Plants

Seed of the same 27 red rice biotypes and rice standards (including M202, a chilling tolerant cultivar from California) were seeded in Crowley silt loam soil in pots, and grown in an environmentally-controlled chamber for 14 days at 30/25°C (86/77°F; day/night) with 14-hour days and light intensity of 1000 µmol/m^2 s (about 50% of full sun). Three plants were present in each pot. After 14 days, when plants were at the 3- to 4-lf stage, half of the pots were moved to a 10°C (50°F) 'chilling' chamber and half remained at the original 'warm' conditions for an additional seven days until 21 days after seeding. The experiment was conducted as a split-plot design with temperature treatments as main plots and red rice biotypes as subplots. The experiment was conducted twice with three subsamples per experiment. Each experiment was considered to be a replication. An analysis of variance was conducted and means were separated using a Least Significant Difference (LSD) at the 0.05 level of probability. Average maximum plant height and relative chlorophyll content (silicon photodiode detector ['SPAD'] measurements) were determined for each biotype before and after the 7-day chilling period. At the end of the chilling period, total above ground dry weight was determined. Also at this time, 12 representative red rice biotypes and two domestic rice standards were selected for measurement of leaf photosynthesis and transpiration with an infrared gas analyzer. These parameters initially were measured on 'chilled' (10°C) plants and again after plants had been returned to the original 'warm' (30/25°C) conditions for 21 hours. To determine the rate of adaptation of plants to temperature extremes, photosynthesis of representative strawhull (13A and the red rice-rice hybrid, KatyRR), blackhull (StgB) red rice biotypes, and M202 was measured periodically for 24 hours after plants, that had been preadapted to 'cold' and 'warm' conditions, were placed into 'warm' and 'cold' chambers, respectively (i.e. plants that had been adapted to 10°C were placed at 30/25°C and plants adapted to 30/25°C were placed at 10°C).

RESULTS AND DISCUSSION

Temperature – Water Depth Effect on Red Rice Germination

Germination of red rice biotypes was most inhibited at the coldest temperature (13°C) and in deep (15 cm) water (Fig. 1). Germination at 13°C was less than 10% of the maximum at 30°C and 0 cm depth. Germination at the 15-cm depth never exceeded 40% of the maximum. Generally, sensitivity of germination to low temperature was similar among red rice biotypes. However, 4A and 20E (strawhull), and 5A (blackhull) were consistently the most inhibited biotypes; 16B and Katy RR (strawhull), and 10A (blackhull) were consistently the least inhibited biotypes; and red rice biotypes were more inhibited than domestic rice at the coldest temperatures (data not shown).

Chilling Temperature Effect on Growth, Chlorosis, and Photosynthesis of Red Rice Plants

Seven days of chilling at 10°C caused chlorosis in both red rice and domestic rice (Fig. 2). As a group, domestic rice lines had the highest relative chlorophyll values (expressed as actual SPAD value or as a percent of the initial SPAD value), strawhull red rice values were intermediate, and blackhull red rice values were lowest. Chilling apparently reduced the chlorophyll level of the strawhull type, 20E the least, and reduced the chlorophyll level of the blackhull biotype, 18E the most. The results suggest that these two biotypes are the least and most sensitive, respectively, to chilling stress. However, 20E was actually one of the most inhibited biotypes at cold temperatures in the germination experiment (Fig. 1), indicating that effects of chilling on germinating seeds and 3-lf seedlings may not necessarily be consistent among red rice biotypes. Averaged across all red rice biotypes and domestic rice standards, chilling reduced chlorophyll content 11% and allowed only 4% additional height increase compared to the pre-chilling levels (Table 1). By contrast, these values increased 9 and 41%, respectively, in nonchilled (30/25°C) plants. Biotype 10A was the most chilling tolerant (least chlorotic) blackhull type. Note that 10A was also one of the most cold tolerant biotypes in the germination experiment (Fig. 1). Surprisingly, inhibition of plant growth and chlorophyll level was not correlated among biotypes (data not shown), suggesting that the most chlorotic biotypes will not necessarily be the most stunted ones. At the end of the chilling period, photosynthesis had fallen to less than 10% of the nonchilled level, but had recovered to about 50% of the nonchilled level within 21 hours of rewarming to the original nonchilled (30/25°C) level (Table 2). Transpiration responded similarly, but was less inhibited by chilling and recovered nearly to the nonchilled levels after rewarming (Table 2). Photosynthesis of cold-adapted red rice remained near zero for three hours after rewarming to 30/25°C and increased to near nonchilled levels within 22 hours (Fig. 3). By contrast, photosynthesis of hot-adapted red rice began to decline within one hour of chilling to 10°C and had declined to less than 25% of the initial level within 22 hours. Generally, chilling reduced photosynthesis of M202 (chilling tolerant cultivar) more than that of red rice.

SIGNIFICANCE OF FINDINGS

Germination, seedling growth, and chlorosis of red rice biotypes exhibited a wide range of responses to chilling and flooding stresses. With the possible exception of the blackhull biotype 10A, none of the biotypes appear to be consistently less tolerant than others to both of these stresses. However, the diversity among these red rice biotypes is probably great enough to influence the interaction of a particular red rice biotype within a particular management or environmental setting.

ACKNOWLEDGMENTS

We thank the Arkansas Rice Research and Promotion Board for partial funding of this research and Keena Taylor for technical support.

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Table 1. Relative chlorophyll content and plant height of red rice biotypes after one-week adaptation to 30/25°C or 10°C.[z]

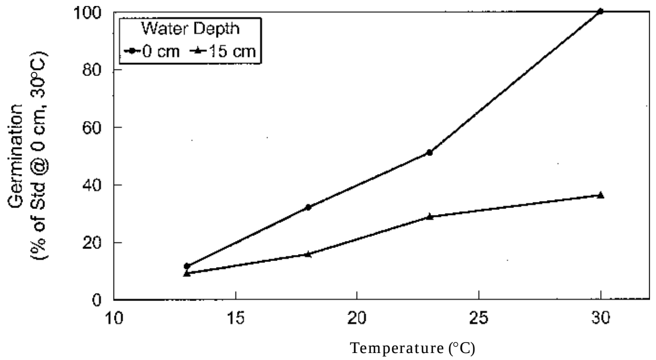
Ambient temperature	Relative chlorophyll content		Plant height	
	(SPAD value)	(% change from initial)	(cm)	(% change from initial)
30/25°C std	35	9	38	41
10°C	29	-11	28	4
LSD 0.05	1	4	2	3

[z] Initial temp: 30/25°C. Data averaged over 27 red rice types and 3 domestic rice standards.

Table 2. Adaptation of photosynthesis and transpiration of chilled red rice[z] **(10°C) to warm (30/25°C) temperatures.**

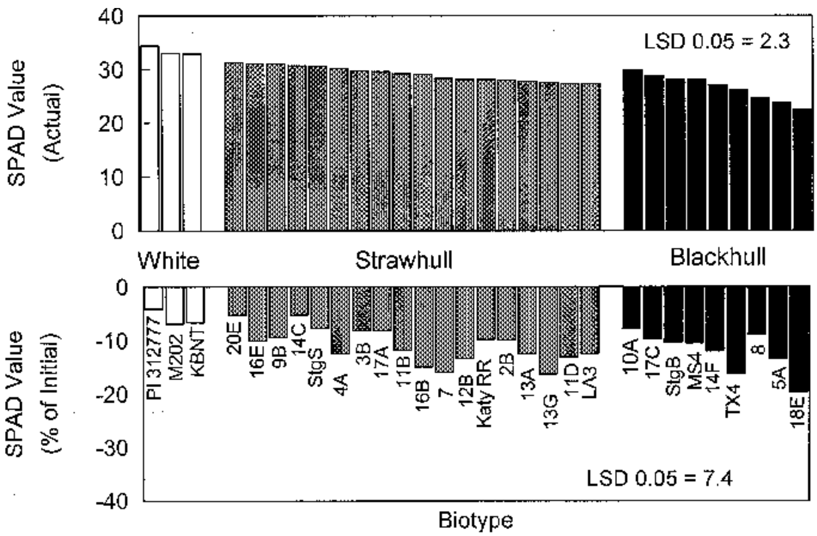
Pre-adapted temperature	Hours at new (30/25 C) temperature	Photosynthesis	Transpiration
		µmoles/m²s	mmoles/m²s
30/25°C std	0	11.1	1.9
10°C	0	0.8	0.4
LSD 0.05		1.5	0.4
30/25°C std	21	19.2	3.7
10°C	21	9.8	3.1
LSD 0.05		4.0	NS

[z]Data averaged over 10 red rice types and two domestic rice standards.



1) Most inhibited reds: 5A, 4A, 20E; Least inhibited reds: 16B, 10A, Katy RR
2) @cold temps, inhibition of reds>whites; @ 30°C, inhibition of reds<whites.

Fig. 1. Relative sensitivity of red rice and standard cultivars germination to water temperature and depth. Data points are averaged over all biotypes and rice standards.



(Note: At 30°C average, SPAD values increased 9%.)

Fig. 2. Relative chlorophyll content (SPAD value) of red rice biotypes and standard checks after chilling one week at 10°C. Values less than 0% of initial, indicate that SPAD values after chilling were lower than initial levels before chilling.

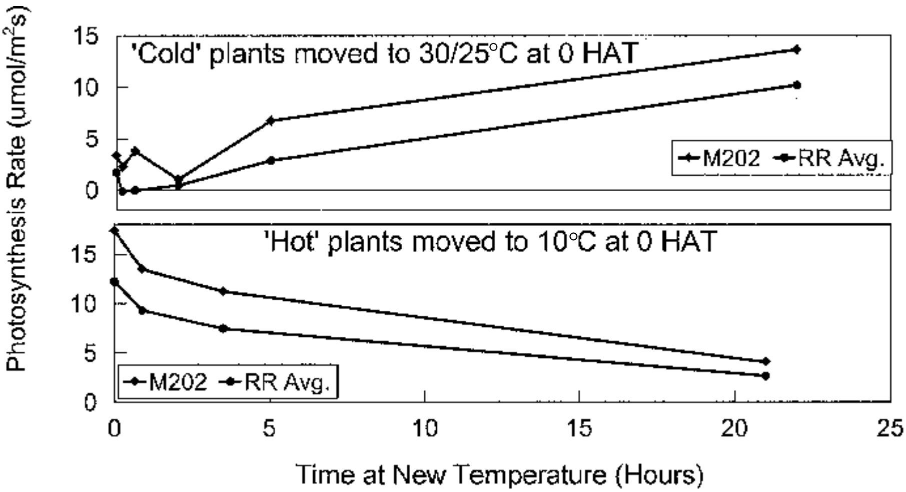


Fig. 3. Adaption of red rice and rice photosynthesis to temperature extremes. In upper frame, RR Avg. is average of biotypes 13A and StgB. In lower frame, RR Avg. is average of biotypes 13A, StgB, and a red rice-rice hybrid (Katy RR). M202 is a medium-grain, chilling-tolerant white rice cultivar from California.

POTENTIAL INHIBITION OF DUCKSALAD (*Heteranthera limosa*) GERMINATION WITH BLUE DYE IN FLOOD WATER

D.R. Gealy and H.L. Black

ABSTRACT

The aquatic weed ducksalad (*Heteranthera limosa*) can be troublesome in water-seeded rice fields. In preliminary laboratory tests, ducksalad germination was almost completely inhibited in the dark and at oxygen concentrations above 1%. Very specific red light wavelengths (in the range of 650 to 660 nm) are thought to trigger ducksalad germination. We attempted to use this knowledge to prevent ducksalad from germinating under flooded conditions. A blue-colored dye which absorbs red light ('Blue Vail'; max absorbance 625 nm) was dissolved in floodwater covering germinating ducksalad seeds. Seed germination was reduced in pot studies, but the reduction was less than 50% even at the highest (uneconomical) doses tested (160 ppm v/v 'Blue Vail' dye). The reduction was in the same range as that from a standard bensulfuron ('Londax') application (1 oz active ingredient [ai]/acre) under these test conditions. Overall, this nontraditional physiological approach to suppressing ducksalad in rice seems to be worth pursuing from a biological standpoint, but economics and efficacy appear to be far from acceptable at this time.

INTRODUCTION

Ducksalad is a major aquatic weed problem in water-seeded rice production in Arkansas and the southern United States. The weed can normally be controlled adequately with bensulfuron in combination with dense rice stands. However, the long-term management of this weed may require additional options because application costs can be as high as $18 to $20 per acre, and herbicide resistance has frequently developed in other weed species treated repeatedly with this class of herbicide. Ducksalad is an extremely small-seeded aquatic weed that will not germinate in darkness or in the presence of normal atmospheric oxygen concentrations (Marler, 1969). Ducksalad seeds require exposure to red (650 to 660 nm) light (phytochrome response) before they will germinate (Marler, 1969). Certain commercially available blue dyes are capable of absorbing the red light required for germination and potentially may be a useful nonherbicide means of suppressing ducksalad germination in water-seeded rice production. The objective of this study was to evaluate the ability of a red light-absorbing dye ('Blue Vail') to reduce germination of ducksalad under flooded conditions.

PROCEDURES

Petri Dish Study. Petri dishes containing about 200 ducksalad seeds each were incubated in 'ziplock' style plastic bags (Gealy, 1998) at oxygen concentrations (in nitrogen) of 0, 1, 2, 4, 8, and 20% (v/v) at ~25°C (77°F) under low light (< 20 uE / m^2 s) or in the dark for seven days. Germinated seeds were then counted. The experiment was conducted with a factorial arrangement of treatments consisting of two light intensities and six oxygen concentrations. Data were subjected to analysis of variance and means were separated with Least Significant Difference (LSD) at P=0.05.

Field Study. On 15 May 1998 10-cm (4-inch) floods were established in 12 inch deep by 30 inch square steel enclosures (artificial levees) in silt loam soil in a rice field near Lonoke. 'Blue Vail' dye (625 nm maximum absorbance) was added to the floodwater within one day of flooding to establish dye concentrations of 0, 10, 33, and 100 ppm (v/v). A bensulfuron treatment at the rate of 69 g ai/ha, a plain water treatment, and a plain water, light-free treatment were included as standards. Water depth in each enclosure was maintained at approximately 4 inches by adding supplemental water. Stand counts were taken one, two, and three weeks after addition of dye. Water from within enclosures was sampled on 15 May, 19 May, 29 May, and 6 June 1998, placed in glass vials, and analyzed on a scanning spectrophotometer to determine percent transmittance of light at 650 nm. Low transmittance values at this wavelength indicate that low levels of red light are reaching the soil surface, which should reduce the germination rates of ducksalad present. There were three replicates in a randomized complete block design and the experiment was conducted once. Data were subjected to analysis of variance and means were separated with an LSD at P=0.05.

Pot Study. A pot study was conducted in Crowley silt loam in 8-inch plastic pots at Stuttgart, using methods and treatments similar to those employed in the field study, with the exception that natural infestations of ducksalad were supplemented with several hundred seed sprinkled on the soil before flooding, and dye was added to flood water immediately after initial flooding at concentrations of 0, 10, 40, and 160 ppm (v/v). Stand counts were taken approximately one week after addition of dye. There were five replicates in a randomized complete block design and the experiment was conducted twice. Data were subjected to analysis of variance and means were separated with an LSD at P=0.05.

RESULTS AND DISCUSSION

Low oxygen (<2%) and light were required for germination of ducksalad (Table 1). Previous work indicated that ducksalad requires red light (650 to 660 nm) for optimal germination (Marler, 1969). The Blue Vail dye used in the present study absorbed light best at a wavelength of 625 nm (Gealy unpublished data), which is very near this optimum. Red light transmission through flood water increased with time in the field

(Fig. 1) suggesting that there was a loss of dye (i.e. red light absorbing capability) over time. The reasons for the loss may be due to adsorption of dye to the walls of the steel enclosures or to soil, or perhaps to degradation due to sunlight. Germination counts were not consistent in the field test and will not be presented. The inconsistency may have resulted from the violent intermixing of water and soil in the enclosures that occurred when water levels were reestablished periodically. In pots, both dye concentrations greater than 10 ppm, and bensulfuron reduced germination of ducksalad about 30% (Fig. 2). This level of germination suppression is probably not adequate by itself and may be too expensive to consider as a weed control option (Chris Isbel, personal communication).

Overall, blue dyes may be worth pursuing as an alternative weed control method for aquatic weeds in rice, but economic considerations and efficacy appear to be unacceptable at this time. Using a blue dye with an optimum light absorption that matches that of the optimum sensitivity of ducksalad (660 nm) may improve the suppression of ducksalad germination.

SIGNIFICANCE OF FINDINGS

This research demonstrated that with the use of blue dyes, germination of ducksalad can be reduced by restricting the amount of red light that penetrates through flood water. Long-term, such technology may be useful to farmers if several requirements are met. First, an affordable blue dye with an absorption maximum that exactly matches the optimum wavelength for ducksalad (650 to 660 nm) must be found. Second, the dye should persist in floodwater at near initial concentrations for an extended period (probably at least three to four weeks). Finally, the dye should be rapidly and uniformly dispersable into rice field flood water through irrigation pump injectors or through aerial application.

ACKNOWLEDGMENTS

We thank the Arkansas Rice Research and Promotion Board for partial funding of this research, Keena Taylor and Rebecca Chavez for technical assistance, and Paul Counce and Linda White for spectrophotometric analyses.

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Table 1. Ducksalad (*Heteranthera limosa*) germination under differing oxygen and light levels.

Oxygen concentration	Dark	Light (<20 μE/m²s)
%	--------------- % germination	--------------
0	<1	21
1	<1	15
2	0	1
4	0	<1
8	<1	0
20	0	<1

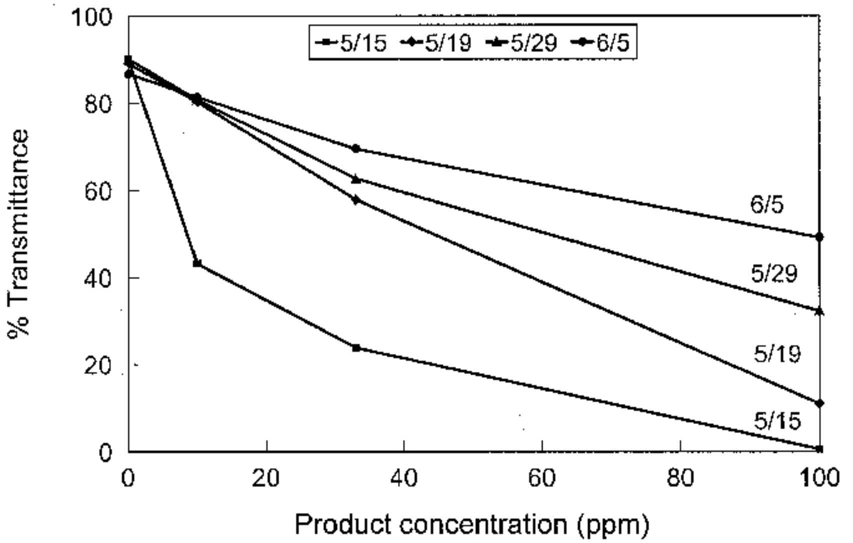

Fig. 1. Relative percent transmittance of red light (650 to 660nm) through rice field flood water spiked with Blue Vail dye. Dye was added to flood water on 15 May 1998 and monitored periodically for three weeks.

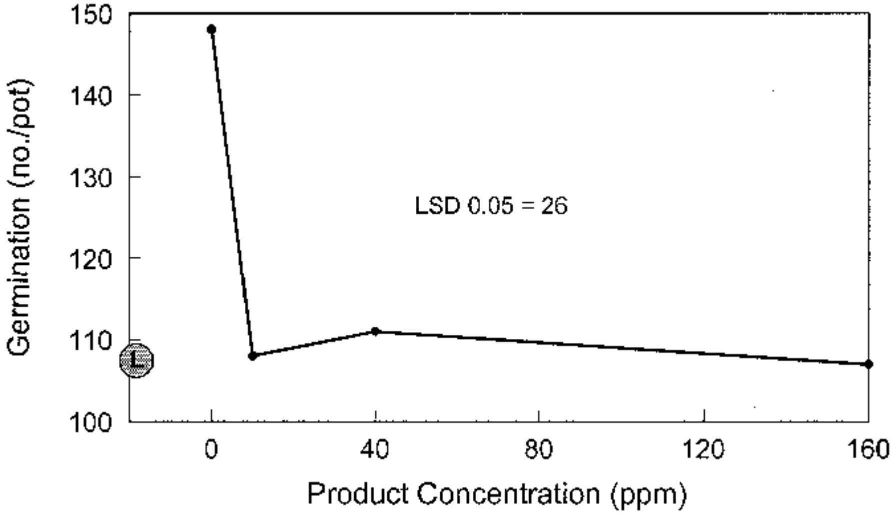

Fig. 2. Effect of Blue Vail dye concentration on ducksalad germination in the greenhouse. The circled 'L' symbol on the y-axis indicates the level of germination in the bensulfuron standard.

IMAZETHAPYR ('PURSUIT') EFFECT ON RED RICE (*Oryza sativa* L.) BIOTYPES

D.R. Gealy, R.H. Dilday, F.L. Baldwin, and H.L. Black

ABSTRACT

Numerous red rice accessions ('biotypes') have been collected from rice-growing areas of the South. Field studies were conducted at Stuttgart to determine biological characteristics of these biotypes (1995-1998) as well as tolerance to 1X (0.063 lb active ingredient [ai]/acre) and 2X (0.125 lb ai/acre) postemergence applications of imazethapyr ('Pursuit') (1997-1998). Broad differences in growth and development patterns and moderate differences in susceptibility to imazethapyr were found among the biotypes. The cultivar 'Kaybonnet' was shorter strawed than all of the red rice biotypes. Days to heading ranged from 83 for 14C to 108 for biotype LA3. Most red rice biotypes produced more than twice the number of tillers per m of row compared to the Kaybonnet standard. Nearly all biotypes were almost completely killed by 1X and 2X rates of imazethapyr. Several biotypes were slightly tolerant to this herbicide at the 1X rate in both 1997 and 1998, but control was always at least 90%. These include the blackhull biotypes TX4 and 1995-8. Control of all biotypes at both rates exceeded 85% in both years. Ten strawhull categories and six blackhull categories of red rice were identified using banding patterns for the seed isozymes. The most prevalent biotype was the local Stuttgart strawhull type (StgS), which had the same isozyme patterns as 13 other strawhull biotypes.

INTRODUCTION

Red rice is a troublesome weed in the drill-seeded rice cropping systems in the southern United States and is not controlled adequately using current cropping and weed control practices. Several common rice cultivars have been altered to be resistant to common herbicides that can kill red rice. This technology will allow farmers to selectively kill red rice in a rice crop using herbicides that would otherwise have killed the rice. Presently, rice varieties are being developed with resistance to postemergence applications of the nonselective herbicide, glufosinate (Liberty) (Oard *et al.*, 1996; Schwarzloze *et al.*, 1998; Wheeler *et al.*, 1998), and to preemergence and early postemergence applications of the soybean herbicide, imazethapyr (Pursuit) (Dillon *et al.*, 1998; Hackworth *et al.*, 1998; Sanders *et al.*, 1998). Glyphosate-resistant soybeans are being marketed throughout the United States, and glyphosate-resistant rice is under development.

Numerous biotypes of red rice can be found in the rice regions of the southern United States (Gealy and Dilday, 1997; Hessler *et al.*, 1998; Noldin *et al.*, 1994). Presently, there is great interest in the biological characteristics and levels of susceptibility of these red rice biotypes to potential herbicides for red rice control, including glufosinate (Gealy and Dilday, 1997; Noldin *et al.*, 1994; Hessler *et al.*, 1998), imazethapyr, and glyphosate. Applications of these, and other herbicides not previously used against red rice, will tend to kill the most susceptible individuals in the red rice population. The surviving population will become increasingly tolerant over time to these herbicides. In addition, herbicide-resistant rice in these fields has the potential to outcross to red rice. Outcrossing rates between rice and male sterile rice are inherently low - less than 35% (Hu and Rutger, 1991). Hybridization between rice and red rice is even lower, generally ranging from 1 to 7%, however, hybridization with the 'Nortai' cultivar was as high as 52% (Langevin *et al.*, 1990). Hybrids of red rice and herbicide-resistant rice not only would be highly resistant to the herbicide, but also would have other undesirable traits of red rice such as reddish-colored pericarps (Sankula *et al.*, 1996), and potentially elevated levels of dormancy and shattering (Gealy and Gravois, 1998; Oard *et al.*, 1998). If these hybrids were generated in sufficiently large numbers, management schemes for the red rice biotype, red rice hybrid complex, would be complicated greatly.

Seed of red rice biotypes was obtained from the rice-growing regions in Arkansas and other southern states, classified with respect to growth characteristics and seed isozyme types, and tested for susceptibility to imazethapyr in field studies at Stuttgart from 1995 to 1998.

PROCEDURES

Field Studies

In 1995 and 1996, biological characteristics of 19 strawhull biotypes and 8 blackhull biotypes were evaluated at Stuttgart in conjunction with an evaluation of the response of these types to glufosinate and glyphosate (Gealy and Dilday, 1997). 'Kaybonnet' and two other white rice lines were included as standards. Seeds of each entry were drilled in rows, 4.5 ft long, in late May to early June (15 seed / row, 1995; 20 seed / row, 1996). One hundred lb / acre of nitrogen (N) fertilizer as urea was applied uniformly to plots immediately before establishing the permanent flood. The experimental design was a randomized complete block with three replications.

Tolerance to imazethapyr (Pursuit[1]) of 16 blackhull and 36 strawhull biotypes (including those that were used in 1995 and 1996) were evaluated in 1997 and 1998 at Stuttgart. Thirty seed / row were drilled into rows, 4.5 ft-long on 19 May 1997. Fifty seed / row were drilled into rows 6 ft long on 21 May 1998. Plants emerged 7 to 10 days later. Imazethapyr was applied postemergence at the 3- to 4-leaf (lf) stage of red rice 22 days after seeding at rates of 0, 0.063 lb / acre and 0.125 lb / acre (1997 only). These

[1] Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by USDA.

were considered to be 0, 100, and 200%, respectively, of the standard use rate for red rice control. A nonionic surfactant was included at 0.25% v/v with imazethapyr applications. Rates 1X of propanil and bentazon were applied approximately 10 days after (1997) or 10 days before (1998) imazethapyr to control unwanted vegetation. One hundred lb/acre of N as urea was applied uniformly to plots before establishing the permanent flood. The experimental design was a split plot with three replications. Herbicide rates were main plots and red rice types and white rice standards were subplots.

Growth characteristics in the field, including final plant height, days to heading, tillers per meter of row, and total dry weight per meter of row of untreated plants were determined for each biotype in all four years. Visual percent control (1997: 18 July; 1998: 23, 24 June and 14 July), and final plant height and total dry weight (expressed as a percent of the untreated control [UTC]) were also determined for each biotype. Only visual control data are presented from the 1998 study.

Classification of Biotypes with Seed Isozyme Analysis

Populations of plant species can be classified into closely related ancestral groups by analyzing enzymes or DNA fragments in seeds or other plant tissues (Glaszmann, 1987; Mackill, 1995; Black and Durig, 1995). A simple and inexpensive method comparing seed isozyme banding patterns from isoelectric focusing (IEF) electrophoresis was used in the present study to categorize biotypes of red rice (Black and Durig, 1995). Forty-four red rice biotypes, including most of those used in field studies described above, were evaluated. Seed isozyme analyses were conducted by Hypure, Isolab Inc., Akron, Ohio. They employed the following procedure; four dry seeds of each biotype of red rice were bulked, crushed, and extracted overnight at 4 to 8°C with an enzyme extraction solution. After centrifugation, 12 ul of each supernatant was applied to electrophoresis gels for isozyme analysis. The enzyme esterase (EST) was run with a pH gradient of 3 to 10 on HyPure Gel FS-5480 gel. The enzyme phosphohexose isomerase (PHI) was run with a pH gradient of 3 to 7 on HyPure Gel FS-5080. Gels were focused for 90 minutes, stained for 20 to 30 minutes, washed, and dried. Biotypes were classified based on the presence or absence of bands in the gels. Because banding patterns of strawhull and blackhull biotypes were evaluated separately, results from different hull color groups should not be compared.

RESULTS AND DISCUSSION

Field Studies

Leaves of white rice cultivar/varieties usually were darker green in color than the red rice types. This is consistent with field observations that red rice plants usually can be differentiated visually from the cultivars they infest by their lighter green color, as well as by their nearly erect flag leaves protruding above the white rice canopy.

At maturity, white rices often had shorter straw than red rices (Table 1). Kaybonnet was 101 cm, and 13A red rice was 161 cm tall. The shortest red rice was 18E at 118 cm. Many of the taller red rice types lodged late in the season. Generally, blackhull red rice types headed at about the same time, or later, than the Kaybonnet standard while some strawhull red rice types headed earlier and some headed later than the Kaybonnet standard of 96 days. Days to heading ranged from 108 for 12B and LA3, to 83 for 14C and 16B. Most red rice biotypes produced more than twice the number of tillers per m of row compared to the Kaybonnet standard of 110 tillers per m of row. Total red rice biomass per m of row ranged from 2 to 3.5X the Kaybonnet standard of 286 g per m of row. Growth and development patterns of a presumed hybrid of 'Katy' rice and red rice (KatyRR) were similar to those of Kaybonnet and other modern long-grain cultivars. Its harvestable grain yield was as high as all other entries in the study (data not shown).

In 1997, imazethapyr at 0.125 lb / acre provided nearly 100% control of most biotypes of red rice and more than 95% control at 0.063 lb / acre (Table 2). A few plants from sixteen of the biotypes regrew enough from the injury at the lower herbicide rate to produce measurable biomass, but did not produce seed and were too small to be very competitive. Seven of these were blackhull types (44% of all blackhulls) and nine were strawhull types (25% of all strawhulls) suggesting that the blackhull types as a group may be somewhat more tolerant to imazethapyr. In 1997, the blackhull biotypes 1995-8 and 1995-10 were marginally more tolerant than all other biotypes to imazethapyr, producing 15 and 6%, respectively of the biomass produced by untreated plants.

In 1998, most red rice biotypes were killed completely by 1X imazethapyr. By the July rating period, the most tolerant types were 10A, 1995-4, and 13H (Table 2). These generally were not the same types that were most tolerant to 1X imazethapyr in 1997 (there was a significant year x biotype interaction), but control of all biotypes equalled or exceeded 85% in both years. Several types remained 'slightly' tolerant (90-96% control) to the herbicide in both 1997 and 1998. These were the blackhull biotypes TX4 and 1995-8. TX4 is a biotype that is about twice as tolerant as other red rice biotypes to glufosinate (Gealy and Dilday, 1997).

In previous research that determined tolerance of red rice biotypes to glufosinate and glyphosate, the most susceptible types did not survive 0.25 lb ai / acre glufosinate or glyphosate, whereas, the most tolerant types survived 0.5 lb ai / acre of these herbicides. None of the types in the previous study survived 1 lb ai / acre rates, and an awned blackhull type from Texas (TX4) was about twice as tolerant to glufosinate than were most other types (Gealy and Dilday, 1997).

Classification of Biotypes with Seed Isozyme Analysis

The combination of banding patterns of seed isozymes from esterase (EST) and phosphohexose isomerase (PHI) enzymes previously were classified into distinct biotype categories (Gealy and Dilday, 1997)(Table 3). Ten strawhull categories and six blackhull categories were identified using this method. The most prevalent biotype was StgS which had the same EST and PHI patterns as 13 other strawhull types. StgS is the standard local strawhull red rice biotype that has been used by researchers at Stuttgart for many years. Knowledge about biotype classification should be useful in chemical and cultural control decisions in red rice management. At the present time, it is not known whether herbicide susceptibility, flooding tolerance, etc., can be predicted from these seed isozyme categories.

Overall, these results indicate that red rice biotypes in Arkansas generally are highly susceptible to imazethapyr with relatively small differences among the populations tested thus far. Therefore, these data suggest that imazethapyr, as well as glufosinate and glyphosate, could be considered for use in herbicide-resistant rice cropping systems so long as prudent herbicide rotation regimes are implemented that will minimize the selection pressures for herbicide-tolerant biotypes.

SIGNIFICANCE OF FINDINGS

There were broad differences in growth and development patterns of the red rice biotypes, but differences in susceptibility to imazethapyr do not appear to be of practical significance, suggesting that imazethapyr could be used with herbicide-resistant ('IMI') rice with minimal risk of selecting for highly imazethapyr-tolerant red rice biotypes. The fact that 10 strawhull categories and 6 blackhull categories of red rice were identified from among 42 biotypes tested, suggests that genetic variability among red rice biotypes of the South is substantial, and probably great enough to ensure the successful adaptation of red rice to most new cropping practices. Because the local Stuttgart strawhull biotype (StgS) proved to be the most prevalent biotype in our isozyme characterization studies, it should continue to be an appropriate standard for weed control and weed biology studies in Arkansas. Related ongoing research with red rice biotypes at Stuttgart addresses chilling temperature responses, soil and flood emergence characteristics, plant competition characteristics, seed dormancy, red rice-rice hybridization rates, and classification of biotypes using molecular techniques. We continue to acquire and evaluate additional red rice biotypes in field, greenhouse, and laboratory studies at Stuttgart. Currently, our red rice collection contains more than 150 total entries, with about two-thirds being strawhull types, one-third being blackhull types, and seven being suspected hybrids of red rice and white rice.

ACKNOWLEDGMENTS

This research was supported in part by grant funds received from the Arkansas Rice Research and Promotion Board. We thank Keena Taylor for technical support, and Linda Durig at Hypure, Isolab, Inc., Akron, Ohio, for electrophoresis analysis and interpretation.

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Table 1. Growth characteristics of selected red rice biotypes in Stuttgart,1995- 1996.

Biotype	Final plant height	Time to heading	Tillers	Total dry weight
	cm	days	no./m of row	g/m of row
Strawhull types				
StgS	122	83	277	769
2B	130	88	245	713
3B	137	87	286	661
4A	133	88	272	789
7	135	85	278	719
9B	143	86	272	809
11B	130	85	293	756
11D	151	100	286	548
12B	157	108	216	591
13A	161	105	248	650
13G	134	86	296	779
14C	134	83	333	805
16B	122	83	319	782
16E	137	86	205	688
17A	135	89	315	754
20E	126	84	275	657
LA3	152	108	322	967
MS4	133	105	267	768
Blackhull types				
StgB	142	106	345	979
5A	151	94	311	730
8	142	97	305	563
10A	142	104	300	821
14F	139	97	338	838
17C	123	89	219	652
18E	118	102	239	588
TX4	142	103	283	899
White rice types				
KBNT	101	96	110	286
PI 414714	126	106	112	386
PI 414715	128	90	242	522
KatyRR (1996 only)	114	93	138	739
LSD(0.05)	14	9	107	166

Table 2. Response of red rice biotypes to a 1X (0.063 lb ai/acre) rate of imazethapyr (Pursuit) applied postemergence at the 3- to 4-leaf stage in 1997 and 1998.[z]

Biotype	Visual ratings for 1X Pursuit			Final plant height 9-15-97			Total plant biomass		
	7-18-97	6-24-98	7-14-98	UTC	1X Pursuit	2X Pursuit	UTC	1X Pursuit	2X Pursuit
	----- % control ------			cm	---------%UTC --------		kg/m of row	------ %UTC -------	
Blackhull Types									
StgB	97	62	100	152	0	0	1.68	0	0
10A	100	58	85	154	0	0	1.46	0	0
17C	100	63	95	136	0	0	1.05	0	0
18E	99	63	88	144	35.5	0	1.00	0.7	0
1995-1	98	63	100	130	43.9	0	0.86	1.4	0
1995-10	88	62	100	181	63.6	0	1.33	6.4	0
1995-13	100	70	100	96	0	0	0.98	0	0
1995-4	100	68	85	129	0	0	0.51	0	0
1995-8	90	68	96	134	49.1	0	0.95	14.7	0
1995-9	95	62	99	170	0	0	1.34	0	0
1996-11	98	70	98	150	42.2	0	1.24	1.8	0
1997-1	98	70	100	120	0	0	0.97	0	0
1997-27	97	---	---	151	47.0	0	1.37	2.5	0
19A	100	62	96	162	0	0	1.32	0	0
8	100	62	100	147	0	0	1.30	0	0
TX4	94	57	93	158	37.7	0	1.36	2.0	0
Strawhull types									
StgS	99	63	100	147	63.8	0	1.24	1.4	0
11A	100	67	100	155	0	0	1.07	0	0
11B	100	65	100	147	0	0	1.23	0.3	0

continued

Table 2. continued.

Biotype	Visual ratings for 1X Pursuit 7-18-97	6-24-98	7-14-98	Final plant height 9-15-97 UTC	1X Pursuit	2X Pursuit	Total plant biomass UTC	1X Pursuit	2X Pursuit
	-----	% control	------	cm	---------%UTC	--------	kg/m of row	------ %UTC	-------
Strawhull Types continued									
11C	100	72	98	147	0	0	0.37	0	0
11D	100	67	100	151	0	0	1.08	0	0
13G	100	58	96	142	0	0	1.33	0	0
13H	100	68	85	98	0	0	0.65	0	0
15A	100	65	100	137	0	0	1.25	0	0
16B	100	63	97	148	0	0	1.43	0	0
16E	96	63	100	153	39.7	0	1.38	1.9	0
17A	99	62	100	140	0	0	1.39	0	0
1995-11	100	62	100	138	0	0	1.07	0	0
1995-12	99	63	97	150	0	0	1.48	0	0
1995-15	99	70	97	162	0	0	1.28	0	0
1995-2	100	63	96	131	0	0	0.83	0	0
1995-3	100	62	93	149	0	0	1.59	0	0
1995-5	100	65	93	140	0	0	1.15	0	0
1995-6	100	65	98	141	0	0	1.25	0	0
1995-7	97	60	100	144	0	0	1.09	0	0
KatyRR (1996-1)	100	63	97	118	0	0	0.98	0	0
1996-10	100	58	95	146	0	0	1.24	0	0
1997-3	100	65	98	139	0	0	1.25	0	0
1997-22	100	70	98	153	0	0	1.21	0	0
1997-23	100	68	100	153	0	0	1.46	0	0
1997-24	98	67	97	150	0	0	1.29	0	0

continued

Table 2. continued.

Biotype	Visual ratings for 1X Pursuit			Final plant height 9-15-97			Total plant biomass		
	7-18-97	6-24-98	7-14-98	UTC	1X Pursuit	2X Pursuit	UTC	1X Pursuit	2X Pursuit
	-----	% control	------	cm	---------%UTC	--------	kg/m of row	------ %UTC	-------
Strawhull Types continued									
1997-25	100	68	99	147	0	0	1.33	0	0
1997-26	100	62	92	149	0	0	1.18	0	0
1997-28	99	67	100	146	0	0	1.29	0	0
20A	98	68	95	155	0	0	1.25	0	0
21A	100	67	99	138	0	0	1.24	0	0
2B	95	67	100	149	38.6	0	1.31	1.2	0
3B	100	70	100	152	0	0	0.96	0.3	0
4A	93	60	97	145	41.6	0	1.15	3.2	0
7	97	63	96	155	54.7	0	1.11	2.7	0
LA3	98	67	92	148	41.6	0	1.31	2.8	0
MS4	100	68	98	140	39.0	0	1.07	0.9	0
White types									
KBNT	100	73	95	109	0	0	0.74	0	0
PI414714	100	75	100	121	0	0	0.81	0	0
LSD(0.05)	4	6	8	15	51	NS[y]	0.3	3.7	NS

[z] In 1997, 2X Pursuit controlled all biotypes 98% or greater (data not shown). The 1998 data for final plant height and total plant biomass are not yet available.

[y] Not significant.

Table 3. Red rice isozyme categories as determined by isoelectric focusing (IEF) electroporesis of esterase (EST) and phosphohexose isomerase (PHI) enzymes extracted from dry seeds.[z]

Strawhull biotypes isozyme category[y]				Blackhull biotypes isozyme category			
Entry	EST	PHI	No. of biotypes in category	Entry	EST	PHI	No. of biotypes in category
StgS, 2B, 3B, 4A, 11B, 13G, 14C, 16B, 16E, 17A, 20A, 6A, 1995-5, 1995-6	A	A	14	StgB	O	N	1
11D, 12B	B	A	2	5A, 8, 19A, 1995-4	M	M	4
0.125	C	A	1	10A, 1995-10, 1996-3, 1996-4, 1996-9	N	O	5
1995-7	D	A	1	17C, 18A, 18E, 14F, 1995-13	O	O	4
KOREA	E	B	1	1995-1	P	P	1
LA3	F	C	1	TX4	Q	M	1
1995-13, 1995-14	F	A	2				
1995-12	G	A	1				
MS4, 1995-15, 1996-2, 1996-6	H	A	4				
1996-5	I	A	1				
1996-7	J	A	1				

[z]Table recreated from Gealy and Dilday, 1997.
[y] Analysis by Isolab Inc., Akron, Ohio. Every isozyme type shown in table represents a distinctive category of isozyme. Strawhull and blackhull biotypes cannot be compared directly.

CHEMICAL ASPECTS OF RICE ALLELOCHEMICALS FOR WEED CONTROL PROJECT REPORT - FEBRUARY 1999

J.D. Mattice, B.W. Skulman, R.H. Dilday, K Moldenhauer, and T.L. Lavy

ABSTRACT

Companion planting of barnyardgrass with various varieties of rice in the greenhouse has shown that some varieties will inhibit growth of barnyardgrass up to 40% compared to the cultivar 'Rexmont'. Experiments performed to differentiate between allelopathy and competition indicate that both mechanisms may be involved. High performance liquid chromatography (HPLC) chromatograms of methanol extracts of leaf tissue from 10-day-old rice plants contain six peaks corresponding to six compounds that are either present in much lower amounts or are not present at all in the nonallelopathic rice compared to the allelopathic rice. These may or may not be the causative compounds, but they may be used to predict if a given variety will have a weed control effect.

INTRODUCTION

Some strains of rice have been shown to inhibit growth of ducksalad (*Heteranthera limosa* [Sw.] Willd.) and barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.) (Dilday *et al*, 1989; Hasan *et al*., 1998; and Kim and Shin, 1998). Our original work was with PI 312777 which has shown relatively strong control of ducksalad compared to the lack of control from the cultivar Rexmont. We chose ducksalad as the target species because the effect was first noticed with this species; however, since then, we and others have found that some accessions of rice also inhibit growth of barnyardgrass, and that is where our focus has been during the past year.

We have two research objectives. One is to determine if the effect is due to allelopathy or competition, and if it is allelopathy to identify the allelochemicals responsible for the effect. Two is to develop a laboratory assay to screen varieties, and perhaps also individual plants within varieties, for weed control activity. This screen would be applicable whether the effect was due to allelopathy, competition, or a mixture of both. If an assay can be developed that can be used to screen 1- to 2-week-old plants grown in the greenhouse, then assays can be conducted year-round in a minimum amount of time with a minimum amount of space and labor compared to growing the plants in the field. Our ultimate goal is to be able to help breeders identify accessions and perhaps individual plants that would be useful for breeding.

PROCEDURES

Rice/Barnyardgrass Companion Planting Bioassays

The top of a 16-oz plastic cup was removed to yield a container with a 6-cm bottom diameter that was approximately 6 cm high. Crowley silt loam soil (Typic Albaqualfs) from the Rice Research and Extension Center, Stuttgart was sieved through a 2-mm mesh screen, and 110 g of the soil was placed in the cup. Twenty-three rice seeds were placed around the sides of the cup and either 8 barnyardgrass seeds for treatment 1 (T1) or 23 barnyardgrass seeds for treatment 2 (T2) were placed in the center. Forty g of the sieved soil was carefully sprinkled over the top taking care to not appreciably move the seeds. The samples were thoroughly watered with a hose, with the nozzle set at mist, in order to leave the seeds undisturbed. The samples were watered as needed and thinned to 15 rice plants and either 4 (T1) or 12 (T2) barnyardgrass plants per cup. Barnyardgrass heights were normally recorded at 11, 14, 18, and 22 days after planting. It was anticipated that some replications might have poor germination, so 12 replications were prepared for each treatment and 10 replications were used for data analysis. If some cups had insufficient germination of barnyardgrass, these cups were omitted. If a choice had to be made regarding which replication to leave out, by definition the highest replication number was omitted so there would not be a bias regarding which cup to omit.

Rice Leaf Analysis With High Performance Liquid Chromatography

Fifteen rice seeds were planted in 100 g of sieved Stuttgart soil. They were watered as needed and thinned to 10 plants per cup. Three replications were prepared for each accession. At approximately 10 days after emergence, all the leaves were removed and cut into approximately 1 cm long sections, weighed, and placed in a 25 or 50 mL erlenmeyer flask. Enough HPLC grade methanol was added so that the ratio of tissue to methanol was 10 mg/mL. The samples were capped with plastic film and placed in a refrigerator overnight. The next day 750 µL of extract and 750 µL of deionized water along with 47.5 µL of 158 µg/mL simazine as an internal standard were combined. The samples were analyzed using HPLC. Analysis was done by injecting 30 µL onto a 25 cm x 4.6 mm id Phenomenex Prodigy C18 column. The two solutions used for the mobile phase were acetonitrile (ACN) and 1% acetic acid in deionized water. The gradient program was as follows:

Time	% ACN	Flow (mL/min)	Comment
0.0	10	1.5	
3.0	10	1.5	
30	50	1.5	Linear gradient
30.1	100	2.0	Column flush
32	100	2.0	
32.1	10	2.0	Re-equilibration
39.9	10	2.0	
40.0	10	1.5	

Detection was at 320 nm for all compounds except for simazine which was at 270 nm.

Analysis of Barnyardgrass Leaf Tissue for Nutrients

Nutrient analysis was done at the soil test lab at the University of Arkansas Altheimer Laboratory.

RESULTS AND DISCUSSION

Three cultivars of rice, which showed little or no inhibition of ducksalad and/or barnyardgrass growth, along with seven accessions which have shown an effect in the field were investigated. The nonallelopathic varieties were ‘Rexmont’, ‘Drew’, and ‘Lemont’. Those showing inhibition were PI 312777, PI 338046, PI 373026, PI 366150, PI 350468, ‘Teqing,’, and ‘Guichow’.

Table 1 shows the average height of the barnyardgrass (10 replications) that grew with the rice entries as a percent of the height of barnyardgrass that grew with Rexmont. If the effect is due to competition, we should see more of an effect with the 12 barnyardgrass plants (T2), because there were more plants competing for the limited resource. If the effect is due to allelopathy we should see more of an effect with the four barnyardgrass plants (T1) because there was more of the toxin for each plant than if it is shared among 12 plants. There was a statistically significant reduction in barnyardgrass height for plants grown with strongly inhibitory rice varieties compared to those grown with Rexmont within each treatment. We saw little difference between treatments for the same variety; when a difference was seen there seemed to be a little more weed control with the 12 barnyardgrass samples. The results indicate there could be a mixture of allelopathy and competition occurring either concurrently or sequentially producing the weed control. Significant differences were seen 10 days after emergence which is consistent with what we are seeing with the chromatographic results.

Approximately two weeks after planting, the basal leaves of barnyardgrass growing with PI Nos. 312777, 373026, 366150, and Guichow showed definite yellowing. Analysis of these leaves from the plants growing with PI 312777 and Guichow showed that they contained 63% of the amount of nitrogen and 77% of the amount of potassium in barnyardgrass plants growing with Rexmont.

The barnyardgrass grown with the allelopathic varieties was also more spindly, and generally appeared less healthy.

Analysis of methanol leaf extracts of rice plants with HPLC revealed six compounds that were present in much higher amounts in the allelopathic accessions. In some cases, the compounds were not present at all in the nonallelopathic varieties. The difference existed in plants that were only five days old. Figures 1 and 2 illustrate this for two of the peaks. Each peak is caused by a compound that was extracted from leaf tissue, and the size of the peak is proportional to the amount of that compound. For the two peaks indicated, the amount of the compound is much larger in the extracts from the samples inhibiting barnyardgrass growth. The heavy lines are for varieties that do not show much effect, and the thin lines are for varieties showing the effect. Table 2 shows the areas for the six peaks. The identity of these compounds is yet to be determined.

These compounds may or may not be responsible for the weed control, but if they serve as markers they could identify allelopathic varieties using 5- to 10-day-old plants without having to take the samples to the field. We are hopeful that this technique could also be used to identify individual plants within a variety that would have a strong weed control ability and be useful for breeding purposes. The technique can be done on as little as 10 mg of a sample (a small leaf). We will be adding an additional 60 varieties to our database this year and also growing the varieties in the field to see how well the chromatographic results correlate with weed control in the field.

SIGNIFICANCE OF FINDINGS

If this trait, whether allelopathy, competition, or a mixture of the two, can be bred into useful cultivars we may be able to eliminate some herbicide applications or reduce the rates, resulting in savings to the farmer. Being able to identify the chemicals or to provide a rapid assay for screening varieties or individual plants for the trait, will help breeders to incorporate this trait into commercially useful cultivars of rice.

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ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board for funding for this project.

Table 1. Influence of rice cultivar/variety on the height of barnyardgrass as expressed as a percent of height of barnyardgrass grown with Rexmont at 22 days after planting. Four or 12 barnyardgrass plants per treatment.

	Barnyardgrass plants per treatment[y]	
Cultivar/variety[z]	T1 (4 plants)	T2 (12 plants)
	------------- (% height difference) -------------	
Rexmont	100	100
Lemont	84	81
Drew	95	91
PI 312777	91	85
PI 373026	74	82
PI 366150	92	88
PI 350468	75	55
Teqing	67	60
Guichow	70	59

[z]15 rice plants per treatment.
[y]10 replications per treatment.

Table 2. High performance liquid chromatograph peak areas of six chemical compounds extracted with methanol from leaves of allelopathic and non-allelopathic rice plants[z].

Cultivar/	Peak areas					
variety	Peak 14	Peak 16	Peak 18	Peak 22	Peak 24	Peak 28
	--------------------------------- (Relative areas) ---------------------------------					
Rexmont	11253 c[y]	0 e	7885 d	5695 d	0 g	0 g
Drew	7731 de	6598 d	1450 e	0 e	0 g	0 g
Lemont	4881 e	0 e	895 e	0 e	0 g	0 g
PI 312777	12183 c	26576 a	19281 a	15939 b	19072 a	15221 c
PI 338046	26744 b	8542 d	0 e	19284 a	10382 d	8011 e
PI 366150	6060 e	14298 c	13702 b	12966 c	14953 c	10695 d
PI 350468	38128 a	7574 d	0 e	19980 a	7887 e	6069 d
PI 373026	10600 cd	19391 b	10750 c	18617 a	2174 f	0 g
Tequing	6795 e	13739 c	18927 a	12078 c	17598 b	18040 b
Guichow	5744 e	13822 c	19545 a	16145 b	15994 c	21971 a

[z] Rice plants were 10 days old.
[y] Numbers within columns followed by different letters are significantly different at 0.05 level of probability. Comparison of numbers cannot be made across rows.

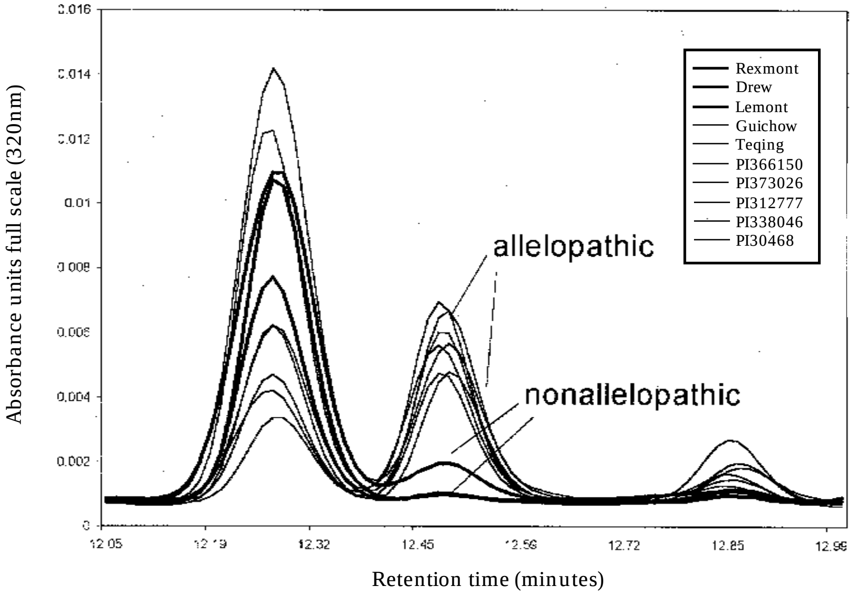

Fig. 1. HPLC chromatograms of methanol leaf extracts from 10-day-old rice plants showing the presence of a compound eluting at 12.5 minutes from allelopathic samples and little or none of the compound from nonallelopathic samples.

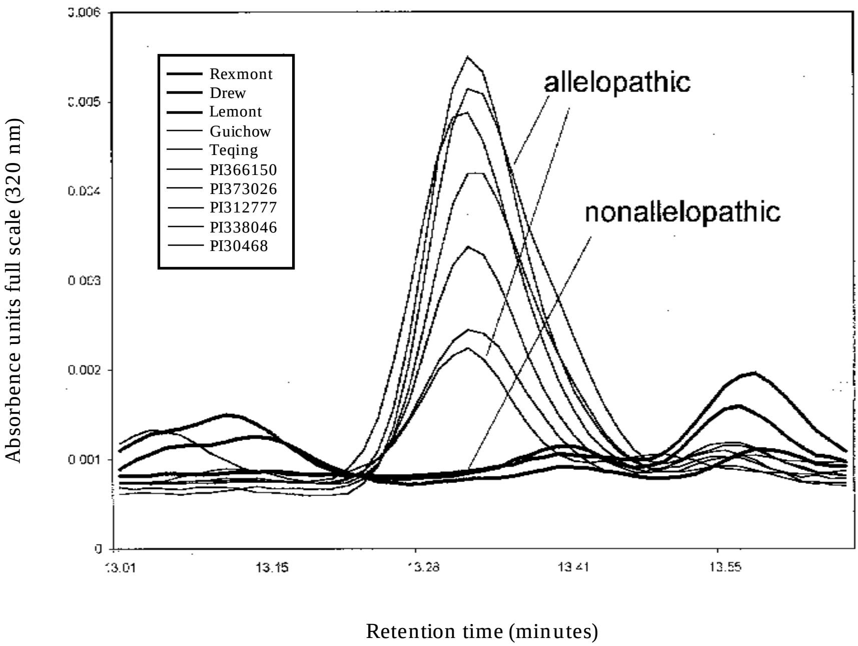

Fig. 2. HPLC chromatograms of methanol leaf extracts from rice plants showing the presence of a compound eluting at 13.3 minutes from allelopathic samples and little/none of the compound from nonellelopathic samples.

ENVIRONMENTAL IMPLICATIONS OF PESTICIDES IN RICE PRODUCTION PROJECT REPORT - FEBRUARY 1999

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

ABSTRACT

In 1997 and 1998, water samples were collected from six sites in the rice-growing region of Arkansas. Pesticides were detected in 2.5% of the possible cases. Molinate was the most frequently found pesticide in 18.2% of the samples and was also found in the highest concentration in 1997 at 22.5 parts per billion (ppb). Molinate was not found in any consecutive samples from the same site in 1997, but was found in consecutive samples several times at two sites in Lee County in 1998.

INTRODUCTION

Some rice pesticides have been found to persist in surface waters in California. This project is to determine if 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 17 rice pesticides in Arkansas during 1997 and 1998. 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 two-week 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.

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 1998 samples have been analyzed. Results for each sample that contained at least one detection of a pesticide in 1997 and 1998 are given in Tables 2 and 3.

There have been 35 detections, out of 1391 possible detections if every compound had been detected in every sample, which equates to 2.5% detections. The most frequently detected compound was molinate. It was detected in 18.2% of the samples. Thiobencarb was detected in 8.9% of the samples. Molinate was also detected in the highest concentration (22.5 ppb on 7/15/97 at site D, see Table 2).

Table 3 shows that there were 16 samples containing only one compound, five samples containing two compounds, and three samples containing three compounds. Table 3 also shows that the two sites that produced the most detections were in Lee County at sites D and E.

Detection of the same compound at the same site on consecutive sampling intervals could indicate that the compound is continually being introduced to the water as opposed to a limited, intermittent introduction. In 1997, thiobencarb was detected at low levels on three consecutive dates at site E (1.0 ppb on 3 June, 0.5 ppb on 17 June, and 1.4 ppb on 1 July). There were no consecutive detections of molinate. In 1998, there had been four consecutive detections of molinate at site D between 30 June and 25 August of 0.8, 0.8, 2.8, and 0.7 ppb. There were also three consecutive detections of molinate at site E between 30 June and 3 August of 2.4, 8.0, and 1.4 ppb.

Molinate is the compound that was found most frequently and was also found in the highest concentration. In 1997, molinate was not found in consecutive samples, but it was found in consecutive samples in 1998 as mentioned previously. Since molinate was one of the compounds of concern in California, it is wise for us to be especially watchful to ensure it does not start showing up more frequently, in higher concentrations, or in more consecutive sampling periods.

SIGNIFICANCE OF FINDINGS

It is not unreasonable to find some compounds in surface water during the application season; however, the detections have been sporadic and at low levels. Unfortunately in 1998, molinate was found at low levels on several consecutive sampling dates at two locations in Lee County. At this point we don’t know if this represents a trend due to increased use or changing management practices, or if it is simply a random occurrence as a result of environmental conditions during 1998. The results from the analysis of future samples should provide evidence if this is a trend or a random occurrence.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board for funding for this project.

Table 1. Water sample collection sites for the detection of pesticides.

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. Water samples that contained at least one detection of a pesticide.

Date	Site	Carbaryl	Molinate	Propiconizole	Fenoxaprop-ethyl	Quinclorac	Triclopyr	Thiobencarb
		(ppb in water)						
5/20/97	F	1.6	-	-	-	-	-	-
6/3/97	A	-	-	7.1	-	-	-	1.3
	D	2.2	5.5	-	-	9.2	-	-
	E	4.2	2.2	-	-	-	-	1.0
	F	16.7	-	-	-	-	-	-
6/17/97	E	-	-	-	-	-	-	0.5
7/1/97	D	-	-	-	-	1.7	0.8	-
	E	-	-	-	-	-	-	1.4
7/15/97	D	-	22.5	-	-	-	-	-
	E	-	9.9	-	-	-	-	-
6/2/98	A	-	-	-	-	2.0	-	0.8
	B	-	-	-	-	-	-	0.2
	C	-	-	-	-	-	-	0.5
	D	-	2.3	-	-	5.3	-	-
	F	-	6.8	-	-	-	-	-
6/30/98	C	-	-	-	1.7	-	-	-
	D	-	0.8	-	-	-	-	-
	E	-	2.4	-	-	-	-	-
7/14/98	D	-	0.8	-	-	-	-	-
	E	-	8.0	-	-	-	-	-
8/3/98	A	-	0.6	-	-	-	-	-
	D	-	2.8	-	-	-	1.1	-
	E	-	1.4	-	-	-	-	-
8/25/98	D	-	0.7	-	-	3.4	0.6	-

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

	Sampling site					
Date	A	B	C	D	E	F
5/20/97						carbaryl
6/3/97	propiconizole			carbaryl	carbaryl	carbaryl
	thiobencarb			molinate	molinate	
				quinclorac	thiobencarb	
6/17/97					thiobencarb	
7/1/97				quinclorac	thiobencarb	
				triclopyr		
7/15/97				molinate	molinate	
6/2/98	quincloraclorac	thiobencarb	thiobencarb	molinate		molinate
	thiobencarb			quinclorac		
6/30/98			fenoxaprop	molinate	molinate	
7/14/98				molinate	molinate	
8/3/98	molinate			molinate	molinate	
				triclopyr		
8/25/98				molinate		
				quinclorac		
				triclopyr		

CONFIRMATION, POPULATION GENETICS, AND CONTROL OF PROPANIL-RESISTANT AND -SUSCEPTIBLE BARNYARDGRASS

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

ABSTRACT

Propanil resistance in barnyardgrass continues to spread each year in Arkansas. Propanil-resistant barnyardgrass (R-BYG) was first confirmed in 1990 and now has been confirmed in 171 populations (nine new populations were added in 1998) in 20 Arkansas counties. Through genetic relationship studies, it was determined that propanil resistance was not the result of a single mutation at one location which then spread to other areas. Propanil in combinations with pendimethalin (Prowl®), propanil + molinate (Arrosolo®) and the synergists anilofos, piperophos, and carbaryl (Sevin®) whether single applications or sequentially, gave excellent control of R-BYG and susceptible barnyardgrass (S-BYG). Clomazone (Command®) at 0.4 lb / acre applied preplant incorporated (PPI), preemergence (PRE) or delayed preemergence (DPRE) gave excellent control of barnyardgrass under a wide range of moisture conditions. Clomazone was also effective in barnyardgrass control when used in herbicide programs aimed at broadleaf weed control. Other alternative herbicides that provided excellent control of R- and S-BYG were bispyribac-sodium (Regiment®) applied to 4- to 6-leaf (lf) rice and cyhalofop-butyl (Clincher®) applied to 2- to 3-lf rice.

INTRODUCTION

The most important weed in rice worldwide is barnyardgrass (*Echinochloa crus-galli*) because of its ability to interfere with the growth of rice. Barnyardgrass has adapted to rice production systems in the United States recently by developing resistance to the most widely used rice herbicide, propanil. Propanil is well established as a postemergence herbicide for the control of annual grasses and some broadleaf weeds (Smith, 1961; 1965; 1988).

It was first used in Arkansas rice fields for the control of annual grasses in 1962. After its introduction, rice grain yields in the United States increased 34 - 74% (Smith, 1965). This was one of the first effective herbicides for barnyardgrass control in rice and is currently used on 98% of the rice acreage in Arkansas (Carey *et al.*, 1995). Many producers use two or more sequential applications of propanil per year consisting of 3 to 4 lb / acre. Bridges (1992) conservatively estimated that 4.5 million lb (active ingredient [ai]) of propanil were applied yearly to Arkansas rice fields.

R-BYG was first confirmed in 1990 and has since been documented in 171 locations (nine were added in 1998) in 20 Arkansas counties through 1998. Since the first propanil resistance in Arkansas was confirmed in Poinsett County, it has been assumed that this was the origin of the resistant barnyardgrass (Carey *et al.*, 1992). Although there has been much work on trying to control this resistant biotype, little has been done to determine the origin or distribution patterns of this resistant barnyardgrass. There is also little known about the genetic variation among populations of R- and S-BYG distributed within the state. The application of the random amplified polymorphic DNA (RAPD) molecular marker technique may give us a better understanding as to the initial development of the resistance and its dispersal.

The increasing populations of R-BYG in the state have led to the evaluation of alternative methods for its control such as synergists with propanil and the herbicides clomazone, bispyribac-sodium, and cyhalofop-butyl.

Both carbamate and organophosphate insecticides increase propanil activity on rice and R-BYG by inhibiting aryl acylamidase activity (Caseley *et al.*, 1996). Therefore, combinations of propanil with carbaryl, anilofos, or piperophos may be useful in controlling R-BYG.

Clomazone (Command®) is currently being developed by FMC for barnyardgrass control in rice. Past research has shown excellent control of R- and S-BYG with clomazone when applied PPI, PRE, or DPRE. Clomazone is expected to be registered for use in rice by the year 2000.

Bispyribac-sodium (Regiment®) is a new postemergence herbicide currently under development by Valent USA. Past research has shown bispyribac-sodium to be excellent in controlling barnyardgrass at a wide range of growth stages ranging from the first true leaf through the tillering stage. The mode of action of bispyribac-sodium is inhibition of the acetolactate synthase enzyme, which produces valine, leusine, and isoleusine in the plant. The registration of bispyribac-sodium is expected to occur in the year 2000.

Cyhalofop-butyl (Clincher®) is a new postemergence rice herbicide currently under development by Dow AgroSciences. The mode of action of cyhalofop-butyl is inhibition of the Acetyl CoA carboxylase (ACCase) enzyme.

The objectives of this research were: 1) to obtain a better understanding of the population genetics of propanil-resistant and -susceptible barnyardgrass populations in Arkansas which could clarify the origin of the resistance and how it spread throughout the state and 2) to evaluate efficacy for propanil-resistant and -susceptible barnyardgrass control with propanil synergists, clomazone, bispyribac-sodium, and cyhalofop-butyl.

MATERIALS AND METHODS

Genetic Relationship of Resistant and Susceptible Barnyardgrass Populations in Arkansas

This study was conducted to obtain a better understanding of the population genetics of propanil-resistant and -susceptible barnyardgrass populations in Arkansas that could clarify the origin of the resistance and how it spread throughout the state. Seed sources for this study were obtained from samples that have been sent in by producers for resistance screening since 1991 with a susceptible standard obtained from Azlin Seed Service in Leland, Mississippi. Arkansas counties from which these samples originated are listed in Table 1. Leaves were collected from approximately five plants of each population growing in the greenhouse. Genomic DNA was extracted using CTAB (hexadecyltri-methylammonium bromide) buffer and chloroform extraction. The RAPD technique was used to assess the relationship between the populations. Statistical analysis of data obtained from the RAPDs was performed in SAS and included clustering analysis and the calculations of simple matching coefficients (SMC) and genetic distance (GD) by the following formula: GD = 1 - SMC.

Efficacy of Resistant and Susceptible Barnyardgrass Control in Rice

The following studies were conducted in 1998 at the Rice Research and Extension Center at Stuttgart. The experimental design for all experiments unless otherwise noted was a randomized complete block with four replications. The rice cultivar 'Drew' was drill-seeded at a rate of 120 lb / acre into plots 6 x 16 ft with row spacing of 6.5 inches. At seeding, R- and S-BYG were seeded across the plots in two rows perpendicular to the rice rows. A natural infestation of barnyardgrass was also present at this location. Normal rice production practices were used throughout the growing season. Herbicide applications were made with a three-nozzle backpack sprayer at a carrier volume of 15 gallons per acre. Effects of the herbicide treatments were evaluated by weed control ratings, crop injury ratings, and rough rice yield. Percent weed control and crop injury for each plot were visually evaluated with 0% representing no effect and 100% representing complete kill. An untreated check was included in all studies for comparison. At maturity, 12 ft of the center four rows of each plot were harvested, adjusted to 12% moisture, and converted to lb / acre. All data were subjected to analysis of variance and means were separated using the LSD (Least Significant Difference) test at the 5% level of significance.

Field Evaluation of Propanil Synergists

Rates of synergists with propanil were based on the results of this test from the previous year. Treatments were either applied early postemergence (EPOST) in combination with 4 lb / acre of propanil or sequentially at EPOST followed by pre-flood in combination with propanil at 3 lb / acre. Synergist applied with propanil at the EPOST and sequential timings included anilofos at 0.25 lb / acre, piperophos at 0.375 lb / acre, and carbaryl at 0.03 and 0.005 lb / acre. Standard herbicide treatments were also applied EPOST with propanil for comparison and included thiobencarb at 3 lb / acre, quinclorac at 0.25 lb / acre, and pendimethalin at 1 lb / acre. The propanil formulations of Super Wham® at 4 lb / acre and Arrosolo at 6 lb / acre were included at the EPOST timing for comparison as well. Plots were rated at 7, 14, 28, and 56 days after treatment (DAT).

Clomazone Application Timings and Water Management

Clomazone (Command 3 ME®) was evaluated at 0.2 and 0.4 lb / acre PPI, PRE, and DPRE. Comparison treatments consisted of pendimethalin, at 1.0 lb / acre, quinclorac at 0.38 lb / acre, and thiobencarb at 4.0 lb / acre, all applied DPRE. Separate experiments were conducted under normal flushing and very delayed flushing to reduce soil moisture conditions. Visual ratings of percent control were taken at 7, 14, 21, 28, 43, and 60 days after rice emergence (DAE). Data were analyzed as split-plot analyses with the main effect as water management, and the subplot effect as treatments.

Clomazone in a Herbicide Program for the Control of a Broad Spectrum of Weeds

Clomazone, at 0.2 and 0.5 lb / acre DPRE, was evaluated for its potential use in herbicide programs in combination with quinclorac, thiobencarb, pendimethalin, carfentrazone, propanil, and bensulfuron, along with a comparison treatment of quinclorac DPRE followed by (fb) propanil. Visual ratings of weed control were taken on hemp sesbania, northern jointvetch, palmleaf morningglory, and barnyardgrass at 7, 14, 21, 28, 43, and 60 days after rice emergence.

Control of Resistant and Susceptible Barnyardgrass with Bispyribac-sodium

Bispyribac-sodium at 0.28 oz / acre or 0.32 oz / acre with a non-ionic surfactant (Kinetic®) at 0.125% v/v was applied to 4- to 6-lf rice. The standard treatment of molinate + propanil (Arrosolo) at 6 lb / acre was also applied at the 4- to 6-lf rice stage for comparison. Evaluations were taken at 9 and 42 days after treatment (DAT) for crop injury and R- and S-BYG control. Rice was harvested on 19 September.

Control of Resistant and Susceptible Barnyardgrass with Cyhalofop-butyl

Cyhalofop-butyl was applied at two application timings, 2- to 3-lf or 4- to 6-lf rice, at rates of 0.06, 0.13, 0.19, 0.25, or 0.5 lb / acre with a crop oil concentrate (Agri-Dex®) at 1.25% v/v. A standard included propanil at 4 lb / acre applied to 2- to 3-lf or 4- to 6-lf rice. Another standard was quinclorac at 0.38 lb / acre applied to 2- to 3-lf rice or 0.5 lb / acre applied to 4- to 6-lf rice with a crop oil concentrate (Agri-Dex) at 1.25% v/v. Evaluations for crop injury and R- and S-BYG control were taken at 29 days after the 2- to 3-lf application timing which corresponds to 17 days after the 4- to 6-lf application timing. Rice was harvested on 19 September.

RESULTS AND DISCUSSION

Genetic Relationship of Resistant and Susceptible Barnyardgrass Populations in Arkansas

Seventeen barnyardgrass populations (10 resistant and 7 susceptible) were grouped into two distinct clusters by the clustering analysis based on their genetic similarity from RAPD data (Fig. 1). This clustering could not be attributed to biotypes (both clusters contain R- and S-BYG) or to geographic location (both clusters contain populations from different regions of the state) (Fig. 2). Because these clusters are so genetically distant and both contain resistant biotypes, we can conclude that propanil resistance is not the result of a single mutation at one location, which then spread to other areas. This leads us to the fact that despite the classification of barnyardgrass seed as noxious, and limiting its dispersal in crop seed, the continued use of propanil will result in the development of resistance in areas where it had not previously occurred.

Efficacy of Propanil-Resistant and –Susceptible Barnyardgrass Control in Rice Field Evaluation of Propanil Synergists

All treatments gave excellent control of resistant (>90%) and susceptible (>87%) barnyardgrass (Table 2). The EPOST treatment of propanil + piperophos gave the numerically highest grain yield of the trial. Other EPOST treatment yields from applications of Arrosolo, and propanil with anilofos, 0.005lb / acre carbaryl, or pendimethalin were not significantly different from the propanil + piperophos treatment. This was also true for sequential treatments of propanil and propanil plus anilofos, piperophos, or the low rate of carbaryl. Treatments with the higher rates of carbaryl caused serious injury at 7,14, and 28 DAT and apparently reduced yields. There was no significant rice injury at 56 DAT.

Clomazone Application Timings and Water Management

Clomazone at 0.4 lb / acre controlled barnyardgrass, ≥95%, regardless of application timing in both the flushed and delayed-flush experiment. Clomazone at 0.2 lb / acre had a significant decrease in control at 60 DAE, where flushing was delayed: flushed trial had 93% control PPI, 92% PRE, and 99% DPRE for barnyardgrass, while the delayed flush trial gave 76% control PPI, 49% PRE, and 84% DPRE for barnyardgrass (Table 3). Comparison treatments also gave season-long control of ≥98% of barnyardgrass where flushed at 60 DAE. Except for the quinclorac comparison, treatments in the delayed flush failed to give season-long control of barnyardgrass. Quinclorac gave 99% control, but pendimethalin and thiobencarb gave only 66% and 69% control of barnyardgrass, respectively.

Clomazone at 0.4 lb / acre gave season-long control of barnyardgrass under a wide range of moisture conditions. Rice grain yield responses were related to the level of barnyardgrass control. Under limited moisture, yields were reduced because of inadequate weed control from 0.2 lb / acre of clomazone, 1.0 lb / acre rate of pendimethalin, and 4.0 lb / acre of thiobencarb.

Clomazone in a Herbicide Program for the Control of a Broad Spectrum of Weeds

Clomazone at 0.2 and 0.5 lb ai / acre DPRE used before sequential treatments of broadleaf herbicides in a herbicide program gave 99% control of barnyardgrass (Table 4).

Palmleaf morningglory was controlled (>96%) with programs of quinclorac, bensulfuron, molinate, and carfentrazone. Treatments of clomazone tank-mixed with thiobencarb or pendimethalin and clomazone fb propanil were ineffective for control of palmleaf morningglory. Quinclorac however, provided excellent control of palmleaf morning glory even at 1 / 2 X the label rate.

Hemp sesbania control was exceptional (99%) for all treatments except for those programs of clomazone followed by bensulfuron, or clomazone tank-mixed with thiobencarb or pendimethalin. Clomazone tank-mixed with quinclorac or fb propanil, and carfentrazone gave season-long control of hemp sesbania.

Northern jointvetch control was limited to programs that included propanil or quinclorac. Programs containing these herbicides ranged in control from 86% to 99% control.

Clomazone was shown to provide excellent grass control alone, but had limited activity on broadleaf weeds only (data not shown). For broadleaf weed species, a program approach can be used.

Control of Propanil-Resistant and -Susceptible Barnyardgrass with Bispyribac-sodium

Bispyribac-sodium at 0.28 or 0.32 oz/acre controlled R- and S-BYG (>88%) at 9 DAT (Table 5). The standard treatment of propanil + molinate at 6 lb/acre provided poor control of both biotypes at 9 DAT. Control with both rates of bispyribac-sodium was greater at 42 DAT (>91%) and was better than the molinate + propanil standard which provided only 63% control. All treatments exhibited less than 10% injury at 9 DAT and no injury was observed at 42 DAT. Rice grain yields from all herbicide treatments were greater than the untreated check and the plots with bispyribac-sodium applied at 0.32 oz/acre yielded better than those at the 0.28 oz/acre rate.

Control of Resistant and Susceptible Barnyardgrass with Cyhalofop-butyl

Cyhalofop-butyl at all rates applied to 2- to 3-lf rice controlled R- and S-BYG (>85%) at 29 DAT, similar to quinclorac at 0.38 lb/acre and greater than propanil at 4 lb/acre (Table 6). Neither cyhalofop-butyl at 0.06 to 0.25 lb/acre or propanil at 4 lb/acre applied to 4- to 6-lf rice controlled R- and S-BYG by 17 DAT. The 0.5 lb/acre rate of cyhalofop-butyl applied to 4- to 6-lf rice controlled R- and S-BYG (>83%) at 17 DAT which was similar to the control by quinclorac (>83%) applied at the same timing. No injury was evident from any treatment by 29 DAT.

SIGNIFICANCE OF FINDINGS

Propanil resistance in barnyardgrass is a very serious and widespread problem in Arkansas. The genetic relationship studies indicate that despite the classification of barnyardgrass seed as noxious, which limits dispersal in crop seed, the continued use of propanil will probably result in the development of additional resistant populations of barnyardgrass. Propanil in combination with the synergists anilofos, piperophos, and carbaryl offers alternatives for the control of propanil-resistant barnyardgrass. Other alternatives to propanil that provided excellent control of propanil-resistant barnyardgrass included clomazone applied preemergence and delayed preemergence, and the new herbicides, bispyribac-sodium and cyhalofop-butyl, applied postemergence. With the continued cooperation of the manufacturers of these products and the Environmental

Protection Agency (EPA) in labeling, these new technologies will soon be very useful alternatives for the control of propanil-resistant barnyardgrass by growers.

ACKNOWLEDGMENTS

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

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Table 1. County of origination of barnyardgrass samples used in genetic studies.

Resistant	Susceptible
Arkansas	Arkansas
Cross	Jackson
Jackson	Lafayette
Lawrence	Leland, MS
Miller	
Woodruff	

Table 2. Outstanding treatments of propanil mixtures for R- and S-BYG control, Stuttgart, 1998.

			R- and S-BYG control							
		Application	7 DAT[y]		14 DAT		28 DAT		56 DAT	
Treatment	Rate	timing[z]	R-	S-	R-	S-	R-	S-	R-	S-
	(lb/acre)		(%)							
Untreated Check			0	0	0	0	0	0	0	0
Propanil + anilofos	4 + 0.25	EPOST	100	100	97	97	93	95	94	93
Propanil + piperophos	4 + 0.38	EPOST	99	99	94	97	94	94	95	97
Propanil + carbaryl	4 + 0.005	EPOST	98	99	84	94	91	95	93	90
Propanil + pendimethalin	4 + 1	EPOST	98	99	88	92	95	95	95	95
(Propanil + molinate)[x]	6	EPOST	98	98	85	90	91	94	93	85
Propanil fb		EPOST								
propanil	3 fb 3	LPOST	91	93	85	90	86	93	90	83
Propanil + anilofos fb	3 + 0.25 fb	EPOST								
propanil + anilofos	3 + 0.25	LPOST	96	99	88	90	93	95	93	95
Propanil + piperophos fb	3 + 0.38 fb	EPOST								
propanil + piperophos	3 +0.38	LPOST	97	97	95	93	94	94	96	96
Propanil + carbaryl fb	3 + 0.005 fb	EPOST								
propanil + carbaryl	3 + 0.005	LPOST	99	99	89	90	94	94	93	95
$LSD_{(0.05)}$			3	3	6	4	6	3	5	8

continued

Table 2. Continued.

Treatment	Rate	Application timing[z]	Rice injury 7 DAT[y]	14 DAT	28 DAT	56 DAT	Rice yield
		(lb/acre)	(%)				(lb/acre)
Untreated Check			0	0	0	0	2200
Propanil + anilofos	4 + 0.25	EPOST	16	18	1	0	7470
Propanil + piperophos	4 + 0.38	EPOST	15	13	0	3	8920
Propanil + carbaryl	4 + 0.005	EPOST	11	8	0	0	8310
Propanil + pendimethalin	4 + 1	EPOST	15	11	0	3	8000
(Propanil + molinate)[x]	6	EPOST	4	5	0	4	7330
Propanil fb		EPOST					
propanil	3 fb 3	LPOST	9	5	0	4	7350
Propanil + anilofos fb	3 + 0.25 fb	EPOST					
propanil + anilofos	3 + 0.25	LPOST	15	10	0	4	7320
Propanil + piperophos fb	3 + 0.38 fb	EPOST					
propanil + piperophos	3 +0.38	LPOST	13	11	3	3	7380
Propanil + carbaryl fb	3 + 0.005 fb	EPOST					
propanil + carbaryl	3 + 0.005	LPOST	15	10	1	4	7420
$LSD_{(0.05)}$			8	5	2	7	1780

[z]EPOST = early postemergence; LPOST = late postemergence.
[y]DAT = days after treatment.
[x]Arrosolo® 6 EC (3 lb/gallon propanil + 3 lb/gallon molinate).

Table 3. Barnyardgrass control 60 DAE[z] and rice yield as influenced by application timing and water management at Stuttgart, 1998.

			Barnyardgrass control		Rice yield	
Treatment[y]	Rate	Timing[x]	Flushed	Delayed flushed	Flushed	Delayed flushed
	(lb/acre)		(%)		(lb/acre)	
Untreated Check	--	--	0	0	3760	780
Clomazone	0.2	PPI	93	76	7200	6060
Clomazone	0.4	PPI	99	98	7350	7760
Clomazone	0.2	PRE	92	49	6930	5100
Clomazone	0.4	PRE	94	99	7830	7140
Clomazone	0.2	DPRE	99	84	8180	6020
Clomazone	0.4	DPRE	99	99	7990	7800
Quinclorac	0.38	DPRE	99	99	7670	6720
Pendimethalin	1	DPRE	98	66	8230	5750
Thiobencarb	4	DPRE	98	69	6890	6020
$LSD_{(0.05)}$			14		1670	

[z] DAE = days after emergence.
[y] Clomazone = Command® 3 ME.
[x] PPI = preplant incorporated; PRE = preemergence; and DPRE = delayed preemergence.

Table 4. Control of various weeds at 60 DAE[z] and rice yield from various herbicide programs with clomazone at Stuttgart, 1998.

		Application	Weed Species[w]				
Treatment[y]	Rate	Timing[x]	ECHCG	IPOWR	AESVI	SEBEX	Rice yield
	(lb/acre)		(%)				(lb/acre)
Untreated check	--	--	0	0	0	0	1790
Clomazone + quinclorac	0.5 + 0.38	PRE	99	99	83	99	8570
Clomazone + quinclorac	0.2 + 0.19	PRE	99	99	23	99	8740
Clomazone + quinclorac	0.5 + 0.38	DPRE	99	97	96	99	8120
Clomazone + quinclorac	0.2 + 0.19	DPRE	99	99	96	99	8260
Clomazone + thiobencarb	0.5 + 4	DPRE	99	18	63	0	7280
Clomazone + thiobencarb	0.2 + 2	DPRE	99	20	52	0	8030
Clomazone + pendimethalin	0.2 + 1	DPRE	99	10	3	0	7220
Clomazone fb carfentrazone + 0.25% v/v NIS	0.5 fb 0.02	PRE fb PREFLD	99	99	48	99	8260
Clomazone fb propanil	0.5 fb 3	PRE fb PREFLD	99	70	93	99	7960
Clomazone fb bensulfuron + 1.0% v/v COC	0.2 fb 0.04	PRE fb PREFLD	99	99	25	55	8040
Clomazone fb (molinate + propanil) + bensulfuron	0.2 fb 4.5 + 0.04	PRE fb PREFLD	99	99	86	99	8150
Clomazone fb carfentrazone + 0.25% v/v NIS	0.5 fb 0.02	DPRE fb PREFLD	99	99	71	99	8540
Clomazone fb propanil	0.5 fb 3	DPRE fb PREFLD	99	40	94	99	7980
Quinclorac fb propanil	0.38 fb 3	DPRE fb PREFLD	99	99	99	99	7810
$LSD_{(0.05)}$			1	22	27	16	1350

[z] DAE = days after emergence.
[y] NIS = AG-98®, COC = Agri-Dex®.
[x] PRE = preemergence; DPRE = delayed preemergence; PREFLD = preflood.
[w] ECHCG = barnyardgrass; IPOWR = palmleaf morningglory; AESVI = northern jointvetch; and SEBEX = hemp sesbania.

Table 5. R- and S-BYG[z] control and crop injury at 9 and 42 DAT[y] with bispyribac-sodium and propanil + molinate[x] applied to 4- to 6-leaf rice, Stuttgart, 1998.

	R-BYG control		S-BYG control		Rice injury		
Treatments[w]	9 DAT	42 DAT	9 DAT	42 DAT	9 DAT	42 DAT	Rice yield
(rate/acre)	----------	----------	----------	(%)	----------	----------	(lb/acre)
Untreated Check	0	–[v]	0	0	0	0	2250
Bispyribac-sodium, 0.28 oz + 0.125% v/v NIS	88	--	85	91	9	0	4900
Bispyribac-sodium, 0.32 oz + 0.125% v/v NIS	90	--	88	93	9	0	6160
Propanil + molinate, 6 lb	0	--	0	63	1	0	4180
$LSD_{(0.05)}$	8	--	7	7	2	NS[u]	810

[z] R- and S-BYG = Propanil-resistant and -susceptible barnyardgrass.
[y] DAT = days after treatment.
[x] Arrosolo® (3 lb/gallon propanil + 3 lb/gallon molinate).
[w] NIS = non-ionic surfactant.
[v] Propanil-resistant barnyardgrass could not be distinguished from susceptible barnyardgrass; therefore, no data is available.
[u] Not significant.

Table 6. Control of R- and S-BYG[z] and rice injury at 29 DAT[y] with cyhalofop-butyl applied to 2- to 3-leaf rice and 4- to 6-leaf rice, Stuttgart, 1998.

Treatment[x]	Rate	Application timing	R-BYG control	S-BYG control	Rice injury	Rice yield
	(lb/acre)		----------	(%)	----------	(lb/acre)
Untreated Check	--	--	0	0	0	1550
Cyhalofop-butyl + 1.25%v/v COC	0.06	2-3	85	87	0	3590
Cyhalofop-butyl + 1.25%v/v COC	0.13	2-3	90	93	0	5950
Cyhalofop-butyl + 1.25%v/v COC	0.19	2-3	98	97	0	4570
Cyhalofop-butyl + 1.25%v/v COC	0.25	2-3	95	96	0	7200
Cyhalofop-butyl + 1.25%v/v COC	0.5	2-3	97	96	0	7020
Propanil	4	2-3	60	25	0	2620
Quinclorac + 1.25% v/v COC	0.38	2-3	86	84	0	5200
Cyhalofop-butyl + 1.25%v/v COC	0.06	4-6	38	43	0	1470
Cyhalofop-butyl + 1.25%v/v COC	0.13	4-6	28	25	0	1420
Cyhalofop-butyl + 1.25%v/v COC	0.19	4-6	45	38	0	1260
Cyhalofop-butyl + 1.25%v/v COC	0.25	4-6	51	56	0	2110
Cyhalofop-butyl + 1.25%v/v COC	0.5	4-6	86	83	0	4500
Propanil	4	4-6	33	26	0	1930
Quinclorac + 1.25% v/v COC	0.5	4-6	85	83	0	4590
$LSD_{(0.05)}$			12	13	NS[w]	1240

[z] R- and S-BYG = propanil-resistant and -susceptible barnyardgrass.
[y] DAT = days after treatment; 29 days after 2- to 3-lf rice application or 17 days after 4- to 6-lf rice application.
[x] COC = crop oil concentrate (Agri-Dex®).
[w] Not significant.

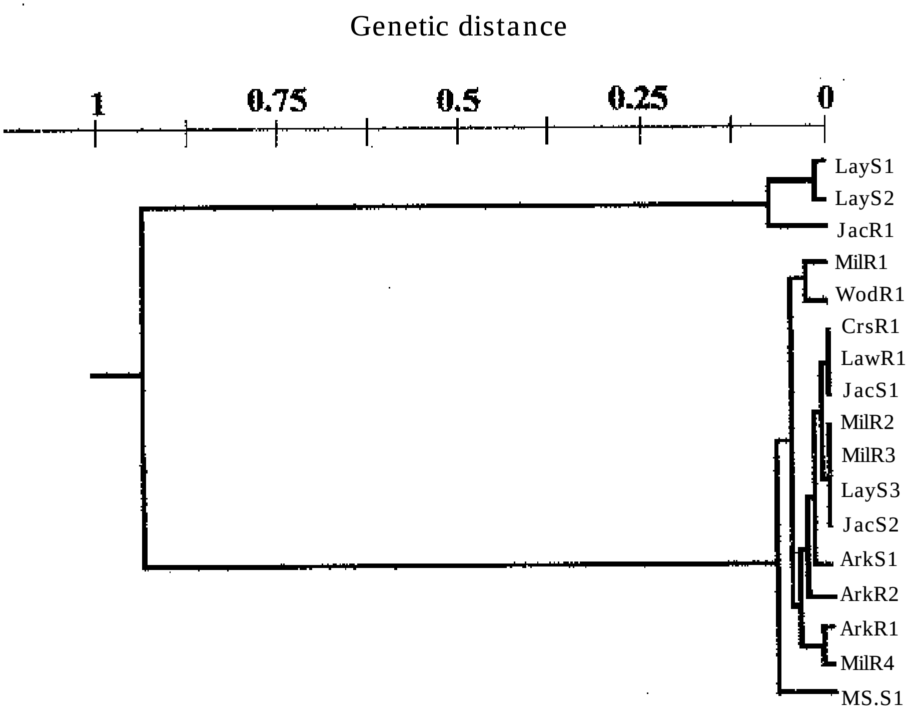

Fig. 1. Genetic distances between different samples of barnyardgrass throughout Arkansas counties.

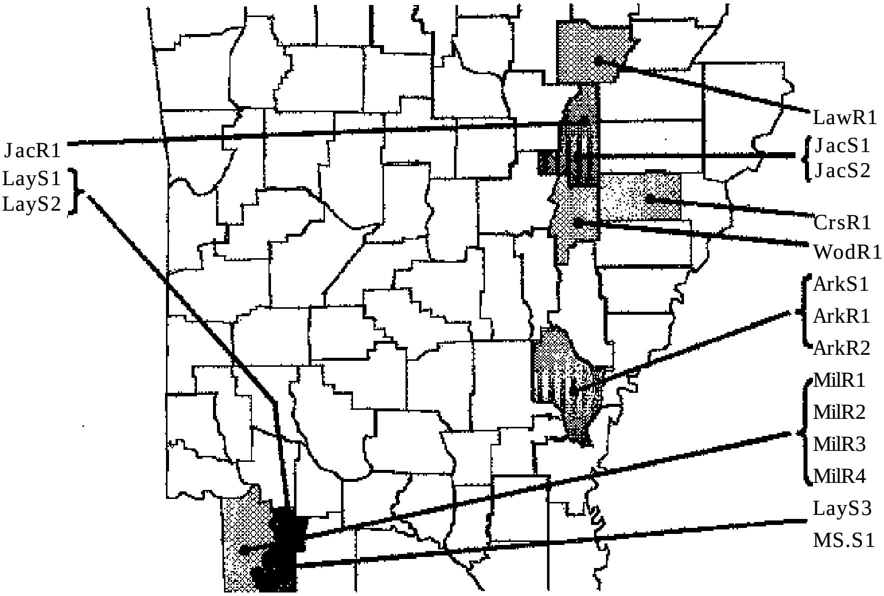

Fig. 2. Geographic distribution of different barnyardgrass samples in Arkansas used in genetic studies.

SCREENING RICE LINES FOR SUSCEPTIBILITY TO DISCOLORED KERNELS: RESULTS OF A STATEWIDE RICE SURVEY FOR DISCOLORED KERNELS

J.L. Bernhardt

ABSTRACT

A total of 2309 rough rice samples were collected from rice cooperative storage facilities in 1996. Samples were from Arkansas (94%), Missouri (4%), Mississippi (1%), and Louisiana (1%). Each sample was evaluated for amounts of kernel discolorations caused by rice stink bugs, kernel smut, other diseases that cause bran and kernel discolorations, and linear damage. General trends that had been reported from small-plot studies such as the Arkansas Rice Performance Trials conducted for 10 years, were also noted in these samples. For example, varietal susceptibilities to rice stink bugs, kernel smut, other bran and kernel discolorations, and linear damage, were similar to rankings previously reported. These data allow breeders to be more confident in small-plot evaluations for discolored kernels and to use the information in the selection of lines for further tests and the elimination of lines which are clearly more susceptible to damage. Rice growers can also use the information to choose cultivars and use management practices that will reduce discounts due to discolored kernels.

INTRODUCTION

In small field plots rice kernels can be discolored 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. The same agents are also common in Arkansas rice fields and cause similar kernel discolorations. Local environmental conditions vary greatly over the state each year, and variations greatly influence agents that cause kernel discolorations.

A portion of the entomology research program has placed emphasis on the evaluation of rice lines for susceptibility to kernel discolorations. These evaluations are routinely completed in small plots. Whether conclusions taken from small rice plots in a few locations will apply to rice fields over the state is a concern for rice researchers. This report is a summary of evaluations of rice samples taken from rice fields in several states for levels of kernels discolored by rice stink bugs and other causes.

PROCEDURES

Arkansas rice cooperatives collect and store tens of thousands of rice samples from individual lots of rice offered at dryer locations. Among detailed records that accompany each sample are identifiers for cultivar, and state and county of origin. The cooperatives also record the overall green-rice total weight and the green-rice totals at each dryer location for each cultivar delivered. With the cooperation of the rice cooperatives, 250-gram samples were taken from each cultivar at each dryer location in proportion to the amount delivered to that dryer, but with a set maximum number of samples from each cooperative. Within all samples from a dryer location and rice cultivar, individual samples were chosen at random. In 1996, a total of 2309 rough rice samples representing 19 rice cultivars were collected.

The rough rice samples were hulled and the 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 amount of discolored kernels in a category was weighed and expressed as a percentage of the total weight of brown rice.

RESULTS AND DISCUSSION

The number of samples from each state were as follows: Arkansas - 2165; Missouri - 93; Louisiana - 31; and Mississippi - 20. Samples originated in 31 counties in Arkansas and five counties in each of the other three states. Rough rice samples were of 19 rice cultivars in the following distribution of grain types: 14 long; 3 medium; and 2 short (Table 1). Results of the evaluations for discolored kernels are summarized by cultivar in Table 1 and grouped by grain type for each Arkansas county in Fig. 1. Rice cultivars 'Nortai', 'Maybelle', and 'Lebonnet' had only one sample each and were not included in the table or figure.

Rice Stink Bug

Based on data from the Arkansas Rice Performance Trials (ARPT) infestations of the rice stink bug varied from moderate to very high over the state in 1996 (Bernhardt, 1997). Although infestations may have been very high, estimates from various sources indicate that less than 5% of the rice acreage in Arkansas was treated for rice stink bug. Unfortunately, no records were available about the fields the rice samples were taken from for this survey concerning the treatment for infestations of the rice stink bug. The probability of any one of the randomly selected samples having been treated for rice stink bugs is low, and even if a small number had been treated, the effect on the overall average would be minimal.

Trends that had been noted in small-plot studies conducted for several years were also noted in these samples (Bernhardt, 1997). For example, (1) all samples had discolored kernels due to rice stink bug feeding; (2) the amount of discolored kernels in medium-grain cultivars ('Bengal', 'M204' and 'Mars') was more than that in the long-grain types; (3) long-grain cultivars such as 'Katy', 'Kaybonnet', and 'LaGrue', that routinely have less damage from rice stink bug in small-plot tests also had the lowest amounts of damage of all the long-grain types in this survey (Table 1); (4) no rice cultivars have resistance to rice stink bug, but some (Katy, Kaybonnet, and LaGrue) are less susceptible to damage from rice stink bugs probably due to differences in panicle size and the rate of grain development.

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 method of sample preparation removes totally consumed kernels, but detects kernels which have been only partially consumed by a kernel smut infection.

In 1996, environmental conditions were very conducive to kernel smut infection and the incidence of partially consumed kernels, in samples from the ARPT, was high in susceptible types (Bernhardt, 1997). Rice cultivars 'Cypress', LaGrue, M204, 'Alan', 'Jackson', and 'Newbonnet' previously have been identified as either very susceptible or susceptible to kernel smut (Cartwright *et al.*, 1997) and no surprises were noted in this survey for varietal susceptibility to kernel smut (Table 1).

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 category called 'other damage'. Brown discolorations are often confined only to the bran layer but pink, red, purple, or brown discolorations stain kernels. Some bran discoloration has been associated with severe brown spot (*Helminthosporium*) on the hull, and others appear to be common to a cultivar or caused by an interaction between cultivar and weather conditions. The amount of kernels in this category varies from year to year even within a cultivar. However, certain cultivars appear to be more susceptible than others. For example, 'M202', Bengal, Cypress, and Alan had moderate to high levels of other discolorations in the 1996 ARPT (Bernhardt, 1997). In this survey, only M204 and Bengal had moderate levels of discolorations in this category.

Linear Discolorations

This type of discoloration was described in 1950 by Douglas and Tullis. The damage is characterized as a linear 'cut' on the kernel that exposes the white kernel, and the area around the cut is either very dark brown or black. The discoloration is not limited to the bran, and milling does not eliminate the discoloration. Although all cultivars have small amounts of linear damage, medium- and short-grain types with Asian varieties as a parent are more susceptibile to linear damage. Results of 1996 ARPT evaluations show that conditions may not have been very favorable for linear damage (Bernhardt, 1997), but 'Koshihikari', M202, and Bengal had moderate levels of linear damage. This 1996 rice survey showed two cultivars 'Akitacomochi' and M204 with moderate levels of linear damage.

Red Rice

During the evaluations for discolored kernels, red rice was also encountered. The distribution of samples with red rice had 1261 (58%) with no red rice and 904 (42%) with red rice. Of the samples with red rice, 87% had less than 0.5% by weight and 1.2% had more than 5% by weight.

SIGNIFICANCE OF FINDINGS

Evaluations for levels of discolored kernels in rice samples taken from grower fields can be compared with information obtained from small-plot studies. The comparisons will enable researchers to verify the results of small-plot studies. If cultivars from rice fields have similar susceptibilities to causes of discolored kernels noted in small plots, then information from small plots will substitute for more expensive large-plot testing. Breeders can be more confident in small-plot evaluations for discolored kernels and use the information in the selection of lines for further tests and the elimination of lines which are clearly more susceptible to damage than exist at the present time. Rice growers can also use the information to choose cultivars and use management practices that reduce rice quality problems due to discolored kernels.

ACKNOWLEDGMENTS

I want to thank Sue Bennet, Kay Refeld, Sue Hale, and Clay McDaniel for steadfastness with the demanding hours required for sample preparation and evaluation. I also want to thank Producers Rice Mill and Riceland Foods for their cooperation and allowing me to obtain rice samples.

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Table 1. Average percent, by weight, of discolored kernels found in 16 rice cultivars from a total of 2165 samples taken in 31 counties of Arkansas, 1996.

		Cause of discolored kernels							
	No. of	Rice stink bug		Kernel smut		Other		Linear	
Cultivar	samples	Average	Range	Average	Range	Average	Range	Average	Range
Adair	15	0.64	0.36-1.22	0.071	0-0.467	0.74	0.21–3.15	0.013	0-0.053
Akitacomochi	4	0.53	0.26-0.75	0.014	0-0.032	0.93	0.38-1.46	0.132	0.01-0.21
Alan	103	0.76	0.05-2.27	0.112	0-1.215	0.61	0.08-2.68	0.005	0-0.034
Bengal	526	1.45	0.38-4.14	0.042	0-0.217	1.27	0-6.05	0.035	0-0.194
Cypress	516	0.55	0.08-2.62	0.188	0-1.654	0.51	0-5.29	0.002	0-0.141
Jackson	16	0.66	0.31-1.33	0.152	0-0.851	0.80	0.18-2.61	0.004	0-0.018
Jodon	2	0.61	0.46-0.76	0	-	1.31	1.03-1.59	0	-
Katy	21	0.41	0.13-0.94	0.023	0-0.100	0.41	0.13-1.43	0.001	0-0.011
Kaybonnet	593	0.36	0.07-1.41	0.028	0-1.100	0.40	0-3.49	0.004	0-0.036
LaGrue	197	0.37	0.08-1.46	0.334	0-2.307	0.43	0.04-2.50	0.005	0-0.04
Lacassine	24	0.61	0.30-1.08	0.016	0.-0.106	0.68	0.19-1.92	0.001	0-0.01
Lemont	49	0.57	0.10-1.58	0.026	0-0.735	0.50	0.13-1.32	0.001	0-0.033
M204	2	1.14	0.87-1.42	0.130	0.02-0.24	1.53	1.51-1.55	0.149	0.14-0.154
Mars	3	0.92	0.71-1.10	0.005	0-0.015	0.57	0.51-0.63	0.003	0-0.008
Millie	43	0.60	0.16-1.45	0.115	0-0.825	0.44	0.08-1.67	0.017	0-0.331
Newbonnet	48	0.64	0.19-1.82	0.109	0-0.508	0.43	0.04-2.90	0.007	0-0.093

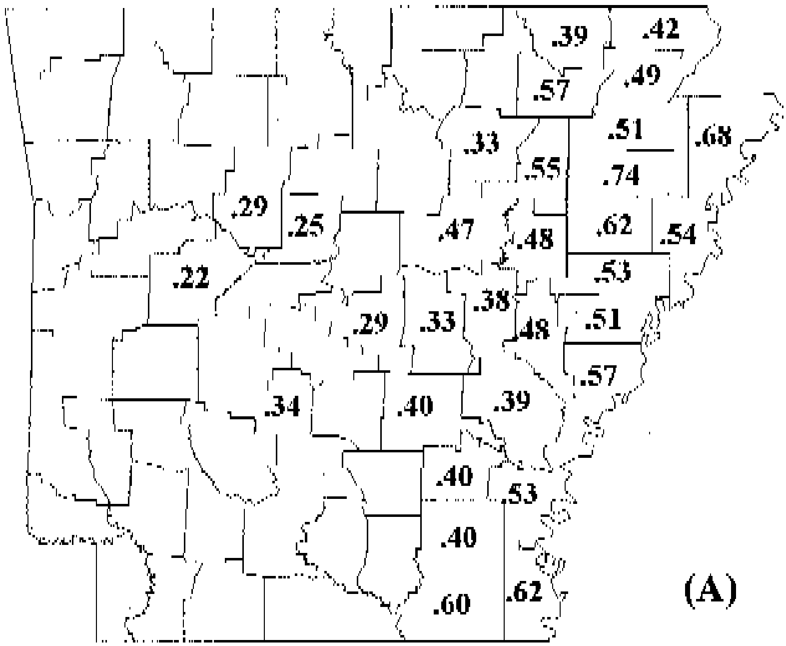

Fig. 1a. Percent, by weight, of kernels discolored by rice stink bug in all long-grain cultivars for Arkansas counties in the 1996 surveys.

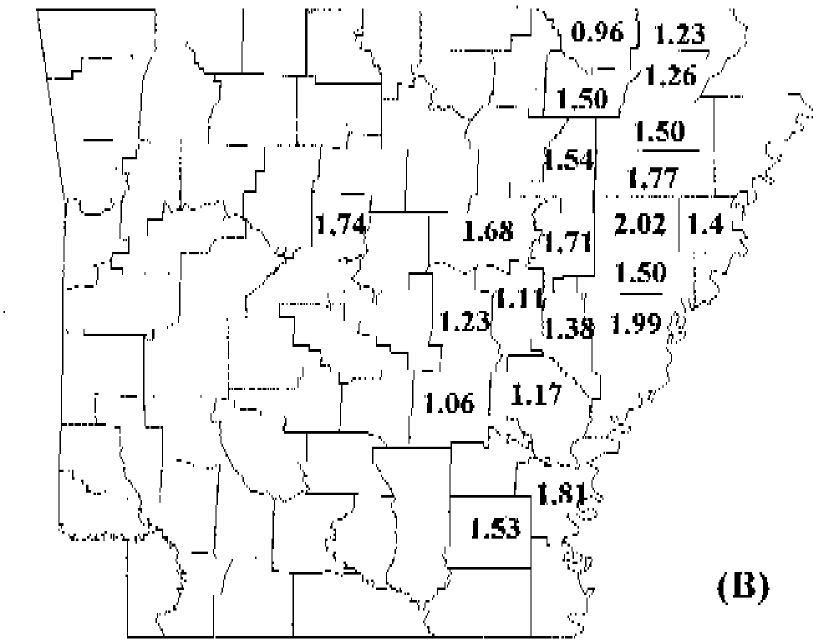

Fig. 1b. Percent, by weight, of kernels discolored by rice stink bug in all medium-grain cultivars for Arkansas counties in the 1996 survey.

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

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ABSTRACT

Rice lines were evaluated for susceptibility to causes of kernel discolorations. Advanced rice lines in the Arkansas Rice Performance Trials (ARPT) were compared to check cultivars for susceptibility, to feeding by rice stink bugs, to kernel smut infection, to other causes of bran and kernel discolorations, and to linear damage. In 1998, moderate to high levels of discolorations caused by rice stinkbugs and kernel smut infection were found in the ARPT. The short-grain lines RU9601096 and RU9601099 ('Koshihikari'/'Mars' crosses) had high levels of kernel discolorations due to rice stink bug and linear damage. The rice line RU9601053 is being considered for release with the cultivar name 'Wells'. Based on evaluations from 1996 to 1998, the line should be considered moderately resistant to kernel smut, moderately susceptible to bran discolorations, not susceptible to linear damage, but highly susceptible to damage from rice stink bugs. These data from yearly evaluations of rice lines and cultivars 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 choose cultivars and use management practices that will decrease quality reductions due to discolored kernels.

INTRODUCTION

Rice lines have different 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 most rice kernels at all stages of development, except at hard dough and maturity. 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 often influences the acceptability and value of rough rice.

The entomology research program has placed emphasis on the development of control strategies that integrate control methods such as use of 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 and, perhaps, to safeguard against the release of more susceptible cultivars from all breeding programs that exist at the present time, and to evaluate the rice germplasm for sources of resistance.

To accomplish the objectives, rice grain samples must be obtained from several sources for several years and evaluated for the amount of discolored kernels. Results from the evaluations of rice lines are compared and conclusions drawn on the relative susceptibility of rice lines 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 Arkansas Rice Performance Trials (ARPT) (1988-1998); (2) rice lines from breeding programs of other universities and private seed companies in the ARPT (1988 - 1998); and (3) advanced rice lines placed in the Uniform Regional Rice Nursery (URRN) (1993-1998). Locations of the ARPT were the Rice Research and Extension Center, Stuttgart (RREC, Arkansas County); Jackson County near Tupelo, Arkansas; Pine Tree Branch Experiment Station, Colt (PTBES, St. Francis County); Northeast Research and Extension Center, Keiser (NEREC, Mississippi County); and the Southeast Branch Experiment Station, Rohwer (SEBES, Desha County). Locations of the URRN were the RREC in Arkansas (1993-1998); Rice Research Station, Crowley, Louisiana (1994-1996, 1998); Texas Agricultural Experiment Station, Beaumont, Texas (1994-1998); and Delta Research and Extension Center, Stoneville, Mississippi (1995-1998). Among the entries in the ARPT and URRN, check cultivars are used for comparisons. Data from check cultivars and advanced rice lines in the ARPT from 1991 through 1998 are included in this report. Data from the 1998 URRN and from the advanced lines in the midseason maturity group of the ARPT are not yet available.

Uncleaned rough rice samples were taken 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 amount of discolored kernels in a category was weighed and expressed as a percentage of the total weight of brown rice.

RESULTS AND DISCUSSION

Rice Stink Bug

Large field tests, such as the ARPT, rely on natural infestations of the rice stink bug. In 1998, infestations of the rice stink bug varied from moderate levels at the RREC to very high at SEREC. General trends, that were noted in other years of the ARPT and other varietal studies (Bernhardt 1992), remained the same (Table 1). For example, the amount of discolored kernels in two medium-grain cultivars was more than that in the 12 long-grain cultivars. Also, long-grain cultivars that routinely have less damage from rice stink bug, such as 'Katy', 'Kaybonnet', and 'LaGrue', had the lowest amounts of damage in all the long-grain entries tested in 1998.

Of the 13 advanced long-grain rice lines in the very-short-season maturity group only 15% had levels of damage equivalent to those of 'Jefferson'; 46% had levels equivalent to 'Alan', 'Jackson', and 'Millie'; and 38% had levels much higher than all check cultivars. The short-grain lines RU9601096, RU9601099, RU9801096, and RU9801099 had high levels of damage.

Of the 16 advanced long-grain lines in the short season maturity group, all had levels of damage higher than that of LaGrue and Kaybonnet. The rice line RU9601053 is currently under review for possible release as rice cultivar 'Wells' and is susceptible to rice stink bug at levels similar to 'Cypress' and 'Newbonnet'. Both of the medium-grain lines had levels of damage equivalent to that of 'Bengal'.

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 method of sample preparation removes that type of infected kernels, but often detect kernels which have been only partially consumed by a kernel smut infection. Environmental conditions in 1998 were conducive to kernel smut, and the incidence of partially consumed kernels in samples from the ARPT, was similar to that of 1996 (Table 2). Susceptible cultivars, such as Cypress, LaGrue, 'M202', Alan, Millie, and Newbonnet, had more kernel smut than other cultivars. Of the long-grain lines in the very-short-season group, only two had levels of kernel smut that were consistently lower than the check cultivars. The short-grain lines RU9601096 and RU9601099 were resistant to kernel smut. Of the long-grain lines in the short season group, 94% had levels substantially lower than that of LaGrue. RU9601053 had very low levels equivalent to those of Kaybonnet and Katy.

Other Discolored Kernels

Our method of evaluation of rice also detects kernels that are discolored by something other than rice stink bugs, kernel smut, or linear damage. These kernels are placed in a category called 'other damage'. The discoloration is most often confined only to the bran layer. Causes for most of the bran discolorations have not been identified, however, a portion of the bran discoloration has been associated with severe brown spot (*Helminthosporium*) on the hull. Other discolorations appear to be common to a cultivar or caused by an interaction between cultivar and weather conditions. The amount of kernels in this category varies from year to year even within a cultivar (Table 3), however, certain cultivars appear to be more susceptible than others. For example, the medium-grain cultivars M202 and Bengal and the long-grain cultivars Cypress and Alan often have moderate to high levels of bran discolorations. The short-grain lines RU9601096 and RU9601099 and the long-grain cultivars 'Cocodrie' and 'Lemont' had moderate levels of bran discoloration. RU9601053 had low levels of damage.

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 weakened 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 cultivars have some damage, medium- and short-grain cultivars with Asian cultivars as one parent are more susceptibile to linear damage. It is suspected that high temperatures during grain fill or maturation cause more linear damage in the susceptible varieties. Results of 1998 ARPT evaluations show that conditions were not very favorable for linear damage (see Table 3), but the two short-grain lines RU9601096 and RU9601099 (Koshihikari is one parent of these lines) and the long-grain rice line Cypress had moderate levels of linear damage. No other advanced rice lines were susceptible to linear damage.

SIGNIFICANCE OF FINDINGS

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

The rice line RU9601053 is being considered for release with the cultivar name Wells. It should be considered moderately resistant to kernel smut, moderately susceptible to bran discoloration, 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 Newbonnet or Cypress, Wells may require applications of insecticides to control stinkbugs and reduce excessive discounts due to discolored kernels.

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

Maturity group and cultivar/variety	Grain type	Year 1991	1992	1993	1994	1995	1996	1997	1998
		(%)							
Midseason									
Cypress	L	-	0.44	1.30	0.59	0.99	1.62	0.53	1.67
Newbonnet	L	0.79	0.44	1.50	0.64	1.02	1.40	0.67	1.34
Lemont	L	0.45	0.30	1.14	0.43	0.74	1.40	0.70	1.56
Katy	L	0.31	0.21	0.98	0.41	0.51	0.85	0.36	0.88
Drew	L	-	-	0.82	0.48	0.67	1.26	0.55	1.17
Short-season									
Bengal	M	-	1.24	2.36	1.42	1.69	2.18	1.09	2.80
Kaybonnet	L	-	0.31	0.92	0.28	0.48	0.93	0.39	0.89
LaGrue	L	0.36	0.30	0.78	0.31	0.51	0.71	0.42	0.94
Cocodrie	L	-	-	-	-	-	-	0.76	1.99
RU9601053	L	-		-	-	-	0.60	0.88	1.83
Very-short-season									
Millie	L	0.58	0.36	1.15	0.54	0.35	1.26	0.64	1.50
Alan	L	0.69	0.56	1.65	0.84	0.66	1.49	0.72	1.48
Jefferson	L	-	-	-	-	-	0.87	0.47	1.21
M202	M	-	-	-	-	-	2.41	1.44	2.63
RU9601096	S	-	-	-	-	-	1.40	1.02	1.84
RU9601099	S	-	-	-	-	-	1.32	1.16	1.96

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

Maturity group and cultivar/variety	Grain type	Year 1991	1992	1993	1994	1995	1996	1997	1998
		(%)							
Midseason									
Cypress	L	-	0.023	0.075	0.000	0.006	0.202	0.066	0.269
Newbonnet	L	0.099	0.002	0.123	0.000	0.008	0.132	0.037	0.084
Lemont	L	0.014	0.008	0.035	0.006	0.003	0.053	0.073	0.080
Katy	L	0.009	0.003	0.007	0.030	0.002	0.038	0.004	0.046
Drew	L	-	-	0.025	0.042	0.005	0.058	0.015	0.097
Short-season									
Bengal	M	-	0.006	0.016	0.000	0.002	0.033	0.010	0.093
Kaybonnet	L	-	0.006	0.021	0.000	0.001	0.056	0.008	0.066
LaGrue	L	0.027	0.035	0.090	0.000	0.011	0.471	0.063	0.321
Cocodrie	L	-	-	-	-	-	-	0.014	0.165
RU9601053	L	-		-	-	-	0.072	0.021	0.068
Very-short-season									
Millie	L	0.001	0.013	0.081	0.136	0.005	0.351	0.016	0.384
Alan	L	0.000	0.001	0.034	0.171	0.006	0.316	0.029	0.255
Jefferson	L	-	-	-	-	-	0.254	0.016	0.261
M202	M	-	-	-	-	-	0.397	0.068	0.277
RU9601096	S	-	-	-	-	-	0.003	0.001	0.073
RU9601099	S	-	-	-	-	-	0.004	0.001	0.037

Table 3. Average percent, by weight, of linear discolorations and kernels discolored by other causes in brown rice samples of rice cultivars in the Arkansas Rice Performance Trials.

Maturity group	Grain	All Other discolored kernels					Linear damage		
and cultivar/variety	type	1994	1995	1996	1997	1998	1996	1997	1998
		(%)							
Midseason									
Cypress	L	0.55	0.83	2.00	0.44	0.59	0.007	0.002	0.217
Newbonnet	L	0.52	0.80	1.36	0.26	0.25	0.085	0.011	0.037
Lemont	L	0.75	0.68	1.66	0.43	0.66	0.008	0.000	0.029
Katy	L	0.28	0.41	1.07	0.16	0.20	0.019	0.002	0.013
Drew	L	0.17	0.27	0.69	0.17	0.28	0.014	0.005	0.014
Short-season									
Bengal	M	0.95	1.43	2.49	0.48	0.68	0.119	0.076	0.097
Kaybonnet	L	0.15	0.29	0.64	0.16	0.24	0.018	0.013	0.023
LaGrue	L	0.23	0.41	0.83	0.44	0.30	0.016	0.012	0.014
Cocodrie	L	-	-	-	0.42	0.79	-	0.014	0.036
RU9601053	L	-	-	0.60	0.25	0.36	0.016	0.010	0.024
Very-short-season									
Millie	L	0.54	0.47	1.11	0.35	0.44	0.075	0.011	0.028
Alan	L	0.64	0.73	2.08	0.51	0.52	0.047	0.027	0.025
Jefferson	L	-	-	1.42	0.43	0.45	0.061	0.007	0.020
M202	M	-	-	6.69	1.56	1.81	0.261	0.141	0.099
RU9601096	S	-	-	1.39	0.72	0.68	0.694	0.266	0.189
RU9601099	S	-	-	1.88	0.71	0.56	0.360	0.271	0.150

TRAPPING ADULT RICE WATER WEEVILS WITH FLOATING CONE AND BARRIER TRAPS

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

ABSTRACT

This study evaluated the use of floating cone traps to monitor adult rice water weevils in rice. Traps of two colors (yellow or gray) without baits or lures were either placed in the bar pits or 20 ft into the rice bay. The traps were checked and adults recorded daily for seven days after permanent flood. Although infestations appeared low, more adults were captured in the bar pits than in the bay interior, and more were taken in yellow traps than white traps. Rice water weevil larvae were also monitored at three and four weeks (wk) post flood. Larval counts were low and were below the Arkansas economic threshold of 10 larvae / core.

A double-ended barrier trap was developed and tested without lures or baits on F_1 rice water weevil adults. Barrier traps were placed next to rice plants in a bay of late-seeded rice. Adult and larval rice water weevil infestations were surprisingly very high. The barrier traps caught 2.5 to 18 times more adults than did the yellow or gray floating cone traps. Trap designs will be tested in 1999 with and without rice plant lures.

INTRODUCTION

Control of the rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel, (Coleoptera: Curculionidae) in drill-seeded rice with the insecticide lambda cyhalothrin (Karate®) had the best results when the application was within 10 days after permanent flood (Bernhardt 1997). Current scouting methods may be inadequate (adult leaf feeding scar method) or too late (larval soil-core sampling) to determine the need or timing for an application of Karate. Therefore, a reliable scouting method for adults is urgently needed.

This study evaluated the use of floating cone and barrier traps to monitor adult rice water weevils. The floating cone trap was based on the teepee trap design previously tested (Hix *et al.*, 1997) and the barrier trap was a new design.

PROCEDURES

Experiment 1. A randomized complete block design was used with four blocks consisting of four bays 290 by 60 ft seeded with 'Cypress' rice at the Rice Research and Extension Center (RREC) near Stuttgart. On 3 June, 10 gray floating cone traps or 10 yellow floating cone traps (Fig. 1a) per bay were placed in the borrow pits or 20 ft into the bay interior. No lures or attractants were placed in the traps. The traps were checked daily for seven days after permanent flood. Larvae were monitored in four plant/soil core samples that were taken from edges and four from the centers of each of the 16 bays at three and four wk post flood. Soil was washed from the plant roots into a 40-mesh sieve screen. The screen was immersed in salt water, and rice water weevil larvae were removed and counted.

Experiment 2. After a severe thunderstorm 5 June, it was noted that some overturned traps still captured weevils. A double-ended barrier trap (Fig. 1b) was developed and tested on F_1 adult RWW. On 22 July, 16 of the double-ended barrier traps without lures or baits were placed next to rice plants (Fig. 1b) in late-seeded 'Lemont', PI312777, and inter-planted plots (alternate rows) of the two rice lines. In addition, 10 gray and 10 yellow floating cone traps were placed in the bar pits and inter-plot alleys. Adult weevils were removed from the traps on 23 and 24 July. At 29 days after permanent flood (2 July), one plant/soil core sample was taken in eight plots of each rice line and two core samples, one from each line, from eight of the inter-planted plots. Procedures for removing larvae from the cores were as described previously.

RESULTS AND DISCUSSION

Experiment 1. The daily trap catch means for the floating cone traps were low (Figs. 2 and 3), and larval densities in each plot were below the Arkansas economic threshold of 10/core (Fig. 4). The floating cone traps in the borrow pits consistently caught more adults than those in the interior. The 40 yellow floating cone traps in borrow pits captured 15.83 RWW adults/trap (± 1.49 SE) over seven days, while the 40 gray floating cone traps in borrow pits captured 8.3 RWW adults/trap (± 2.45 SE). These rice plots had about two RWW larvae/rice root core sample taken three and four wk post flood. Furthermore, the floating cone design performed better than the teepee trap design (0.3 adult RWW/teepee trap)(Hix *et al.*, 1997).

Experiment 2. The barrier trap catch means for F_1 adults were larger than the catch means for the cone traps (Fig. 5). The F_2 larvae means from the core samples were very high and well above the Arkansas economic threshold of 10 larvae/core (Fig. 6). It is unusual for large numbers of F_2 larvae to occur in Arkansas rice fields. Although, beyond the scope of this study, the circumstances that may have contributed to these high densities were (1) most rice near the RREC in 1998 was seeded during April and early May, (2) F_1 adults emerged from early rice perhaps too early to go to overwintering sites, (3) these plots were seeded later in the season, and (4) one rice line, PI312777, had a more dense diffuse root system than all other southern cultivars which may have enhanced larval survival.

SIGNIFICANCE OF FINDINGS

The data from these studies suggest that a trapping system to monitor adult rice water weevils can be developed in the future to replace the leaf scar method (Morgan *et al.*, 1989; Tugwell and Stephen, 1981) and the core sample. The barrier trap is especially promising even without a lure. This trap design averaged 128.3 RWW F_1 adults / trap (2052 weevils in 16 traps) over a 48-hour period from 24 to 23 July 1998. Thus, the barrier trap may already be a useful monitoring tool for detecting presence of RWW adults post flood. However, barrier traps baited with attractants such as specific odors from flooded rice and / or pheromones from RWW adults may realize further increases in trap capture.

Future studies will focus on relating barrier and floating cone trap catches of adult RWW to subsequent larval core sample counts to determine if adult trap catches relate to core samples. Both the floating cone and the weevil double-ended barrier trap designs, and additional trap designs, will be tested in 1999 with and without rice plant lures. Unfortunately, the floating cone traps were tested in bays with low weevil pressure. Attempts will be made in 1999 to test traps in situations from low to high weevil pressure.

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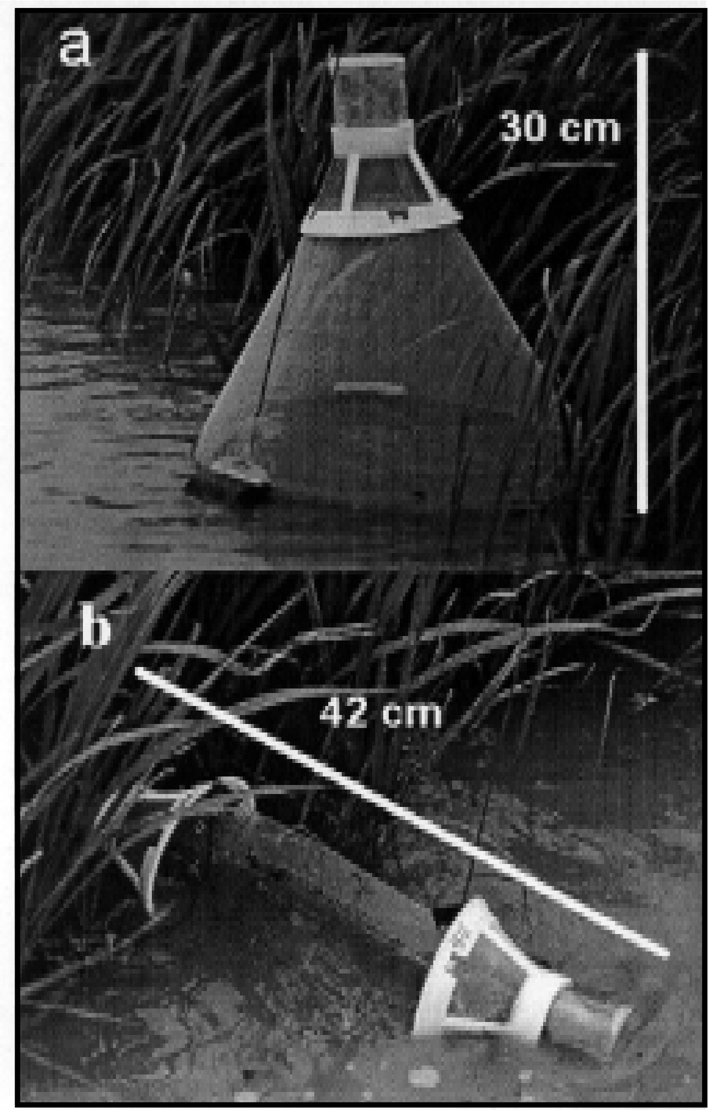

Fig. 1. Adult rice water weevil floating cone trap (a) and barrier trap (b).

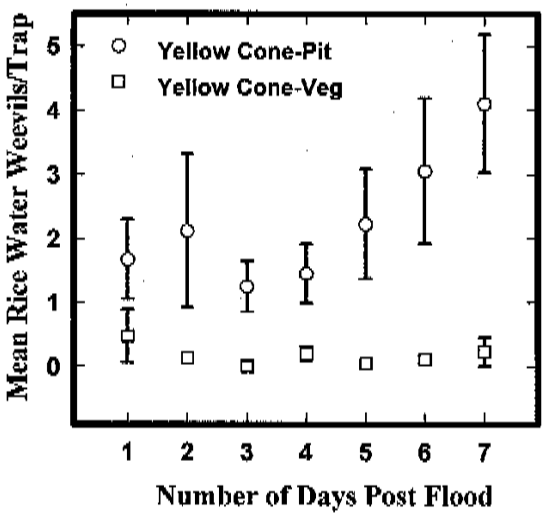

Fig. 2. Daily adult rice water weevil means for yellow floating cone traps. Bars denote SE (N=4).

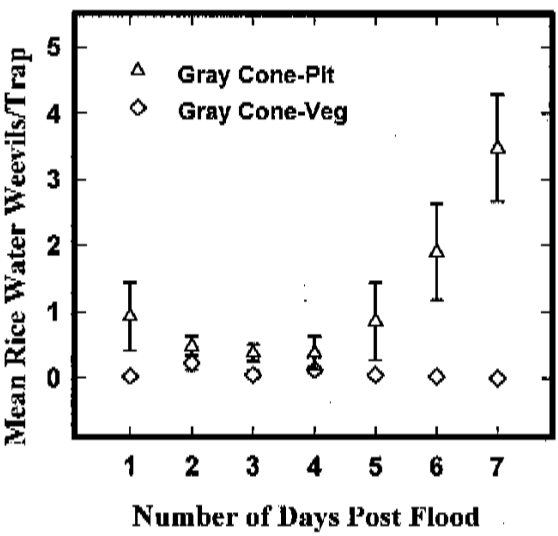

Fig. 3. Daily adult rice water weevil means for gray floating cone traps. Bars denote SE (N=4).

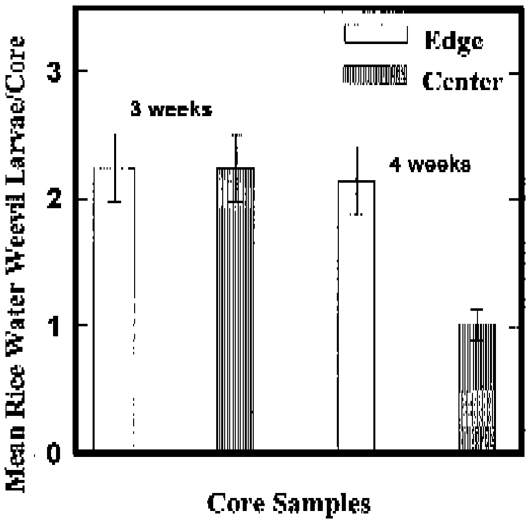

Fig. 4. Larval rice water weevil core samples at three and four weeks post flood. Arkansas economic threshold = 10 larvae/core. Bars denote SE (N=64).

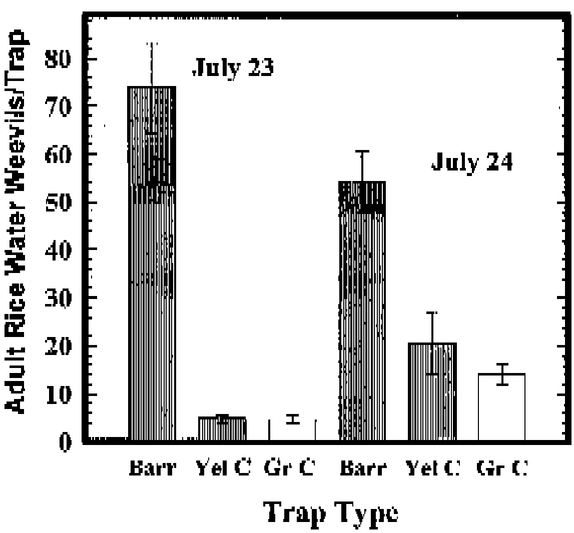

Fig. 5. Trapping of F_1 adult rice water weevils for prototype testing. Bars denote SE (N=16 for barrier traps and N=10 for floating cone traps).
Barr=Barrier, Yel C=Yellow Cone, and Gr C= Gray Cone.

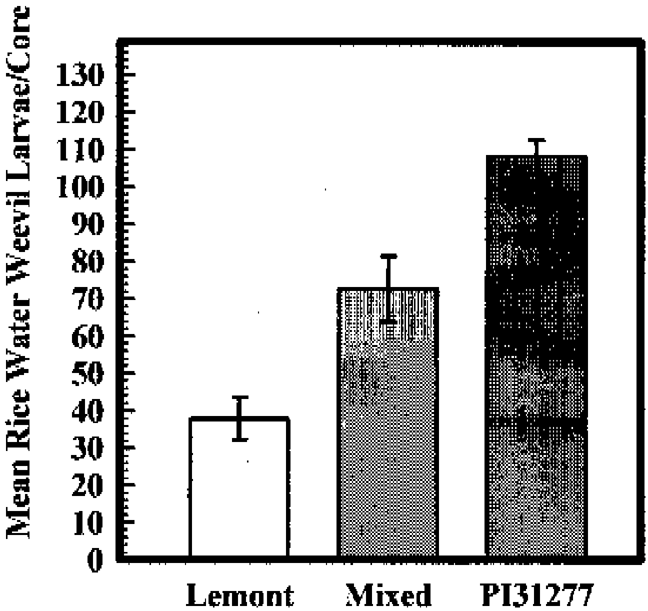

Fig. 6. Core sample of F_2 rice water weevil larvae. Larvae means are significantly above Arkansas economic threshold of 10 larvae/acre. Bars denote SE (N=8).

THE EFFECT OF PANICLE BLAST ON THE PHYSICAL PROPERTIES AND MILLING QUALITY OF RICE CULTIVAR 'M202'

B. L. Candole, T. J. Siebenmorgen, F. N. Lee and R. D. Cartwright

ABSTRACT

Preliminary observations in 1997 indicated a significant reduction in bulk density and head rice yield of cultivar 'LaGrue' due to blast. A study to determine the effect of panicle blast on the physical properties and milling quality of rice was continued in 1998. Since environmental conditions during the 1998 growing season were not conducive for blast development, only one cultivar ('M202') from one location (Pocahontas) was available for sampling. Rough rice from blast-infected panicles had moisture contents lower than the average moisture content of rough rice from blast-free panicles. Sixty-five percent of the kernels from the diseased samples had thicknesses less than the average kernel thickness of the kernels from blast-free samples. The incidences of unfilled, chalky, and fissured kernels in diseased samples were higher by 30, 21, and 7%, respectively, than in blast-free samples. Blast reduced kernel bulk density by 140 kg/m^3 and head rice yield by 12%. The 1998 results concur with those found in 1997 indicating a negative impact of blast on the physical properties and milling quality of rice.

INTRODUCTION

Rice blast caused by *Pyricularia grisea* Cav. is one of the most economically significant fungal diseases of rice in the world (Cu *et al*., 1996). Blast is destructive under conditions favorable for disease in both tropical and temperate areas (Ou, 1985). Reliable estimates and exact figures of grain yield losses caused by blast are very few (Hwang *et al*., 1987; Ou, 1985). Popular press articles indicate that blast can cause up to 50% yield loss in individual rice fields (Gannon, 1997). Heavy blast infection of panicles is often detrimental to rice yields because blast constricts the main node of the panicle which reduces the translocation of photosythates to the kernels (Torres and Teng, 1993).

There is little information on the impact of blast on the physical properties and milling quality of rice. It has been reported that for every 10% of neck blast incidence, there was a 6% grain yield reduction and a 5% increase in chalky kernels, which lowered the rice quality by one to two classes (Katsube and Koshimizu, 1970). Previous research data have also indicated the effect of blast on photosynthesis, translocation of photosynthates, and grain filling (Baastians, 1991; Torres and Teng, 1993). A negative effect of blast on the above yield processes could also have a negative effect on the quality of rice kernels. This study was therefore conducted to determine the effect of blast on the physical properties and milling quality of rice.

PROCEDURES

Sampling. Environmental conditions during the 1998 cropping season were not favorable for blast development in Arkansas. Hence, only one cultivar and one location was sampled. Rough rice samples were collected from varietal performance trial plots in Pocahontas on 12 September 1998. Blast-free and blast-infected panicles of cultivar M202 were collected by hand and hand-threshed individually. Four samples (or replicates) of rough rice each weighing about 300 g from blast-free and blast-infected panicles were collected. Additionally, 20 blast-free and 20 blast-infected panicles per replicate were collected. From these panicles, the number of filled kernels and unfilled kernels was counted to determine the percentage of unfilled kernels per panicle.

Physical Properties. Immediately after sampling, 100 kernels of rough rice from each sample were analyzed for individual kernel moisture content distribution using a Shizuouka Seiki Single Kernel Moisture Tester (CTR-800A). Another 100 kernels of rough rice from each sample were analyzed for individual kernel thickness distribution using a Satake Rice Image Analyzer (RIA1A). The samples were then dried to 12.5% equilibrium moisture content (EMC) in an equilibration chamber set at 21°C and 52-53°C air temperature and relative humidity, respectively. The equilibrated rough rice was then analyzed for bulk density by obtaining the weight of rough rice in a 50-ml beaker and subsequently expressed as kg/m^3. Kernels were collected from each equilibrated sample and were individually dehulled by hand until 100 filled and non-chalky kernels were obtained. From these 100 kernels, the number with fissures was counted to determine the percentage of kernels with fissures. A second sample of 100 kernels was also dehulled by hand and the number of chalky kernels was counted to determine the percentage of chalky kernels.

Milling. One hundred fifty grams of rough rice at 12.5% moisture content (MC) from each sample were dehulled and then milled for 35 s with a McGill No. 2 laboratory mill to determine head rice yield (weight percentage of rough rice that is composed of kernels that are at least three-fourths kernel or more in length after milling). Head rice was analyzed for degree of milling (DOM) in a Satake MM1-B milling meter. The head rice weights were then expressed based on a DOM of 90 (Reid *et al*., 1998).

RESULTS AND DISCUSSION

A typical observation regarding physical property effects is shown in Fig. 1. At the sampling time depicted in Fig. 1, individual kernel moisture content distribution analyses showed that 100% of the kernels from blast-infected panicles had individual kernel moisture contents that were lower than the average moisture content (19.7%) of the kernels from blast-free panicles. Sixty-five percent of the kernels from blast-infected panicles had individual kernel thicknesses that were less than the average thickness (1.96 mm) of the kernels from blast-free samples. Blast significantly reduced kernel bulk density by 140 kg/m^3. This was due in large part to the observation that samples from blast-infected panicles had 30% more unfilled kernels than samples from blast-free panicles (Fig. 2). The data on reduced bulk density due to blast confirmed earlier preliminary (1997) data on cultivar LaGrue. The said data showed that blast reduced the bulk density of LaGrue by 32%.

The incidence of chalky kernels was significantly higher in samples from blast-infected samples (23%) than in samples from blast-free panicles (2%) (Fig. 3). The incidence of fissured kernels was also significantly higher in samples from blast-infected panicles (8%) than in samples from blast-free panicles (1%). This is speculated to be due to fissuring created by rapid moisture adsorption of low moisture content kernels, which were more prevalent in the blast-infected samples (Fig. 1). Moreover, blast significantly reduced head rice yield by12 % (Fig. 4). Preliminary observations in 1997 showed that blast reduced head rice yield of LaGrue by 7%.

SIGNIFICANCE OF FINDINGS

Results demonstrate that blast could be a significant pre-harvest factor affecting the milling and physical properties of rice. Further studies involving more cultivars and more locations are needed to generate more conclusive data. However, the trends reported herein for cultivar M202 agreed with those for LaGrue in 1997. These data provide quantitative information on the effects of blast on milling and other quality indices. Another issue that is currently being addressed is the impact of blast on the functional and processing properties of rice. The latter could provide information to end-use processors on possible discrepancies in functional behavior of lots comprising the same cultivar and harvest location, but having varying levels of kernels coming from blast-infected panicles.

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ACKNOWLEDGMENTS

This study was funded by the Arkansas Rice Research Promotion Board. The authors would like to acknowledge the help of rice consultants Mark Meiher and Duane Johnson; rice producer Greg Baltz; and students Liwen Du, Leah Perdon, Katie Seward, and Nathan Blevins.

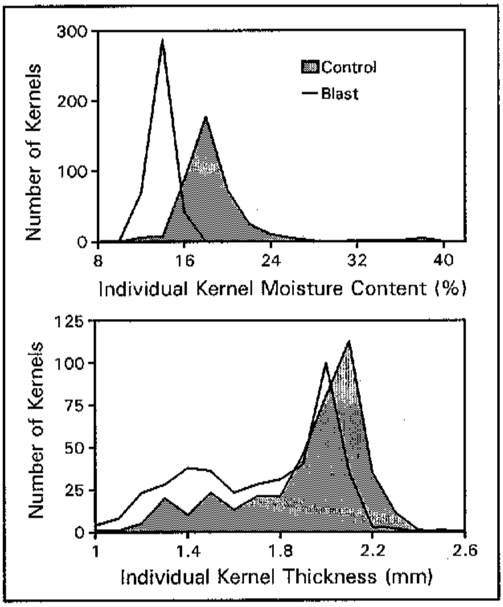

Fig. 1. The effect of blast on the individual kernel moisture content and thickness distributions of rice cultivar M202. Sample size is 400 kernels.

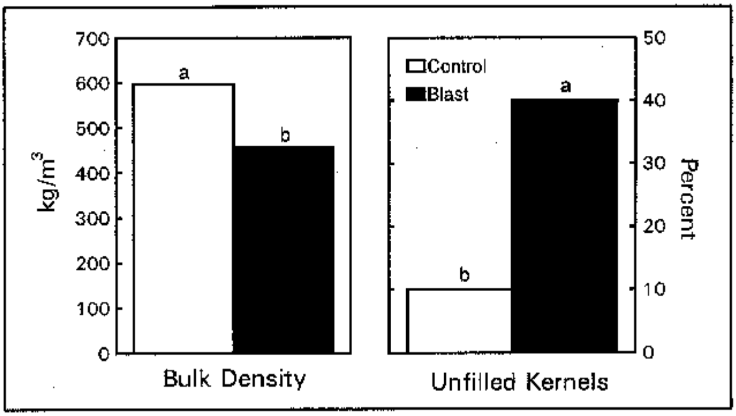

Fig. 2. The effect of blast on the bulk density and incidence of unfilled kernels of rice cultivar M202. Within a property, means with the same letters are not significantly different as tested by LSD at 5% level. Each bar represents the average of four replicates.

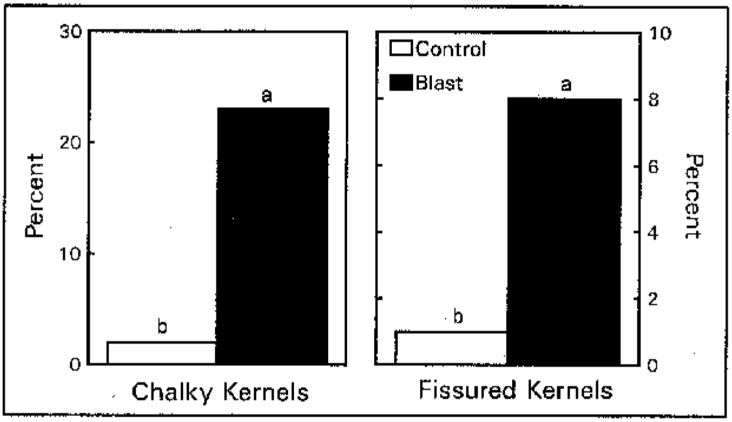

Fig. 3. The effect of blast on the incidences of chalky and fissured kernels of rice cultivar M202. Within a property, means with the same letters are not significantly different as tested by LSD at 5% level. Each bar represents the average of four replicates.

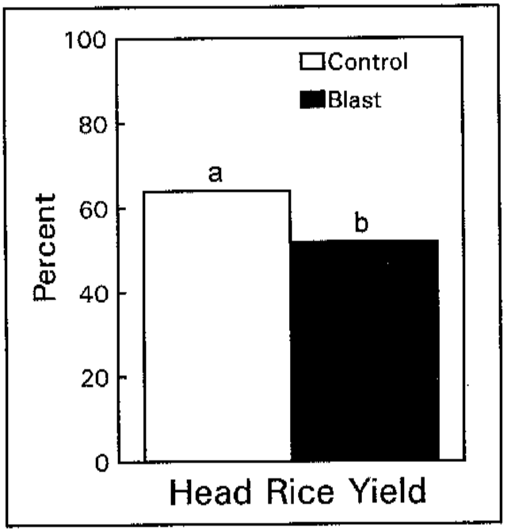

Fig. 4. The effect of blast on the head rice yield of rice cultivar M202. Means with the same letters are not significantly different as tested by LSD at 5% level. Each bar represents the average of four replicates.

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

R.D. Cartwright, F.N. Lee, C.E. Parsons, W.J. Ross, S.R. Vann, and R. Overton

ABSTRACT

In 1998, the Arkansas rice disease monitoring program was continued to determine the identity, distribution, and severity of rice diseases in the state and to evaluate rice cultivar/varieties under on-farm conditions. Monitoring sites featured 20 rice cultivars/lines planted in four replications at 10 locations. Yields varied widely with RU9602074, 'LaGrue', 'Bengal', and 'Wells' having the highest average yield and 'M202' the lowest. Sheath blight was the most widespread and severe disease in the monitoring plots and statewide, especially on highly susceptible semidwarf cultivars, while kernel smut was the most important disease on LaGrue. Blast was almost nonexistent in 1998 with no commercial field damage and only one monitoring site affected. False smut of rice, first observed in 1997 in Arkansas, was reported in 20 counties with the most severe levels in northeast Arkansas where an epidemic at the Craighead monitoring site resulted in comparative data on varietal susceptibility to this new disease.

INTRODUCTION

Rice diseases vary in type and intensity due to geographic location and production practices. In 1985, there were 74 major diseases of rice reported around the world caused by various agents including virus/mmhos, fungi, bacteria, nematodes, and physiological imbalances (Ou, 1985). Since that time, several new diseases have been reported as rice cultivars and cultural practices continue to evolve (Webster and Gunnell, 1992; Cartwright, *et al.*, 1994).

In the United States, there are at least five major diseases (i.e., sheath blight, blast, stem rot, kernel smut, and seed/seedling disease) all caused by fungi and one major physiological disorder termed '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 a nematode disease have 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 of plant diseases is critical to better understand the spectrum of disease problems on a particular crop and their potential for change over time. An example of change occurred in 1997 and 1998, as false smut became more widespread and important–for unknown reasons. Monitoring must be yearly, long-term, and consistent to be of value. Monitoring information guides research and suggests potential disease control options. Monitoring also serves as the first line of defense in the ongoing battle with rice diseases and can provide early warning of new plant diseases or increased importance of an existing minor disease. Early warning allows researchers to develop information on the disease and, hopefully, devise control methods before it causes major losses to producers.

PROCEDURES

A set of 20 rice cultivars / lines with different susceptibility to rice diseases was seeded in grower fields in Clay, Craighead, Cross, Lafayette, Lonoke, Miller, Poinsett, Randolph, White, and Woodruff counties. Grower fields were selected by cooperating extension agents based on disease history, cultural practices, and previous observations. Cultivars were seeded in plots 7 rows x 25 ft 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

The Lafayette location was lost to early flooding and abandoned. Of the remaining sites, yields varied widely as in previous years (Table 1). Yields were highest at the Lonoke site (Table 1) characterized by no problems and lowest at the Woodruff location, a field recently put to grade (Table 1). The line RU9602074 had the highest overall numerical yield followed closely by LaGrue, Bengal, and Wells while M202–a California cultivar not adapted here–had the lowest. Yield performance over several years in this program is detailed in Table 2.

Numerous diseases and lodging observed in the monitoring plots were summarized in Table 3 using the most severe location for the respective problem. Sheath blight was most severe at Clay, Cross, Poinsett, and Randolph counties with the highest severity of eight recorded for 'Lemont', 'Cypress', and 'Madison' cultivars (Table 3). Neck blast was noted only at the Randolph County location where M202, LaGrue, and 'Newbonnet' were infected. Kernel smut was observed at most sites but was most severe at the White County location on LaGrue, 'Litton', Newbonnet, Cypress, 'Priscilla', and 'Jefferson' (Table 3). False smut of rice, caused by the fungus *Ustilaginoidea virens*, was widely observed in 1998 throughout northeast and east central Arkansas and a uniform epidemic occurred at the Craighead site. The most susceptible entries appeared to be AB647, 'Cocodrie', 'Drew', and Newbonnet followed by LaGrue, 'Kaybonnet', Cypress and Wells (Table 3). The most resistant cultivars appeared to be Madison, Litton, Jefferson, and M202 (Table 3). Bengal and Lemont had limited false smut at the Craighead location, but commercial fields of these cultivars sometimes had more disease, supporting the need for additional evaluation of false smut reaction within current rice germplasm. Despite earlier predictions, our conditions appear to favor false smut which is likely to be a persistent problem in the future. Disease reactions for all rice cultivars / varieties in the on-farm evaluation program are shown in Table 4.

SIGNIFICANCE OF RESULTS

Results demonstrate the broad spectrum of rice diseases present in the state as well as their varying intensity as influenced by cultivar, location, and management practices. The disease monitoring program permits accumulation of comparative data from year to year and helps researchers focus on research needs and approaches. This research also provides supplemental data on cultivar reaction to diseases (under grower conditions) for the disease resistance research program (Table 4), helps assess the overall impact of diseases on rice production in a given year, and provides early detection of new diseases or changes in current diseases (false smut). This program has added significant new information to our knowledge of susceptibility of current cultivars / lines to false smut and continues to supplement our disease reaction database on kernel smut of rice. Monitoring sites were also the focus of six county field days, two disease training clinics, and numerous visits by county agents, farmers, and consultants.

ACKNOWLEDGMENTS

This research was funded by rice grower check-off funds through the Arkansas Rice Research and Promotion Board. Special thanks to Dr. K.A.K. Moldenhauer and Dr. Nathan Slaton of the University of Arkansas Rice Research and Extension Center.

Sincere appreciation is expressed to the following Cooperative Extension Service agents for their outstanding cooperation in this research: Q.R. Hornsby, R. Gipson, R.L. Thompson, R. Wimberley, E. Terhune, B. Thiesse, J. Vestal, D. Petty, M. Phillips, M. Hamilton, and D. Wallace.

Finally, deeply sincere appreciation is due to all participating rice growers without whose land, equipment, patience, and excellent advice this program would not have been possible.

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Table 1. Rice disease monitoring plot yields for 1998–sorted by cultivar/variety (yield in bu/acre 12% moisture).

	County location									Mean yield
Variety	Clay	Craighead	Cross	Lonoke	Miller	Poinsett	Randolph	White	Woodruff	by variety
	(bu/acre[z])									
RU9602074	157	178	160	193	91	153	152	170	106	151
LAGRUE	139	151	141	175	114	180	148	151	79	142
BENGAL	128	160	130	177	86	157	137	146	93	135
WELLS	143	150	132	179	94	162	125	164	63	135
AB647	98	150	130	160	126	151	147	79	150	132
DREW	127	161	140	165	107	161	118	135	55	130
COCODRIE	136	148	127	175	107	101	137	150	87	130
NEWBONNET	115	124	127	167	112	166	106	133	78	125
KAYBONNET	112	132	125	163	94	166	123	132	68	124
PRISCILLA	123	120	117	151	102	153	141	128	78	124
LAFITTE	116	146	124	173	93	96	133		98	122
LITTON	126	109	111	163	79	161	132	124	72	120
JEFFERSON	130	142	99	158	100	75	133	115	99	117
CYPRESS	116	143	108	155	88	133	120	117	66	116
MADISON	119	108	109	166	82	149	112	143	51	115
LEMONT	115	118	104	153	85	146	106	138	67	115
L202	142	106	95	164	53	135	138	118	66	113
KATY		133	112	149	79		103	111	87	111
KOSHI-HIKARI		124	96	149	58		128		106	110
M202	122	161	122	174	85	26	71	14	46	91

[z] Bushels per acres x 45 = pounds per acre.

Table 2. Summary yield data of selected cultivars/varieties from rice disease monitoring plots (1994-1998).

Cultivar/variety	Sorted by mean yield (high to low)					
	Yield 1994	Yield 1995	Yield 1996	Yield 1997	Yield 1998	Mean Yield 1994-1998
	(bu/acre)[z]					
BENGAL	181	164	171	162	135	163
LAGRUE	167	146	181	158	142	159
DREW	165	144	172	152	130	153
LAFITTE			172	151	122	148
KAYBONNET	165	138	165	143	124	147
WELLS				151	135	143
AB647				148	132	140
NEWBONNET	141	118	162	135	125	136
PRISCILLA				145	124	135
LEMONT	147	126	149	138	115	135
CYPRESS	140	127	155	136	116	135
KATY	149	128	150	132	111	134
LITTON				140	120	130
JEFFERSON			142	129	117	129
KOSHI-HIKARI				133	110	122
M202			149	114	91	118

[z] Bushels per acre x 45 = pounds per acre.

Table 3. Summary disease data for various rice cultivars/lines at the most severe monitoring location (within year) in Arkansas, 1994-1998.

	Sheath blight					Neck blast					Kernel smut					False smut
Cultivar/variety	1994	1995	1996	1997	1998	1994	1995	1996	1997	1998	1994	1995	1996	1997	1998	1998
	--------------- (0-9)[z] ---------------					-------- (% infected tillers) ------					---(% smutted kernels) ----					#/pan.
AB647				2.5	3.5				0	0				4	5	3.8
BENGAL	5	5	4	4	4.5	1	44	18	4	0	3	6	3	9	5	0.4
COCODRIE					8					0					8	3.1
CYPRESS	6	7	6	6	8	6	10	2	0	0	8	13	7	15	13	1.4
DREW	3	5	4	4.5	6		0	0	0	0	4	7	5	8	9	2.7
JEFFERSON			5	6	7			12	6	0			6	8	11	0.4
KATY	4	6	4	5	7		0	0	0	0	1	3	1	4	6	0.9
KAYBONNET	5	6	5	4.5	6	1	1?	0	0	0	5	4	3	8	7	1.8
KOSHIHIKARI				4	4				0	0				2	1	1.2
LAFITTE			4	4.5	5			0	0	0			8	14	6	0.5
LAGRUE	4	6	4	5	6	4	35	36	18	10	11	18	13	20	19	1.6
LEMONT	6	7	6	6	8	1	70	16	2	0	2	3	1	3	5	0.9
LITTON				4	5				0	0				20	15	0.1
MADISON					8					0					5	0.0
M202			4	4.5	6.5			100	52	50			5	12	6	0.1
NEWBONNET	3	5.5	3	4	5	10	100	40	22	10	9	12	6	14	12	2.4
PRISCILLA				4.5	6				4	0				12	11	1.1
WELLS				4	5.5				1	0				6	8	1.9
RU9602074					4					0					6	1.6

continued

Table 3. Continued.

	Brown spot					Narrow brown leaf spot					Head scab					Lodging
Cultivar/variety	1994	1995	1996	1997	1998	1994	1995	1996	1997	1998	1994	1995	1996	1997	1998	1998
	(0-9)										(no. infected kernels/panicle)					(%)
AB647				1	2									1	2	100
BENGAL	4	3	3	5	4						5	4	8	5	6	0
COCODRIE					3					2					1	15
CYPRESS	1	3	2	3	3		1				2	1	4	2	3	15
DREW	3	3	3	5	4		5	4	4	4	3		1		2	20
JEFFERSON			2	2	3			1		2			1		2	10
KATY	2	2	3	3	4	3	4	4	4	4	1	1	2	1	1	25
KAYBONNET	3	3	3	5	4		3	4	3	4	1	1	1		2	25
KOSHIHIKARI				1	1										1	100
LAFITTE			2	2	3			2	1				4	2	4	50
LAGRUE	2	2	3	3	5	3	2	2	2	2	3	1	2	1	2	10
LEMONT	3	2	3	3	3	2	2	3	3	3	1	1	1		1	0
LITTON				2	2										4	0
MADISON					3										2	0
M202			4	6	4			2	2	2			7	6	8	50
NEWBONNET	3	2	3	4	3	3	4	4	4	4	2	1	1		3	15
PRISCILLA				3	3				2	2				1	2	10
WELLS				2	2										1	0
RU9602074					3										4	100

[z] Diseases were evaluated as follows: sheath blight, brown spot, narrow brown leaf spot = 0-9 ratings where 0 = no disease and 9 = severe disease; neck blast = % infected tillers; kernel smut = % smutted kernels; false smut = no. of false smut balls per panicle; head scab = no. of infected kernels per panicle; and lodging = % of plot down at harvest.

Table 4. Disease reactions[z] for U.S. rice cultivars/lines that have been included in the monitoring/on-farm evaluation program (1994-1998).

Cultivar/variety	Sheath blight	Blast	Stem rot	Kernel smut	False smut	Brown spot	Straighthead
AB647	MS[y]	R	MS	S	VS	R	VS
Bengal	MS	MS	VS	MS	MR	VS	VS
Cocodrie	VS	MS[x]	S	VS	VS	R	
Cypress	VS	MR	MS	VS	S	R	MR
Drew	MS	R	MS	MS	VS	S	MR
Jefferson	S	S	MS	S	MR	R	MR
Katy	MS	R	MS	R	MR	R	S
Kaybonnet	MS	R	MS	MS	S	S	MS
Koshihikari	MS	MR	S	R	MR	MR	-
Lafitte	MS	MR	MS	S	S	MS	VS
LaGrue	S	S	MS	VS	S	R	MS
Lemont	VS	MR	MS	R	MS	R	MR
Litton	S	MS	MS	S	R	-	MS
Madison	VS	R	MS	R	R	R	
M-202[w]	MS	VS	MS	VS	MR	S	S
Newbonnet	MS	VS	S	VS	VS	R	MR
Priscilla	S	S	MS	S	MS	R	
Wells	MS	S	MS	MR	S	R	

[z] Abbreviations: R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible.
[y] Ratings are based on 1998 replicated plot and commercial field data only; should be considered tentative.
[x] Rating based on Louisiana State University observations. Tentative for Arkansas conditions.
[w] Not recommended for Arkansas because of extreme susceptibility to rice blast.

EVALUATION OF RICE GERMPLASM FOR REACTION TO KERNEL SMUT, FALSE SMUT, STEM ROT, AND BLACK SHEATH ROT OF RICE

R.D. Cartwright, F.N. Lee, W.J. Ross, S.R. Vann, R. Overton, and C.E. Parsons

ABSTRACT

A total of 70 rice varieties / lines were evaluated for reaction to kernel smut, stem rot, and black sheath rot in inoculated nurseries during 1998. Reaction to false smut and other opportunistic problems were also recorded in the nurseries and additional information for 20 varieties / lines, with respect to kernel and false smut, was collected at two disease monitoring locations where natural epidemics occurred. While not absolute, data from the inoculated kernel smut nursery allowed identification of highly susceptible lines like RU9701130 and RU 9801161 and preliminary grouping of other susceptible lines. Data from the stem rot nursery indicated that most lines were at least moderately susceptible under these conditions while reaction to black sheath rot varied more widely. Line RU9801179 appeared the most resistant to black sheath rot, with no detectable disease, and this line appeared to be one of the more resistant ones to stem rot as well. While only a first step, continued development of a standardized database for southern U.S. rice germplasm, with respect to these and the major diseases, represents an essential component of future successful breeding programs in rice.

INTRODUCTION

Kernel smut of rice has been a severe problem the past several years in Arkansas, notably on recently released cultivars like 'LaGrue' and 'Cypress'. Black sheath rot and stem rot also remain routine problems throughout Arkansas rice producing areas but little concerted effort to evaluate germplasm has been made in the southern United States. False smut is a new problem in Arkansas. It was first reported in 1997 in four counties. It was widely reported in 1998.

Kernel smut is caused by the fungus, *Neovossia horrida* = (*Tilletia barclayana*) (Whitney, 1989). Kernel smut infection has historically been difficult to induce under controlled conditions, however, improvements in the boot injection technique (Lee *et al.*, 1991), used originally in karnal bunt of wheat research, has resulted in a useful method to study certain aspects of this disease. Using this method, it has been clearly demonstrated that cultivars resistant in the field are not resistant when injected with kernel smut inoculum in the boot (Lee *et al.*, 1991). This method has shown that very few germplasm sources are resistant to kernel smut using the boot injection technique and a more natural inoculation procedure to screen germplasm should improve discovery of 'field' resistant germplasm. Recently, a more natural inoculation and field screening method was developed which was used in this study (Cartwright *et al.*, 1996).

False smut is caused by the fungus *Ustilaginoidea virens*, and the disease cycle--while poorly understood--appears similar to kernel smut of rice (Ou, 1985). In the case of false smut, a 'smut ball' replaces infected kernels and becomes the long-term survival structure for the fungus between crops. Airborne spores from 'smut balls' surviving in the soil produce the first infections at early heading and secondary infections are caused by airborne microscopic spores from developing 'smut balls' on the panicles. Apparently the fungus can also infect and survive on grassy weeds.

Stem rot is caused by the fungus *Sclerotium oryzae* (Krause and Webster, 1972) and black sheath rot by the fungus *Gaeumannomyces graminis* var. *graminis* (Ou, 1985). The stem rot fungus typically attempts to penetrate the culm of the rice plant, resulting in early tiller death and lodging while the black sheath rot fungus usually attacks only the sheaths (similar to sheath blight) although it can cause a node rot on some varieties. The stem rot fungus survives between crops as sclerotia in the soil while the black sheath rot fungus apparently survives on grassy weeds.

Screening of rice germplasm for reaction to these 'minor' and relatively difficult to work with diseases is a component of the overall resistant cultivar development program based at the Rice Research and Extension Center, under direction of the second author.

PROCEDURES

For kernel smut evaluation, two sets of 70 cultivars / lines were seeded using a tray planter in small plots (3 rows, 3 ft long on 1-ft spacings) with four replications per set. Every other replication was in reverse planting order. One set was misted and inoculated with the kernel smut fungus (Cartwright *et al.*, 1996) while the other was not. While kernel smut developed to a degree in both sets, the misted set was abandoned due to blanking from excessive mist and the other set was evaluated. Random panicles (10) were collected from each plot and stored in paper bags (set of 10 panicles per bag) until analyzed. Panicles were analyzed using the KOH method described by Lee *et al.* (1991). False smut developed naturally in some of the plots and was evaluated by counting false smut balls on 10 additional random panicles from affected plots. Additional data on 20 rice cultivars / lines were obtained from the White County disease monitoring site (kernel smut) and the Craighead County monitoring location (false smut). Both sites featured sets of 20 rice cultivars / lines planted in plots (7 rows, 25 ft long on 7-inch spacings) in four replications and managed by the grower with the rest of the field. Neither site was inoculated.

For stem rot and black sheath rot evaluation, additional sets of the 70 cultivars / lines were seeded in adjacent areas with separate water systems using the tray planter as before. 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-inch diameter), then applied with a handheld seeder (Cyclone brand) throughout the plots at panicle initiation and again seven days past panicle differentiation (based on cv. 'Jefferson'). Approximately 1 liter of grain / hull / sclerotia mixture was applied per 100 ft^2 of plots each time. Black sheath rot inoculum was prepared by growing the fungus in V-8 juice broth on a lab shaker for five to seven 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 minute 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 mls of pellets per 100 ft^2 at panicle initiation of Jefferson.

For stem rot, a set of 25 tillers from each plot was collected prior to grain maturity and evaluated according to the rating scale of Krause and Webster (1972). Black sheath rot was evaluated in the field for disease incidence (percent infected tillers), disease severity (relative height of symptoms divided by tiller height = relative lesion height or RLH) for each variety, or severity based on a 0-9 scale as follows: 0 = no disease; 1 = RLH of 1-20; 3 = RLH of 21-40 and / or mild culm / node rot; 5 = RLH of 41-60 and / or moderate culm / node rot; 7 = RLH of 61+ and / or severe culm / node rot; 9 = tillers killed prior to grain fill.

Other diseases (e.g. brown spot and leaf smut) and problems were evaluated as noted in the various plots, using a 0-9 rating scale where 0 = no disease / problem and 9 = severe disease / problem.

Data were analyzed using analysis of variance and a Least Significant Difference (LSD) value reported if there was a significant F test value (P=0.05).

RESULTS AND DISCUSSION

Results of the kernel smut evaluation at the Pine Tree location are presented in Table 1. Kernel smut severity ranged from 0.1 smutted kernels per panicle for 'Koshihikari' to 4.4 for RU9701130. Maximum smutted kernels observed per panicle ranged from 0.5 for Koshihikari to 10.0 for RU9701130. Levels of smutted kernels were less than observed at the White County disease monitoring location (Table 3) where, for example, LaGrue had 23.9 smutted kernels per panicle. Relative kernel smut values at the Pine Tree location were useful for preliminary grouping for kernel smut susceptibility, primarily with respect to lines with an obvious potential weakness with regard to this disease, e.g. RU9701130, RU9801111, RU9701041, RU9801161, RU9801148, etc. However, lines with lower values cannot be assumed to have a great deal of resistance based on a one-year, one location evaluation as evidenced by the conflicting results for Jefferson between the Pine Tree screening nursery (0.4) and the White County site (8.9) as well as other examples. Further refinement of the inoculated screening nursery will be required in the future and field observations will continue to be important for more advanced lines.

Similarly, false smut data at the Pine Tree location was useful for identifying those lines with an obvious weakness, e.g. RU9801151, RU9601064, RU9601076, etc. Again, inclusion of data from other sources like the Craighead monitoring plots (Table 3) will be of critical importance in developing control options for this disease in the future. Efforts to develop an inoculated screening nursery for false smut will be initiated in 1999 to begin preparation for a long-term effort on this disease.

Stem rot evaluation data are presented in Table 2. The disease index (based on degree of stem penetration by the stem rot fungus) varied from a low of 1.3 for AB657 to a high of 4.9 for 'Alan'. Based on previous experience, many of these values probably represent moderate to very susceptible reactions under field conditions that favor the disease. Nutritional status of the plants, especially low levels of potassium, would also heavily influence field performance with respect to stem rot and yield loss, however, inherent genetic susceptibility of a line is important to know before release as a cultivar--given the low potassium levels of many Arkansas rice fields.

Black sheath rot evaluation data are presented in Table 2. Based on relative lesion height (RLH) and 0-9 rating, lines RU9801108, RU9801111, and RU9801142 appeared to be the most susceptible (Table 2) with a similar reaction to the cultivar 'Lemont'--long considered the most susceptible cultivar to black sheath rot under our conditions. While several lines had very low disease severity values (RLH < 20 or 0-9 rating of 1), only RU9801179 had no detectable black sheath rot near the end of the season (Table 2). This line was also quite resistant to stem rot, based on a disease index of 1.9 (Table 2) and had low values for kernel smut and other problems noted at the nursery.

While preliminary grouping of lines can be done with the data collected thus far, additional testing will be required to clearly describe disease resistance within each line. These efforts should prove valuable to the breeding program as these diseases continue to become more important under Arkansas rice growing conditions.

SIGNIFICANCE OF RESULTS

These data represent novel comparative observations on disease reaction among many promising rice lines that may someday be released as commercial varieties (cultivars). It is becoming more critical that growers be immediately aware of any inherent weaknesses (or strengths) of new cultivars to avoid problems and be able to grow the cultivar to maximum economic potential. These and future data will assist growers in this respect and provide the breeding program additional information to design more resistant future varieties.

ACKNOWLEDGMENTS

Funding for this research was provided by rice grower check-off funds through the Arkansas Rice Research and Promotion Board. We gratefully acknowledge the help of Mr. Roger Eason, Director of the University of Arkansas Pine Tree Branch Experiment Station and his staff for making this work possible. We also acknowledge the assistance of Brannon Thiesse and Dean Wallace, county extension agents, for their help with the disease monitoring sites reported. We appreciate the cooperation and support of Dr. Karen Moldenhauer of the University of Arkansas Rice Research and Extension Center in providing seed and technical advice.

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Table 1. Evaluation of 70 cultivars/lines to kernel smut and false smut of rice in 1998 (Pine Tree Branch Experiment Station).

	Kernel smut		False smut			
Cultivar/line	(Avg smutted kernels per panicle)	(Maximum smutted kernels per panicle)	(Avg smut balls per panicle)	(Maximum smut balls for any panicle)	Blanks per panicle	Total florets per panicle
Koshihikari	0.1	0.5			5	83
Jefferson	0.4	2.0			5	105
L204	0.6	1.8			11	91
Alan	1.1	3.0			21	135
Millie	0.8	2.8			14	91
M202	1.5	4.5			8	96
Jackson	0.7	1.8			10	130
RU9801081	0.7	2.0			18	149
RU9801093	2.0	4.8			22	129
RU9801087	0.7	1.8			11	104
RU9601087	1.1	2.5			12	90
RU9701090	0.6	2.0			10	109
RU9801084	1.1	3.0			8	94
RU9601096	0.2	1.0			9	97
RU9601099	0.3	2.0			13	117
RU9801090	1.3	3.8			15	136
RU9801096	1.3	3.0			24	137
RU9801099	0.5	1.3			18	112
RU9801102	1.1	3.0			10	110
RU9701111	1.1	3.3			10	128
RU9601127	0.8	1.5	0.1	0.8	12	107
RU9801105	1.8	3.8	0.0	0.3	9	123
RU9801108	2.5	4.8			14	160
RU9801111	3.7	6.5	0.3	1.8	14	115

continued

Table 1. Continued.

Cultivar/line	Kernel smut (Avg smutted kernels per panicle)	Kernel smut (Maximum smutted kernels per panicle)	False smut (Avg smut balls per panicle)	False smut (Maximum smut balls for any panicle)	Blanks per panicle	Total florets per panicle
Lafitte	2.2	5.5			16	137
Bengal	2.5	5.8			23	132
Kaybonnet	1.7	3.5	0.1	0.5	10	117
Cocodrie	2.1	4.3	0.1	0.8	10	95
LaGrue	2.9	6.0	1.0	3.3	15	131
Priscilla	3.4	6.3			11	109
RU9701151	1.4	3.0	0.4	3.5	17	122
RU9701127	2.3	5.3	0.4	3.0	15	135
RU9701130	4.4	10.0	0.1	0.8	14	112
RU9801121	2.8	6.3			17	128
RU9801124	1.7	3.8			17	146
RU9701030	1.5	3.3	0.3	1.0	11	75
RU9801130	2.4	6.3	0.3	1.3	18	125
RU9601130	2.9	6.0	0.3	2.0	22	140
RU9801136	1.8	3.3	2.0	5.5	17	142
RU9801139	1.6	2.8	1.5	5.5	25	162
RU9801142	1.8	4.3	0.6	2.3	13	133
RU9701133	3.1	6.3	0.6	3.5	20	137
RU9801145	1.2	2.8	0.6	2.8	16	102
RU9801148	3.6	6.3	0.9	1.8	23	131
RU9601053	1.5	5.0	1.1	5.0	13	100
RU9801151	2.4	5.5	3.4	7.8	10	116
Katy	0.6	2.0	0.9	7.0	6	112
Newbonnet	2.2	5.0	1.7	5.8	28	148
Lemont	2.2	5.0	0.5	1.3	9	102
Cypress	2.1	4.5	0.1	0.5	9	92
Drew	2.6	4.5	1.7	6.8	11	119

continued

Table 1. Continued.

Cultivar/line	Kernel smut (Avg smutted kernels per panicle)	Kernel smut (Maximum smutted kernels per panicle)	False smut (Avg smut balls per panicle)	False smut (Maximum smut balls for any panicle)	Blanks per panicle	Total florets per panicle
Litton	3.7	7.3	0.6	2.5	21	106
RU9701161	1.9	4.3	1.0	4.3	10	95
RU9801161	4.1	7.8	1.3	6.0	20	125
RU9601064	2.2	5.0	3.1	13.8	18	100
RU9601067	1.1	3.0	1.9	6.3	13	122
RU9601076	1.8	3.8	3.9	11.3	21	127
RU9701041	3.3	7.5	1.0	2.8	16	102
RU9801164	2.6	5.5	1.1	3.0	24	161
RU9801167	1.7	3.8	0.8	2.5	22	104
RU9801170	3.2	6.3	0.1	0.5	9	95
RU9801173	1.1	2.5	0.3	2.3	17	137
RU9801176	1.0	2.3	2.7	9.5	13	139
RU9801179	0.4	1.8	0.1	0.5	14	125
RU9801182	1.0	2.5	2.1	7.5	12	120
RU9701050	1.3	3.3	0.7	2.0	17	123
RU9801185	1.3	3.8	2.1	8.3	24	148
AB647	0.8	2.0	0.6	5.3	12	117
RU9701179	1.8	4.8	1.5	4.5	18	94
RU9602074	1.5	4.0			28	136
LSD (0.05)	1.7	3.7	1.3	5.0	9.4	37.4

Table 2. Evaluation of 70 rice cultivars/lines to stem rot, black sheath rot, and other incidental diseases/pests in 1998 (Pine Tree Branch Experiment Station).[z]

Cultivar/line	Stem Rot	Black Sheath Rot	Black Sheath rot	Black Sheath rot	Brown spot	Leaf smut	Stem borer	Lodging
	(DI 1-5)	(% infected tillers)	RLH	(0-9 rating)	(0-9 rating)	(0-9 rating)	(0-9 rating)	% of plot
Koshihikari	2.5	5.8	13	1	3	1		100
Jefferson	2.1	42.0	44	5	1	1	3	
L204	1.8	9.0	14	1	2	2		
Alan	4.9	3.3	24	3	1	1		100
Millie	3.1	15.0	20	3	2	2	3	63
M202	2.4	30.8	37	5	5	2		50
Jackson	2.6	26.5	35	5	2	1		
RU9801081	2.5	1.8	7	1	3	2	2	
RU9801093	2.4	28.5	28	3	2	4	3	100
RU9801087	2.9	6.0	16	1	3	2	1	20
RU9601087	2.3	33.0	34	5	1	3		25
RU9701090	3.4	3.6	11	1	2	2	3	100
RU9801084	3.0	41.8	43	5	2	2		50
RU9601096	2.1	1.3	4	1	2	3		
RU9601099	2.4	13.5	20	3	2	2		
RU9801090	2.4	30.5	33	3	2	3	2	
RU9801096	2.8	1.8	9	1	2	2	1	100
RU9801099	2.9	0.5	5	1	1	2	3	100
RU9801102	2.3	9.5	15	1	2	5	1	
RU9701111	2.3	53.5	51	5	5	2		
RU9601127	2.6	33.5	35	3	4	2		100
RU9801105	2.1	44.8	45	5	2	3		
RU9801108	2.3	49.8	50	7	2	2		

continued

Table 2. Continued.

Cultivar/line	Stem Rot	Black Sheath Rot	Black Sheath rot	Black Sheath rot	Brown spot	Leaf smut	Stem borer	Lodging
	(DI 1-5)	(% infected tillers)	RLH	----------	(0-9 rating)	----------		% of plot
Koshihikari	2.5	5.8	13	1	3	1		100
RU9801111	2.1	49.0	51	7	2	1		
Lafitte	1.9	36.8	33	3	2	3		
Bengal	2.9	7.5	27	3	3	2		10
Kaybonnet	3.3	11.8	20	1	3	1		16
Cocodrie	2.8	27.0	36	3	2	1		
LaGrue	3.3	11.5	16	3	1	1		100
Priscilla	2.7	21.8	21	1	2	1		
RU9701151	2.8	4.4	11	3	1	1	1	
RU9701127	2.8	1.6	9	1	3	2		
RU9701130	2.7	26.3	26	3	3	3		20
RU9801121	2.2	0.5	3	1	1	2		
RU9801124	3.0	23.5	27	3	2	2		
RU9701030	2.3	8.8	18	1	2	2		
RU9801130	2.2	8.3	16	1	2	2		
RU9601130	2.7	38.5	46	5	2	2	2	10
RU9801136	3.3	4.5	17	1	1	1		80
RU9801139	1.9	27.8	27	5	2	4		
RU9801142	2.7	48.8	50	7	1	2		20
RU9701133	2.5	32.8	38	5	3	1		
RU9801145	1.7	42.0	45	5	1	1		
RU9801148	3.4	31.5	34	3	2	1	1	100
RU9601053	3.2	22.0	24	3	2	2		24
RU9801151	3.6	18.5	31	3	2	1		100
Katy	3.2	24.8	27	3	1	3	3	18

continued

Table 2. Continued.

Cultivar/Line	Stem Rot	Black Sheath Rot	Black Sheath rot	Black Sheath rot	Brown spot	Leaf smut	Stem borer	Lodging
	(DI 1-5)	(% infected tillers)	RLH	----------	---------- (0-9 rating)	----------	----------	% of plot
Newbonnet	2.8	5.8	17	1	2	2		50
Lemont	2.9	53.8	51	7	2	3		
Cypress	3.0	36.5	41	5	2	4		10
Drew	2.1	20.3	25	3	2	1	2	
Litton	2.6	30.3	31	3	2	3		20
RU9701161	2.0	21.0	25	3	2	2	1	
RU9801161	2.5	23.0	29	3	2	2	1	
RU9601064	2.5	10.8	19	1	1	1		
RU9601067	3.0	15.5	22	3	2	2		65
RU9601076	1.5	16.3	27	3	1	2		
RU9701041	2.0	11.5	21	1	2	3		
RU9801164	2.5	19.0	33	3	2	1		
RU9801167	2.7	6.3	22	3	1	2		
RU9801170	2.0	18.0	34	3	2	3	2	
RU9801173	2.4	2.1	10	1	2	2		
RU9801176	2.0	11.5	19	1	1	2		
RU9801179	1.9	0.0	0	0	1	2		
RU9801182	1.8	28.3	32	5	2	1		100
RU9701050	2.3	45.0	47	5	2	1		
RU9801185	2.3	22.0	31	3	2	2		
AB647	1.3	14.3	23	3	1			
RU9701179	1.9	20.5	38	5	1	1	2	
RU9602074	1.6	3.0	7	1	3	2		100
LSD (0.05)	0.8	7.3	7.5	0.9	0.9	1	0.7	23.4

[z] Stem Rot Disease Index (DI) where 1 = no infection and 5 = tiller culm penetrated. Black Sheath Rot relative lesion height (RLH) = symptom height/ tiller height: 0-9 ratings where 0 = no disease; 1 = RLH of 1-20; 3 = RLH of 21-40 or mild culm/node rot; 5 = RLHof 41-60 or moderate culm/node rot; 7 = RLH of 61 or severe culm/node rot; 9 = tillers killed prior to grain maturity. For other diseases/pests, the 0-9 rating represents 0 = no disease and 9 = severe disease.

Table 3. Evaluation of 20 rice cultivars/lines to kernel smut and false smut under natural conditions at two Arkansas locations, 1998.

Cultivar/ breeding line	Kernel smut (White County location) Smutted kernels	Smutted kernels	Range smutted kernels	False smut (Craighead County location) False smut balls	Maximum false smut balls observed on any panicle
	(no./panicle)	(% of florets/ panicle)	(min.-max. - no./panicle)	(no./panicle)	
AB647	6.5	4.8	2 - 13	3.8	11
Bengal	6.7	4.8	2 - 14	0.4	3
Cocodrie	10.0	7.8	4 - 19	3.1	24
Cypress	14.1	12.8	7 - 24	1.4	5
Drew	14.4	9.1	7 - 28	2.7	8
Jefferson	8.9	10.6	4 - 19	0.4	2
Katy	6.3	5.5	1 - 13	0.9	2
Kaybonnet	11.0	6.7	4 - 24	1.8	5
Koshihikari	0.5	0.6	0 - 2	1.2	3
L202	9.6	10.6	4 - 18	0.7	3
Lafitte	7.9	5.6	3 - 17	0.5	9
LaGrue	23.9	18.6	11 - 38	1.6	5
Lemont	5.1	4.6	2 - 10	0.9	5
Litton	15.6	15.1	9 - 27	0.1	1
Madison	5.1	4.6	2 - 11	0.0	0
M202	5.1	6.0	3 - 9	0.1	3
Newbonnet	16.5	11.9	9 - 31	2.4	10
Priscilla	12.9	11.1	6 - 29	1.1	5
RU9601053	9.8	7.8	5 - 18	1.9	5
RU9602074	9.1	6.0	3 - 19	1.6	7
LSD (0.05)	4.5	4.6		1.4	

LARGE-SCALE SCREENING OF USDA RICE GERMPLASM FOR QUALITATIVE AND QUANTITATIVE RESISTANCE TO TWO COMMON RACES (IC-17 AND IB-49) OF THE RICE BLAST PATHOGEN, *PYRICULARIA GRISEA*

J.C. Correll, T.L. Harp, and F.N. Lee

ABSTRACT

Over 700 entrees in the USDA germplasm collection were screened for both qualitative and quantitative resistance to the rice blast pathogen, *Pyricularia grisea*. The germplasm was screened with two races of the pathogen, IC-17 and IB-49, in a large scale inoculation format whereby 400 entries could be screened per inoculation. Races IC-17 and IB-49 are common races which predominate throughout Arkansas. Qualitative resistance was evaluated based on disease reactions after one infection period (approximately seven days) whereas quantitative resistance was evaluated after one, two, three, and four weeks. The purpose of these efforts is to begin developing a database of resistance genes in the USDA germplasm collection based on bioassays to races which represent concerns to rice production in the state. Identification of qualitative resistance genes, singly or in combination with other qualitative resistance genes as well as the identification of germplasm with quantitative resistance may help in the development of rice cultivars with improved durable resistance.

INTRODUCTION

Rice blast is a major disease problem in all rice-growing regions of the United States. Host resistance to *Pyricularia grisea* can be among the most effective and economical management practices to reduce the impact of rice blast (Kiyosawa, 1972; Lee, 1994). However, as with most plant diseases, the durability of resistance to blast has been less than desirable (Marchetti, 1994; Notteghem, 1993; Roumen, 1994).

Two races, 1B-49 and IC-17, predominate in the contemporary rice blast population in Arkansas (Correll and Lee, 1996). Efforts are underway to characterize rice genotypes to races of the rice blast pathogen which represent production constraints in Arkansas. In addition, efforts are underway to determine the stability of races in the contemporary population in Arkansas (Correll *et al.*, 1999). Identifying major and minor resistance genes in the USDA germplasm collection to races of the blast pathogen will assist our efforts to continue to develop rice cultivars with improved resistance to rice blast. Furthermore, bioassays will assist in our efforts to develop molecular marker-aided selection procedures to enhance our knowledge of resistance genes in rice (Chen *et al.*, 1998).

PROCEDURES

Rice Germplasm. Germplasm used for the disease screening was obtained from the USDA-ARS National Small Grains Collection, Aberdeen, Idaho. Over 750 genotypes were examined (Table 1).

Seeding. Plants to be screened were grown in the greenhouse. Seeds were seeded in ReadyEarth potting mix and fertilized with ammonium sulfate solution after 5, 8, and 11 days. In addition, the cultivars 'M201', 'Mars', 'Zenith', and 'Katy' were included as checks for each inoculation.

Isolates. Two isolates, A598 (race IB-49) and A631 (race IC-17), were used to inoculate all rice genotypes in separate inoculation tests. The isolates were recovered from Arkansas fields in 1993 and were previously characterized for race (Xia *et al.*, 1993). The isolates were grown on rice bran agar for five to seven days. Conidia were then harvested and the spore concentration adjusted to approximately 2.0×10^5 for inoculations.

Inoculations. A total of 385 to 400 genotypes were inoculated per test in addition to the four check cultivars. After inoculation, the plants were placed into a dew chamber at 100% RH at approximately 23°C for 24 hours. The plants were then placed back into the greenhouse for seven days and scored for disease symptoms. After the entries were scored, they were re-inoculated as previously described. Plants were inoculated 14, 21, and 28 days after seeding.

Scoring. The plants were scored for disease development using a standard qualitative and quantitative rating scale of 0 to 9 (Table 2).

RESULTS AND DISCUSSION

The contemporary rice pathogen population in Arkansas is composed of four distinct DNA fingerprint groups (A, B, C, and D) (Fig. 1). Within each group, one haplotype or clone predominates throughout the state (Fig. 2). From the 1500 isolates collected from the contemporary population (1990-1997), two races--IB-49 and IC-17--predominate (Table 3).

Large scale inoculations were facilitated by the use of a large dew chamber built for rice inoculations. Large scale inoculations make it easier to directly compare genotypes for disease resistance and thereby reduce the inherent variability associated with disease screening with rice blast.

A wide range of disease reactions were observed among the rice genotypes examined. With race IB-49, 11 genotypes were ranked as highly resistant or immune to blast (disease rating = 0) (Table 4); 52 genotypes as resistant (disease rating 1-3) (Table 5); 348 genotypes as moderately susceptible (disease rating 4-6), and 353 genotypes as susceptible to highly susceptible (disease rating 7-9) (Table 1). Genotypes rated in the range of 4-5 may have some minor genes for resistance and worthy of further examination under multiple inoculation tests and field epidemics to determine if resistance can be quantified.

A wide range in disease reactions was also observed among the rice genotypes tested with race IC-17. A total of 14 genotypes were ranked as highly resistant or immune to blast (disease rating = 0) (Table 6); 46 genotypes as resistant (disease rating 1-3) (Table 7); 235 genotypes as moderately susceptible (disease rating 4-6), and 425 genotypes as susceptible to highly susceptible (disease rating 7-9) (Table 1). Genotypes rated in the range of 4-5 may have some minor genes for resistance and therefore worthy of further examination under multiple inoculation tests and field epidemics to determine if resistance can be quantified.

Disease screening for blast resistance should continue to identify major and minor genes for disease resistance to common races in Arkansas. Efforts are underway to characterize the germplasm collection to new and potentially damaging races of the pathogen as well as the use of field screening to more effectively quantify minor gene resistance.

SIGNIFICANCE OF FINDINGS

Developing more complete knowledge of resistance genes in rice germplasm through the use of bioassays continues to be a critical step in evaluating and using both major and minor resistance genes in rice. Identifying germplasm with both major and minor (quantitative) resistance to the two common races in Arkansas, namely IB-49 and IC-17, will continue to allow plant breeders to improve yield and quality in rice cultivars by incorporating additional sources of resistance.

ACKNOWLEDGMENT

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

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Table 1. Rice germplasm which was rated as susceptible (disease rating of 4-6) or highly susceptible (disease rating 7-9) to race IB-49 (A), IC-17 (B), or both races (C).

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
15759	CLOR 1487	C	CI 6873	GIMBOZU	C
15760	CLOR 1488	C	CI 6880	TAKENARI 17	C
CI 1561	WATARIBUNE	C	CI 6949	BIMAKE MOCHI	C
CI 1642	SHINRIKI	C	CI 7352	SHINSHU	C
CI 2296	DOKAI	C	CI 7357	MUROSAKI KOYA BOZUC	C
CI 2303	MIYAKO	C	CI 7358	AKAHO	C
CI 2323	TAMA NISHIKI	A	134053	HIDERISIRAZ	C
CI 2343	E NO. 57	A	134056	KURUMIWASE	C
CI 2347	KINKO	C	154484	KARASU-RANKATSU	C
62972	KINAI EARLY NO. 4	C	154502	GIN-BOZU	C
63018	KINAI EARLY NO. 70	C	154509	KAMEJI	C
63117	FUKUYAMA	C	154514	KOMIYAKO	C
63136	KYOTO NO. 388	C	154516	AIKAWA NO. 44	C
63139	KYOTO NO. 391	C	154522	YASUMURA 8	C
CI 6346	GPNO 2016	B	154528	GUNEKI	C
CI 6346	MUBO AIKOKU NO. 22	C	154531	TAMANISHIKI	C
CI 6355	GIN BOZU	C	154533	MIZUHO	C
CI 6421	ISHIJIRO	C	154547	KINOSHITA	C
CI 6435	KAMEJI	C	154548	YOKOZUCHI	C
CI 6468	GPNO 2093	C	154550	SENSHO	C
CI 6606	GUNEKI	C	154551	ASAGA	C
CI 6782	IYO BENKEI 2	C	154552	URASAN	C
CI 6807	KOMYO NISHIKI 1	C	154553	HIRAYAMA	C
CI 6808	KOKURYO MIYAKO 1	C	154556	RIKUU MOCHI NO. 22	C
CI 6856	HAYA SHINRIKI	C	154558	TOSA MOCHI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
CI 9051	MOCHI GOMI	C	162080	DANGO SINRIKI	C
CI 12001	UPLAND	B	162082	DENZINHO	C
CI 12066	MIYAKO SELECTION	C	162083	DOSAN 41	C
CI 12067	MIYAKO SELECTION	C	162085	DOSAN 50	C
CI 12197	CI 5662-1	C	162089	DOSAN 57	C
CI 12198	CI 5662-2	C	162091	DOSAN 59	C
CI 12199	KINAI 388	A	162093	HAYACHIBANISHIKI	C
CI 12254	MOGAMIURUTI SEL. SELECTIONC	C	162096	I. KASE WASE SANAE	C
CI 12255	MOGAMIURUTI SEL. SELECTIONC	C	162099	KIUKI NO. 46	C
CI 12397	DOSAN 50 SEL SELECTIONC	C	162100	KIUKI NO. 52	C
CI 12398	DOSAN 50 SEL SELECTIONC	C	162104	KIUKI NO. 44	C
CI 12446	PI NO. 1 SELECTION	C	162106	KIUKI NO. 50	C
CI 12447	NAGATE EIKOU SEL. SELECTIONC	C	162107	KYONGGI NO. 51	C
CI 12448	NAGATE EIKOU SEL. SELECTIONC	C	162108	KYOTO WASE	C
CI 12449	TOYOHIKARI SEL. SELECTIONC	C	162109	MODOASAI 2	C
CI 12450	TOYOHIKARI SEL. SELECTION SELC	C	162110	MURASAHITSUTSURI	C
CI 12452	CHIKANARI 2 SEL. SELECTIONC	C	162113	NIWAHUTAW MOCHI	C
CI 12453	CHIKANARI 2 SEL. SELECTIONC	C	162114	NORIN 6	C
CI 12454	PI 224801-3	C	162115	NORIN 8	C
CI 12456	NORIN 19 SEL.	C	162116	NORIN 10	C
CI 12460	KUHEI 2	C	162118	NORIN 22	C
162073	AKEBONO	C	162119	NORIN 23	C
162074	AIROKA 1	C	162120	NORIN 26	C
162077	BUNSITO	A	162123	NORIN 37	C
162078	BYOBO	C	162124	OMACHI 2	C
162079	DANGO NAKAINE	C	162126	SENBON ASAI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
162127	SHIN ASAI	C	184500	KYUHEI NO. 2	--
162128	SINRIKI 1	C	184501	SCENTED A	C
162129	SUITO NORIN 1	--[y]	184502	HAINUZUKA SC. B SCENTED BC	C
162131	SUITO NORIN 3	C	184503	EDOMEN SCENTED	C
162132	SUITO NORIN 4	C	184505	SHIMEZUMOCHI	C
162133	SUITO NORIN 5	C	184506	SOMEWAKE	C
162135	SUITO NORIN 7	C	187084	224	--
162136	SUITO NORIN 8	C	187085	225	C
162137	SUITO NORIN 10	C	187088	228	C
162138	SUITO NORIN 12	C	187089	229	C
162139	SUITO NORIN 13	C	187090	230	C
162140	SUITO NORIN 14	C	187091	231	C
162144	SUITO NORIN 20	--	187092	232	C
162149	SUITO NORIN 29	C	187093	233	C
162151	SUITO NORIN 37	C	187095	235	C
162153	TANGIN-BOZU	C	187162	KUNIGANI NO. 1	C
162154	TAISHOMOCHI	C	197395	KAIRYO HABUTAI MOCHIC	C
162157	WASE SHINHIKI 1	C	197397	RIKUU 132 C	C
162158	WOUSHOKTO	C	202943	AICHI ASAHI	C
162159	YAMOTO HINODE	C	202945	ASAHI NO. 7	C
162160	YAMOTO NISHIKI	C	202949	BENKEI	C
184495	FUJISAKI 1	C	202950	CHUKI	C
184496	FUJISAKI 2	C	202951	CHUKYO ASAHI	C
184497	FUJISAKI 3	C	202952	CHUSEI ASAHI NO. 1	C
184498	FUJISAKI 4	C	202953	DOKAI SINRIKI	C
184499	FUJISAKI 5	C	202954	EHIME SUITO	C

continued

Table 1. Continued.

Access. No.^{z}	Name	Race classification	Access. No.^{z}	Name	Race classification
202956	GENHOZU MIIDASHI	C	202998	NORIN MOCHI 5	C
202958	HATUSHIMO	–	202999	OKAYAMA MOCHI	C
202959	HEITAIBO	C	203000	SAKAE	C
202960	HIKARI	C	203003	SHIMOTSUKI	C
202961	IYO SAUTOKU	C	203004	SHINJU 1	C
202962	IYO SENGOKU	C	203005	SHINRIKI	C
202965	KAGAW SINRIKI NO 2	C	203006	SHINRIKIMOCHI	C
202967	KIKUSUI	C	203009	TAKAO MOCHI	C
202968	KINAI NO. 37	C	203010	TAKARA	C
202971	KINKI 25	C	203011	TAKUSHIMA BANTO	C
202973	KITUSKIN	C	203012	TURNGI	C
202975	KOTOBUKI MOCHI	C	203089	RIKUTO KUMATMOTO 1C	C
202976	KUDAI ASAHI	C	203090	RIKUTO NOURIN 13	C
202978	KUSHIR NO. 58	C	203091	RIKUTO NOURIN 26	C
202979	KYOTO ASAHI	C	203092	RIKUTO SANIN 25	C
202981	MII	C	203094	RIKUTO TOUKAI 32	C
202986	NORIN 8	C	203095	RIKUTO TOUKAI M. 27	C
202987	NORIN 12	C	215663	GPNO 7557	C
202988	NORIN 13	C	218193	HYUGA NISHIKI	C
202989	NORIN 18	C	222499	NORIN MOCHI 6	C
202990	NORIN 22	C	222500	NORIN 11	C
202991	NORIN 25	C	222501	NORIN 31	C
202992	NORIN 26	C	224649	EIKOU	C
202993	NORIN 27	C	224650	HUGISAKA 5	C
202994	NORIN 31	C	224653	OKUTO EIKOU	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
224654	TERUNISHIKI	C	224827	KAMARIRAZU	C
224656	TOYOHIKARI	C	224828	KAMEJI	C
224791	AKIKAWA 44	C	224829	KAMENEO 1	C
224792	AIMASARI	C	224830	KANTO 11	C
224793	AKAGE	C	224831	KINAI CHU 74	C
224795	ASAHI 1	C	224832	KINKI 25	C
224796	ASAHI SEN	C	224833	KINKI 47	C
224797	AYASHI 1	C	224834	KINUGASAWASE 121	C
224798	BENISENGOKI	C	224837	KUROBE 1	C
224799	BENKEI	C	224838	KUR MOCHI 22	C
224800	BONSAI-INE	C	224839	KANTO 51	C
224802	CHU KAME	C	224840	MIHONISHIKI	C
224805	FUKUBOZU	C	224841	MITSURYU INE	C
224806	FUSAKU SHIRAZU SAI 1C	C	224842	MOGAMI MOCHI	C
224807	FUTAMIKAWA	C	224843	MOBU AIKOKU	C
224813	HATSUNISHIKI	C	224844	MURASAKI INE	C
224814	HATSUSHIMO	C	224845	MURASAKI KOYABOZU	C
224815	HATTAN 10	C	224846	MUR. MUYOZETSU	C
224816	HAYANORIN	C	224847	NAGURAHO	C
224818	HIKARI	C	224848	NAKASENGOKU	C
224819	HIKOTARO MOCHI	C	224849	NAWASHIRO INE 22	C
224821	ISHIKARI SHIROGE	C	224853	NORIN 8	C
224822	HIRAYAMA	B	224854	NORIN 10	C
224823	HOKURIKU 11	C	224855	NORIN 11	C
224826	KAIRYO AKIKOKU	C	224857	NORIN 14	C

continued

Table 1. Continued.

Access. No.^{z}	Name	Race classification	Access. No.^{z}	Name	Race classification
224858	NORIN 16	C	224889	RIKUTO NORIN 9	C
224859	NORIN 17	C	224890	RIKUTO NORIN 19	C
224862	NORIN 20	C	224891	RIKUTO NORIN 24	C
224863	NORIN 21	C	224892	RIKUU 20	C
224864	NORIN 22	C	224896	SAN IN 17	C
224866	NORIN 24	C	224897	SANUKI SHINRIKI	C
224867	NORIN 25	C	224899	SEKIYAMA	C
224868	NORIN 28	C	224900	SENSHO	A
224869	NORIN 29	C	224901	SHIGA ASAHI 27	C
224870	NORIN 32	C	224902	SHIGA HABYTAE MO. MOCHIC	C
224873	NORIN 36	C	224903	SHIMOTSUKI	C
224874	NORIN 37	C	224904	SHIN 2	C
224875	NORIN 39	C	224905	SHIN 5	C
224876	NORIN 41	C	224906	SHIN 7	C
224877	NORIN 44	C	224907	HINANO 2	C
224878	NORIN 48	C	224908	SHINANO MOCHI 3	C
224879	NORIN 49	C	224909	SHIN ISHIJIRO	C
224880	NORIN 50	C	224913	SODAIRYU INE	C
224882	OBANAZAWA 1	C	224914	TAISEN	C
224883	OBA SO	C	224915	TAKANENISHIKI	C
224884	OITA MII 120	C	224916	TAKARA	C
224885	OMACHI	C	224917	TAKEDA WASE	C
224886	OU 188	C	224918	TAMASARI 1	C
224887	RIKUTO NORIN 1	C	224920	TAREHA INE	C
224888	RIKUTO NORIN 4	C	224921	TAROBE MOCHI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
224922	TEDORIWASE	C	226164	FUZISAKA 2	C
224923	TOKUSHIMA BANTU 1	C	226166	FUZISAKA 4	C
224924	TONEWASE	C	226167	FUZISAKA 5	C
224925	TONO 4	C	226168	HAKKODA	C
224926	TOYAMA 3	C	226169	IHARA 5	C
224927	TOYOKUNI	C	226171	KAGOSHIMA HAK. 1	C
224928	TOZAN 22	C	226172	KAIRYO MOCHI	C
224929	TOZO MOCHI	C	226173	KIDAMA	C
224930	TSURUGIBA	C	226176	KOSHIJI WASE	B
224931	URASAN 1	C	226177	KUHEI 2	C
224933	WASE ASAHI	C	226178	MIHO III	C
224934	WAS ESOZIMA MOCHI	C	226179	NORIN 9	C
224935	YACHINKOGANE	C	226181	RIKUTO ADAGOME D	C
224936	YAMANAKA 2	C	226182	RIKUTO NORIN 6	C
224937	YONOYUKI MOCHI	C	226184	RIKUTO NORIN 12	C
224938	YUBAE	C	226185	RIKUTO NORIN 14	C
224939	ZUIHO	C	226186	RIKUTO NORIN 15	C
224940	MINORI	C	226187	RIKUTO NORIN 17	C
226154	ALCHI ASAHI	C	226188	RIKUTO NORIN 18	C
226155	AKATSUKI MOCHI	C	226189	RIKUTO NORIN 20	C
226156	ASAHI MOCHI	C	226190	RIKUTO NORIN 21	C
226158	CHIKARA SENBON	C	226191	RIK. NORIN MOCHI 26	C
226159	CHUKYO ASAHI	C	226193	RIKUTO JINRIKI 1	C
226162	FATABA	C	226198	RIKUTO SHIROHIGE	C
226163	FUZISAKA 1	C	226199	RIKUTO TERISHIRAZU	C

continued

Table 1. Continued.

Access. No.^{z}	Name	Race classification	Access. No.^{z}	Name	Race classification
226200	SAKAI KANEKO	C	239074	TO TO	C
226202	SENBON ASAHI	C	245692	DWARF	C
226204	SHIMIZU MOCHI	C	245693	RD 1	C
226205	SHINRIKI MOCHI	C	245697	A 58	C
226206	SHUHO	C	264243	GPNO 18773	C
226208	TAISHO AKAHO 66	C	273469	NORIN 22	C
226209	TAKENARI	C	273470	UP 15	C
226210	TERUJU	C	273471	UP 21	C
226211	TOKAI ASAHI	C	273473	UP 98	C
226212	TOKAI SENBON	C	274213	TO TO	C
226213	TOZAN 38	C	274214	PI 4	A
226215	YUTAKA SENBON	C	274215	PI 3	A
226216	ZENNOO	C	280673	AICHI-ASAHI	C
226217	MUBO AIKOKU	C	280675	GINGA	A
230988	HOKKAI 116	C	280676	HOMARE NISHIKI	C
231623	BANSHINRIKIBYOKATAC	C	280677	ISHIKARI SHIROKE	C
231625	BUNKETSUTO	C	280678	KANTO NO. 51	C
231633	MURASAKI DAIKOKU	C	280681	TODUCAN	A
231656	TEF 6-10-10	C	280684	YAKEIKO	C
231659	TEF 6-48-7	C	281629	ISAO MOCHI	C
234973	CHOGOEI	C	281631	TOMOEMASARI	A
234978	NORIN 20	C	281633	WASE SHIROKE	C
234981	TOMEKICHIWASE	C	281785	KONGO	C
238114	T1-47 TETRAPLOID	C	281786	NORIA 1	B
239073	REI-SHI-KO	C	282401	GINGA	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
282403	NORIN 20	C	291657	BOZU	C
291501	KUHEI 2	C	291658	MI MASARI	C
291504	FUZISAKA 1	C	291659	SHIN EI	--
291505	FUZISAKA 2	--	291662	RIKUTO NORIN 22	--
291506	FUZISAKA 3	A	291663	RIKUTO NORIN MOCHI 3C	C
291630	CHUSEI SHIN SEMBON	C	291664	RIKUTO SEKAIICHI	A
291631	GINGA	--	291665	MINAMI HATA MOCHI	--
291632	KOGANE-NISHIKI	C	291666	SHIN HAKABURI	C
291633	KONGO	--	291667	SUSONO MOCHI	C
291634	UKON NISHIKI	C	291668	KYOTO-ASAHI	C
291635	WAKA BA	C	291669	SHIRA-TAMA	C
291636	MUTSU HIKARI	C	291671	SHIOJI	A
291639	TOWADA	C	291672	GIN MASARI	C
291640	FUKU SUKE	C	291673	FO NYAKU MAN GOKU	--
291641	HO NEN WASE	C	291674	SHIN 6	--
291642	KOGANE NAMI	C	291675	KANTO 53	C
291643	KOSHI HIKARI	C	291676	CHIKUMA	C
291644	KINKI 33	C	291677	FUKUMINORI	--
291645	MANRYO	C	291678	YAEHO	C
291646	PI 2	--	292236	FUKEI 53	C
291649	EIKO	C	292237	FUKEI 54	--
291650	KITAMINORI	C	294351	ZUIHO	C
291651	KITAMOCHI	C	294352	KANTO 53	C
291653	NORIN 15	C	294353	GINMASARI	C
291655	TOYOHIKARI	C	294354	NORIN 18	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
294356	HAKKODA	C	331435	SHIRANUI	C
294357	AIMASARI	C	331436	ZENSHO 26	C
294358	KINMAZE	C	338012	HOKURIKU 76	C
294359	SASASHIGURE	C	341929	DOHHOKU 1	C
294360	NORIN 29	C	341930	HIMEHONAMI	C
294363	NORIN 41	C	341931	HOKUTO	C
294364	AKEBONO	C	341932	IBURI WASE	C
294365	HATSUNISHIKI	C	341933	JOHIKU NO. 314	C
294366	MIHONISHIKI	C	341934	JOHIKU NO. 349	C
294367	TOZAN 38	C	341935	SASAHONAMI	C
294368	NORIN 25	--	341936	SHINSETSU	C
318643	HOYOKU	C	341937	YUHKARA	C
318644	REIMEI	--	342639	YUKIMOCHI	A
319192	SHIOKARI	C	343834	NAKATE SHINSENBON	C
329240	KANTO 77	--	343835	SHUHO	C
330462	FUJIMINERI	C	343838	YAMABIKO	C
330463	HONENWASE	--	343839	YAMAKOGANE	C
330464	KOSHIHIKARI	C	344090	FUKUNISHIKI	C
330465	HOYOKU	C	344091	KUSABUE	C
330468	YAMABIKO	--	344092	YONESHIRO	C
330472	SABIENY UAR	--	346406	FUKEI 71	--
330473	HYBRID 170/15 UAR	C	350646	YONESHIRO	--
331432	ARIAKE	C	350649	YUKARA	C
331433	JUKKOKU	C	350650	REIMEI	C
331434	KOKUMASARI	C	360852	FUKU-NO-HANA	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
362099	SHIN-EI	C	388290	KINAI 195	C
362100	SHIRANUI	--	388292	NORIN 17	C
366126	KINMAZE	B	388293	NORIN 29	C
366127	NAKATE SHINSENBON	C	388310	GPNO 16227	C
366260	FUKEI 66	--	388312	HOMARE NISHIKI	C
366261	OOWY 237	C	388313	JAPONES NO. 6	C
373265	TA TSU MI MOCHI	C	388314	JAPONES GIGANTE 229	C
373648	ASUWA	C	388325	AKEBONE NO. 119	C
373673	TSUKIMI MOCHI	C	388396	GPNO 16333	C
373678	HATSU HONAMI	--	388454	GUNEKI	--
373681	TACHIKARA	C	388466	HIRAYAMA	C
373683	HAYATOMO	C	388487	KYUHEI NO. 2	--
373684	KIN MAZE	C	388494	KUIKI NO. 25	C
373685	OYODO	C	388512	MIKO MISHIRI NO. 121	C
378578	TANGIN-BOZU	C	388514	MISUHO	C
378580	MINEHIKARI	--	388521	NORIN 24	--
388242	NORIN 1	C	388522	NORIN 41	C
388245	OIRACE	C	388559	RIKUTO NORIN NO. 13	C
388259	FUJIZAKI NO. 4	C	388569	YAMABIKO	A
388261	HAKKODA NO. 110	C	388586	TOWADA	A
388262	HTSU MISHIKI NO. 120	--	388587	FUJIMINORI	C
388267	NAO TRADUZIDO NO. 2	C	388912	NORIN 18	--
288268	NORIN 28	C	388913	KINMAZE	--
288270	NO IKU NO. 1517	--	388922	NORIN 25	C
388277	AIMASARI NO. 111	--	388924	NORIN 1	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access No.[z]	Name	Race classification
388926	SENBON ASAHI 15	–	389965	TOWEWASE	C
388927	KOGANE 16	--	391242	A-18	C
388929	NORIN 21	C	391341	KINKI 25L 23	C
388932	BENI SENGOKU 21	B	391363	NORIN 28	C
388938	NORIN 12	C	391933	ASAKAZE	A
388954	SHIRAKANE	C	392707	PI 4	C
388955	NEW 7	--	392708	KUSABUE	C
388956	REI-SHI-KO	C	392724	NORIN 22	--
388965	FUKUNISHIKI	A	392877	KYUDAI ASAHI 3	C
388966	TACHIKARA	--	393073	MUTSU HIKARI	C
388967	MANRYO	C	400094	RIKUTO NORIN 11	C
388974	HKAWLPEH	c	400097	YONESHIRO	C
388981	CANAWMJI	--	400337	NORIN 26	C
388984	CALAUGH	C	400339	NORIN 28	C
388988	HKAW PLELO	C	400579	KIBI	C
388992	YOMOMASARI	C	400580	HOMURA	C
388995	SANSANINISHIKI	C	400581	MAN TARO MAI	C
388996	YONESHIRO	C	400582	GORIKI 2	C
388997	MUTSU KOGANE	C	400583	YAKOMO	C
388999	SHIRANUI	C	400590	KOKURYO MIYAKO 3	C
389000	KOTOMINORI	C	400591	IYO SENGOKU 3	C
389183	KANTO 51	C	400592	SHIN AI	B
389185	HOMARE NISHIKI	C	400695	MIZUHO	C
389193	PI NO. 1	C	400740	YONESHIRO	C
389288	PI NO. 5	B	400741	ISARIBI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
400742	MIYOSHI	C	415658	FUJISAKA	C
400744	YAMEJI WASE	C	418221	KIYOKY MOCHI	--
400745	HARUKAZE	C	418222	KURENAI MOCHI	C
400746	YAMABIKO	C	418223	TSUKUSHIBARE	C
400747	YAEGAKI	C	420969	NORIN MOCHI SL 44	C
400748	NISHIKAZE	C	420981	HAYANORIN	B
400749	FUKEI 70	C	420984	CLUSTERED SPIKELET	C
400750	FUKEI 71	C	430259	YUHKARA	C
402523	FUJIMINORI	C	430260	RD 1	C
402524	YONESHIRO	B	431054	SHIN 2	C
403394	FUTABA	C	431098	HOSAKO	B
403399	NORIN 6	C	431120	KUI MAZE	C
403421	GLUTINOUS A-1	C	431121	NORIN 25	C
403466	SHINRIKI 11	C	431122	NORIN 1	B
403614	JOSA 1-L-38	C	431261	NORIN 18	C
403629	KAMENOO	B	431289	SEKTORE	A
404086	02.00.14	B	431294	TATRUMI MOCHI	C
404088	04.00.59	--	431295	YONOSHIRO	B
404090	05.00.12	C	432554	GINBOZMIDASHI	C
404093	92.02.53	C	433789	RIKUTO NORIN 21	C
404094	92.09.31	B	435319	FUJIHIKARI	A
404095	92.09.38	--	435322	NATSUHONAMI	A
404096	92.10.04	C	435325	WAKAGOMA	C
405072	TOHONISHIKA	B	439612	SHIRATAMA	C
413888	NORIN 25	C	439644	AOMORI MOCHI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access No.[z]	Name	Race classification
439656	BOZU	–	458767	HATSUNEMOCHI	C
439680	KITA MOCHI	--	458768	HOUNENWASE	C
439690	MIZUHO ISSUN	C	458770	KITAKOGANE	--
439708	NARUHA	C	458772	KOCHIHIBIKI	--
439714	RIKUTO NORIN MOCHI	--	458773	SURGAWASE	C
439715	RIKUTO NORIN 15	C	458774	TENRYOU	C
439729	TOJONISHIKI	C	458775	TODOROKIWASE	--
439874	SOMEWAKE	--	504472	AKIHIKARI	C
439875	TERU JU	C	504473	FUKUNOHANA	C
442613	AKANEMOCHI	C	504474	HIMENOMOCHI	C
442614	ASOMINORI	C	504475	KAIRYOU SHINKOU	C
442615	HIYOKUMOCHI	C	504476	SAKAKIMOCHI	C
442616	KOGANE MOCHI	C	504477	SUZUHARA MOCHI	C
442617	KURENAI MOCHI	C	504478	TATSUMIMOCHI	C
442618	SAKAE MOCHI	C	504479	YAMATE NISHIKI	C
442620	SENDAI	C	514651	AKIHIKARI	C
442621	TSUKUSHIBARE	A	514652	AKINISHIKI	C
442951	YONESHIRO	C	514653	AKIYUTAKA	--
442956	TA TSU MI MOCHI	C	514655	CHIYONISHIKI	C
445961	FUKEI 69	C	514657	HOUNEWASE	C
445963	HOSOGARA	C	514658	HOUREI	C
445965	KAIRYOUHATTANNARE	C	514659	KIYONISHIKI	C
445970	TATSUMIMOCHI	C	514660	KOCHIHIBIKI	C
445971	TOUGEMOCHI	C	514661	KOSHIHIKARI	B
458765	AKINISHKI	C	514662	NATSUHIKARI	C

continued

Table 1. Continued.

Access. No.[z]	Name	Race classification	Access. No.[z]	Name	Race classification
514663	NIPPONBARE	C	584542	WARABEHATOMOCHI	C
514664	OOZARA	C	584543	HAGINOMAE MOCHI	C
514665	REIMEI	B	584592	HAPPY HILL NO. 1	B
514667	SASANISHIKI	C	584597	WAITO-C	C
514668	TODOROKIWASE	B	226194	RIKUTO KAHEI	B
514669	TOYAMANISHIKI	C	226196	RIKUTO KIRISHIMA	B
514670	TOYONISHIKI	C	388265	IEUSHI MOCHI	C
543881	TOSAHATA MOCHI	C	388935	RIKUU 132	B
543883	CHIYOMINORI	C	403476	HIKARI	A
543884	NORIN PL 2	C	202996	NORIN 37	B
543885	NORIN PL 3	C	12196	AIKOKUAIKOKU KINAI	A
558511	AKITAKOMACHI	C	280682	TE TEP	A
560208	AKENSHOSHI	C	280683	USEN	A
560223	HAPPY HILL NO. 2	C			

[z] Accession Number (PI number unless specified as CI [Cereal Investigation number]); USDA Germplasm Collection, P O Box 307, Aberdeen, Idaho 83210.

[y] Susceptible to either race IB-49 or IC-17, but not tested on both races.

Table 2. A qualitative and quantitative disease rating scale of 0 to 9 was used to assess disease development.

Assigned rating	Disease reaction[z]	Description
0	R	No infections evident
1	R	Small hypersensitive lesions
2	R	Small (<2 mm) lesions with distinct borders, some open centers
3	R	Small (<3 mm) lesions with some border, some necrotic centers
4	S	Expanding "water soaked" type lesions, no distinct border, often diamond shaped (<10% of the leaf surface)
5	S	10 - 25% of leaf area with type 4 lesions
6	S	26 - 50% of leaf area with type 4 lesions
7	S	51 - 75% of leaf area with type 4 lesions
8	S	76 - 90% of leaf area with type 4 lesions
9	S	90% of leaf area with type 4 lesions

[z] Disease reactions were characterized as resistant (R) or susceptible (S).

Table 3. Relationship between MGR586 DNA fingerprint group, vegetative compatibility group (VCG), and race characterization in Arkansas.

MGR586 DNA fingerprint group	VCG	Race
A	US-001	IB-49
B	US-002	IG1, IC-17, IC-17K
C	US-003	IB-49
D	US-004	IC-17

Table 4. Rice cultivars/varieties which were rated as immune or highly resistant to race IB-49 (isolate A598) after 7, 14, and 21 days.

Accession		Disease rating[y]		
number[z]	Name	7	14	21
388928	NORIN 35	0	0	0
388945	ECHIGONEBARI	0	0	0
400338	COLL. NO. 230	0	0	0
404089	04.07.04	0	0	0
318642	CHUGOKU 31	0	0	1
388932	BENI SENGOKU 21	0	0	1
400089	NORIN 21	0	0	1
400114	AYANISHIKI	0	0	1
330466	MANRYO	0	1	1
366126	KINMAZE	0	1	1
431295	YONOSHIRO	0	1	1

[z] Accession number (PI number unless specified as CI [Cereal Investigation number]).
[y] Plants were scored 7, 14, and 21 days after inoculation.

Table 5. Rice cultivars/varieties which were rated as moderately resistant to resistant to race IB-49 (isolate A598) after 7, 14, and 21 days.

Accession		Disease rating[y]		
number[z]	Name	7	14	21
280677	ISHIKARI SHIROKE	1	1	1
280678	KANTO NO. 511	1	1	1
291648	PI 4	1	1	1
341812	R4-B	1	1	1
389288	PI NO. 5	1	1	1
400046	REIMEI	1	1	1
406094	ST 1	1	1	1
431098	HOSAKO	1	1	1
452113	OHSETO	1	1	1
514666	SACHIMINORI	1	1	1
514668	TODOROKIWASE	1	1	1
CI 12445	PI NO. 1SELECTION	1	1	2
431124	BENI SONGOKU	1	1	2
291647	PI 3	1	2	2
431125	NORIN 18	1	2	2
226194	RIKUTO KAHEI	1	2	3
341230	TORIDE 2	1	2	3
280680	NORIN 22	2	2	2
388930	YACHIKOGANE 19	2	2	2
431122	NORIN 1	2	2	2
431231	MIDDLE FARMER	2	2	2
435323	SATIMINORI	2	2	2
439141	RIEHO	2	2	2
514654	AOISORA	2	2	2
CI 6332	GPNO 2016	2	2	3
226183	RIKUTO NORIN 11	2	2	3
CI 12001	UPLAND	2	3	3
400697	OKINAWA EARLY 3	2	3	3
420981	HAYANORIN	2	3	3
CI 12423	SOMEWAKE	3	3	3
202996	NORIN 37	3	3	3
224822	HIRAYAMA	3	3	3
226176	KOSHIJI WASE	3	3	3
281786	NORIA 1	3	3	3
341229	TORIDE 1	3	3	3
388935	RIKUU 132	3	3	3
389001	TADUKAN	3	3	3
400592	SHIN AI	3	3	3
402524	YONESHIRO	3	3	3
403629	KAMENOO	3	3	3

continued

Table 5. Continued.

Accession number[z]	Name	Disease rating[y] 7	14	21
403654	KINAI 37 M 25	3	3	3
403660	KISHINRIKI	3	3	3
403669	KUSABUE	3	3	3
403943	REIHO	3	3	3
404086	02.00.14	3	3	3
404087	02.08.25	3	3	3
404094	92.09.31	3	3	3
405072	TOHONISHIKA	3	3	3
435324	URUMAMOCHI	3	3	3
514661	KOSHIHIKARI	3	3	3
514665	REIMEI	3	3	3
584592	HAPPY HILL NO. 1	3	3	3

[z] Accession number (PI number unless specified as CI [Cereal Investigation number]).
[y] Plants were scored 7, 14, and 21 days after inoculation.

Table 6. Rice cultivars/varieties which were rated as immune or highly resistant to race IC-17 (isolate A631) after 7, 14, and 21 days.

Accession number[z]	Name	Disease rating[y] 7	14	21
341229	TORIDE 1	0	0	0
341230	TORIDE 2	0	0	0
341812	R4-B	0	0	0
400338	COLL. NO. 230	0	0	0
403476	HIKARI	0	0	0
404089	04.07.04	0	0	1
452113	OHSETO	0	0	1
162077	BUNSITO	0	1	1
274215	PI 3	0	1	1
400697	OKINAWA EARLY 3	0	1	1
431125	NORIN 18	0	1	1
431231	MIDDLE FARMER	0	1	1
435324	URUMAMOCHI	0	1	1
514666	SACHIMINORI	0	1	1

[z] Accession number (PI number unless specified as CI [Cereal Investigation number]).
[y] Plants were scored 7, 14, and 21 days after inoculation.

Table 7. Rice cultivars/varieties which were rated as moderately resistant or resistant to race IC-17 (isolate A631) after 7, 14, and 21 days.

Accession number[z]	Name	Disease rating[y] 7	14	21
280682	TE TEP	1	1	1
280683	USEN1	1	1	1
388586	TOWADA	1	1	1
388919	MIHONISHIKI	1	1	1
388930	YACHIKOGANE 19	1	1	1
388945	ECHIGONEBARI	1	1	2
280681	TODUCAN	1	2	2
291648	PI 4	1	2	2
389001	TADUKAN	1	2	2
435319	FUJIHIKARI	1	2	2
435323	SATIMINORI	1	2	2
439141	REIHO	1	2	2
442621	TSUKUSHIBARE	1	2	2
CI 2323	TAMA NISHIKI	1	3	3
CI 12423	SOMEWAKE	1	3	3
435322	NATSUHONAMI	1	3	3
CI 12445	PI NO. 1 SELECT.	2	2	3
291664	RIKUTO SEKAIICHI	2	2	3
388569	YAMABIKO	2	2	3
388928	NORIN 35	2	2	3
400114	AYANISHIKI	2	2	3
CI 12196	AIKOKU KINAI	2	3	3
388475	HAMAYU	2	3	3
406037	CHUGOKU 31	2	3	3
431124	BENI SONGOKU	2	3	3
CI 12199	KINAI 388	3	3	3
224900	SENSHO	3	3	3
274214	PI 4	3	2	3
280675	GINGA	3	3	3
280680	NORIN 22	3	3	3
281631	TOMOEMASARI	3	3	3
291506	FUZISAKA 3	3	3	3
291670	AKIBAE	3	2	3
291671	SHIOJI	3	3	3
318642	CHUGOKU 31	3	3	3
330466	MANRYO	3	2	3
342639	YUKIMOCHI	3	3	3
388965	FUKUNIZHIKI	3	2	3
391933	ASAKAZE	3	3	3
403654	KINAI 37 M 25	3	3	3

continued

Table 7. Continued.

Accession		Disease rating[y]		
number[z]	Name	7	14	21
403660	KISHINRIKI	3	2	3
403669	KUSABUE	3	2	3
406094	ST 1	3	3	3
431289	SEKTORE	3	2	3
400046	REIMEI	3	2	3
400089	NORIN 21	3	2	3

[z] Accession number (PI number unless specified as CI [Cereal Investigation number]).

[y] Plants were scored 7, 14, and 21 days after inoculation.

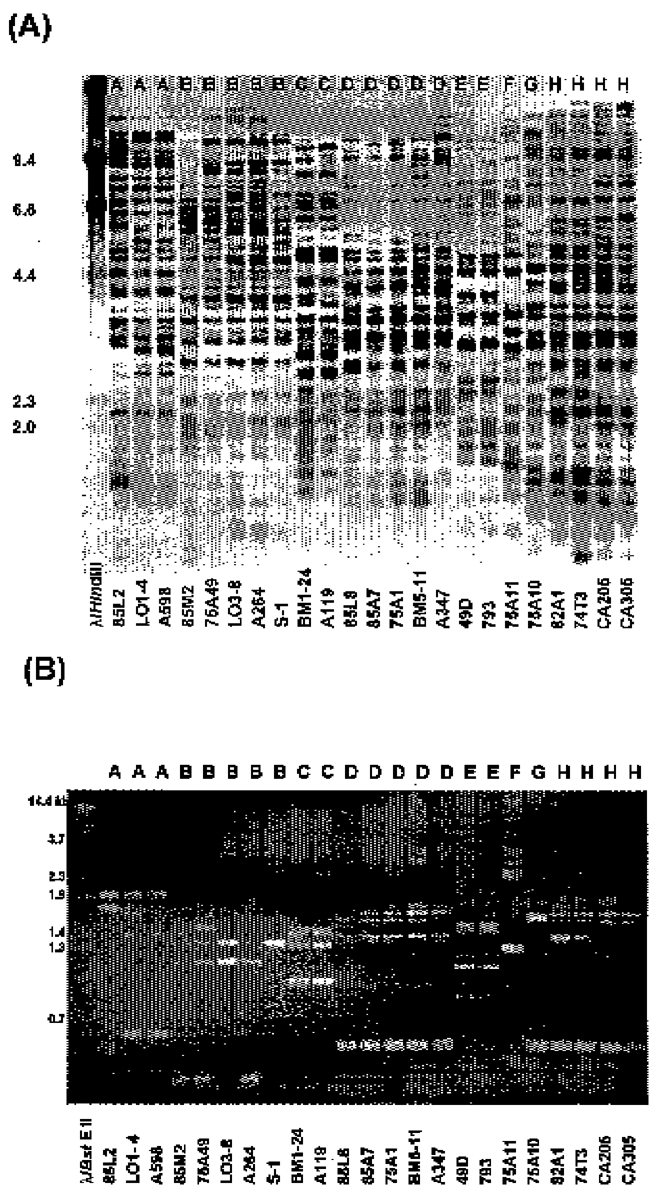

Fig. 1. (A) MGR586 DNA fingerprint groups found in Arkansas between 1974 and 1988. Fingerprint groups A,B,C,and D predominate in the contemporary population (1990-1998). Isolates recently collected from California (CA 205 and CA305) belong to fingerprint group H. (B) A rapid fingerprint procedure also was used to characterize isolates from Arkansas (George, *et al.*, 1998)

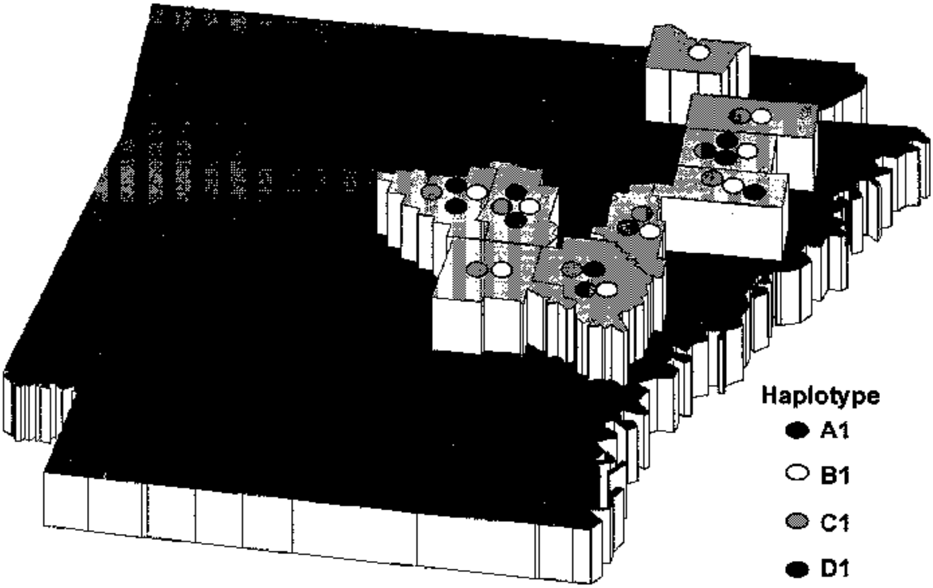

Fig. 2. The location of the four predominate haplotypes recovered throughout Arkansas.

SHEATH BLIGHT AND RICE BLAST RESISTANCE IN RECENTLY INTRODUCED RICE GERMPLASM

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ABSTRACT

Evaluating new rice germplasm in nurseries is an ongoing research activity to discover new resistance gene sources for use in developing high yielding disease resistance rice varieties. Susceptibility to rice sheath blight, caused by *Rhizoctinia solani*, and rice blast, caused by *Pyricularia grisea*, in inoculated field and greenhouse tests was estimated for 282 rice accessions recently introduced into the United States. Approximately 62 of the entries tested have excellent resistance to selected *P. grisea* races commonly found in Arkansas. Approximately 25 entries have excellent sheath blight tolerance, rating 4.5 or less using the standard 0 = no disease to 9 = maximum disease rating scale. Many entries had acceptable sheath blight tolerance, rating 6.0 or less on the disease scale. Eight entries have excellent sheath blight tolerance in combination with desired blast resistance. Entry evaluation will be continued to gather missing disease data and to determine resistance levels to other less important diseases occurring in Arkansas. In addition, the germplasm evaluation will be continued as new entries become available through the Animal and Plant Health Inspection Service (APHIS) and are identified within the existing U.S. germplasm collection.

INTRODUCTION

The rice resistance research project, *Discovery, Identification and Utilization of Resistance Genes for Rice Disease Control in Arkansas*, funded in part by the Rice Research and Promotion Board, routinely establishes various nurseries to evaluate disease resistance in newly obtained rice germplasm and in the many breeding lines of the Arkansas and U.S. cultivar development programs. Entries for these nurseries are obtained from rice germplasm being introduced into the United States from various international rice production areas and from the U.S. rice germplasm collection. Introduced germplasm is first processed through the USDA Animal and Plant Health Inspection Service quarantine to eliminate undesirable insects and diseases.

Rice sheath blight and rice blast are two of the most common and most damaging diseases in the United States. Evaluation tests often serve as a first screen by potential users, such as plant breeders, to identify highly susceptible entries. Thus, the potential for obtaining desirable agronomic characteristics in an entry present can be weighed against disease liabilities. Data presented are from 282 rice lines evaluated for susceptibility to rice blast and sheath blight.

PROCEDURES

Sheath blight resistance evaluations were made in an inoculated field nursery at the University of Arkansas Rice Research and Extension Center, Stuttgart. Four replications of the entries were planted in hill plots on 1-ft^2 centers. The nursery was artificially inoculated using sodium alginate pellets containing *R. solani* grown in lab shake cultures. Plants were evaluated at grain maturity.

Rice blast resistance evaluations were made in standardized greenhouse tests on 3-4 -leaf growth stage plants inoculated with individual *P. grisea* races. Plants were grown in a field soil/sand mixture (3:1). Plants were under moisture stress but leaves were not rolled when inoculated with approximately 5 x 10^5 *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 are well formed, usually 7 to 10 days.

In both tests, plants were visually rated using the standard 0 to 9 scale to estimate disease reaction. A rating of 0 indicates complete disease immunity. A 1 to 3 rating indicates resistance where little loss occurs and, especially in the case of rice blast, pathogen growth is restricted. Conversely, a 9 rating indicates maximum disease susceptibility, which typically results in complete plant death and/or yield loss.

RESULTS AND DISCUSSION

Although several new molecular techniques are promising, the only method currently available to assay for disease resistance is to grow plants, introduce the disease by inoculating with the pathogen, and then evaluate the resulting disease reaction to estimate degree of susceptibility. As previously indicated, the rating scale is 0 = no disease, 9 = maximum disease. These numerical ratings are sometimes converted to letter symbols where 0 to 3 = R (resistant), 3 to 4 = MR (moderately resistant), 5 to 6 = MS (moderately susceptible) 7 = S (susceptible), and 8 to 9 = VS (very susceptible).

Depending upon the disease in question, a disease rating of 4 to 6 is usually indicative of acceptable disease resistance when environmental conditions only slightly favor the pathogen. This is particularly true with rice sheath blight disease where plants rating 3 to 4.5 are considered very tolerant with little yield loss occurring in the field. Approximately 25 of the entries tested during 1998 had excellent sheath blight tolerance rating 4.5 or less. Many entries had acceptable sheath blight tolerance as indicated by a 6.0 or less sheath blight rating. Environmental conditions unfavorable for sheath blight development created in tall plants with an open canopy often result in misleading evaluations. Additional sheath blight evaluations will be conducted to identify those entries having genetic tolerance.

Greenhouse blast tests are the primary means of screening large numbers of entries for reaction to the blast races occurring in Arkansas rice production areas. Although greenhouse results are quite variable and test conditions tend to overwhelm any field resistance present in the entry, this test provides an accurate estimation of disease susceptibility.

Our stated research goal is to use genetic resistance to control blast races presently occurring in Arkansas. However, it is impossible to predict new blast race development or even potential damage by known races in new germplasm. Regardless, the blast data are arranged according to the perceived relative importance of our blast race collection which should represent the genetic variability in the *P. grisea* population. Races IB-49 and IC-17 arose during the devastating 'Newbonnet' blast epidemics of the 1980s and are now commonly isolated from Arkansas production areas. Race IG-1 rarely occurs in Arkansas rice fields but represents races predominate in the 'Starbonnet' cultivar grown prior to Newbonnet. Race IB-1 caused considerable yield reduction in the gulf coast production areas and at times damaged the 'Mars' cultivar in Arkansas. Race IH-1 was common in minor cultivars before and during the period Starbonnet was widely grown. Although poorly adapted and seldom isolated, IE-1_k represents a potential problem if substantial acreage is planted to 'Drew' and 'Kaybonnet'. Originating from laboratory cultures of race IB-49 and never found in field plants, race IB-33 also represents a potential threat to Drew and Kaybonnet.

Approximately 62 of the 1998 entries showed excellent resistance to all *P. grisea* races commonly found in Arkansas rice production areas. Many of the remaining entries are resistant to three or four of the seven races tested. Although blast susceptible, entries with a 5 to 6 blast rating likely have 'field' resistance and may be used with proper production practices. For example, very high yielding 'LaGrue' and 'Cypress' cultivars are blast susceptible but are routinely grown with minimal losses to rice blast.

Eight entries exhibited excellent sheath blight tolerance in combination with the desired blast resistance. This combination of resistance is very desirable because cultivars must perform in the presence of several diseases in grower fields.

Additional information is contained within the data to be extracted later. For example, entries listed as originating in Cote D'Ivoire (Africa) were derived from an interspecific cross between *Oryza sativa* and *Oryza glaberrima* and were obtained as potential sources of disease resistance. A quick examination suggests the desired disease resistance was not transferred from *O. glaberrima* to the resulting offspring.

SIGNIFICANCE OF FINDINGS

A question often asked is "what is being done to find new blast resistance genes and guard against a new blast outbreak". The answer lies within the research results, such as those presented here, of the overall rice research effort. Entries identified during 1998 are immediately available for consideration as resistant gene sources in U.S. breeding programs. Arkansas rice growers will benefit greatly over a period of many years as the identified resistance is incorporated into new high yielding disease resistant rice cultivars.

ACKNOWLEDGMENTS

This research would not have been possible without funding by the Rice Research and Promotion Board and services provided by USDA-ARS, Plant Germplasm Quarantine Office (PGQO) which prevents introduction of new potentially devastating insects and pathogens and the USDA-ARS National Small Grains Collection, Aberdeen, Idaho, which stores and disseminates seed from the U.S. rice germplasm collection.

Table 1. Sheath blight (*R. solani*) and blast (*P. grisea*) race susceptibility ratings of 1998 tests of recently introduced rice germplasm[z].

PI Number	Name or identity	Country of origin	Sheath blight	*P. grisea* race IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 602649	BR736-20-3-1	Bangladesh	3.5	0.3	0.0	0.3	0.0	0.0	0.3	5.0
PI 602647	BR4363-8-11-4-9	Bangladesh	3.8	0.0	0.0	0.0	0.0	0.0	0.5	5.3
PI 584669	PANAMA 1048	Colombia	4.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
PI 574661	BR4	Bangladesh	4.0	0.0	0.0	.	0.0	0.0	0.0	5.7
PI 584668	ORYZICA LLANOS 5	Colombia	4.0	0.0	1.0	0.0	0.0	0.5	0.0	0.0
PI 574663	BR6	Bangladesh	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3
PI 574664	BR7	Bangladesh	4.3	0.0	0.0	0.0	0.0	0.0	0.0	5.3
PI 560283	TOX1859-102-6M-3	Colombia	4.5	0.0	0.3	0.0	0.0	0.0	0.5	1.0
PI 584659	ALIANCA	Colombia	4.8	0.0	0.3	0.0	0.0	0.0	0.7	0.3
PI 584696	CT10179-13-5-M	Colombia	4.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PI 584716	CT10310-15-9-M	Colombia	4.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PI 584719	CT10323-8-2-M	Colombia	4.8	0.0	1.0	1.0	0.3	0.0	0.0	0.0
PI 602646	BR1257-31-1-1	Bangladesh	4.8	0.3	0.0	0.0	0.0	0.0	0.0	5.3
PI 584718	CT10323-3-2-M	Colombia	4.8	0.5	1.0	0.0	0.0	0.0	0.0	5.0
PI 584727	CT10336-13-3-M	Colombia	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PI 584737	J-104	Colombia	5.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0
PI 584746	CEA 3	Paraguay	5.0	0.0	0.0	0.0	0.0	0.0	3.3	0.7
PI 597078	B 4142	Philippines	5.0	0.0	0.0	0.0	0.0	0.0	0.0	.
PI 602640	BG1219	Sri Lanka	5.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3
PI 584662	CR5272	Colombia	5.0	0.0	0.3	0.0	0.0	0.0	0.0	0.7
PI 584666	INIAP 11	Colombia	5.0	0.0	0.3	0.0	0.0	0.0	0.0	5.3
PI 584698	CT10184-1-1-M	Colombia	5.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PI 584751	ICTA VIRGINIA	Guatemala	5.0	0.0	0.3	0.0	0.7	0.0	1.3	0.3
PI 584720	CT10323-13-3-M	Colombia	5.0	0.0	0.3	0.5	0.0	0.3	0.0	0.0
PI 602650	BR802-118-4-2	Bangladesh	5.0	0.3	0.3	0.0	0.0	0.0	0.0	6.5

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 597080	ST 2375	Philippines	5.0	0.5	0.0	0.3	0.0	0.0	0.7	5.7
PI 574672	BR16	Bangladesh	5.3	0.0	0.0	0.0	0.0	0.0	0.0	5.7
PI 584704	CT10204-5-2-M	Colombia	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PI 597085	CNA 4127	Colombia	5.3	0.0	0.0	0.0	0.0	0.0	0.0	4.3
PI 602644	BG936	Sri Lanka	5.3	0.0	0.0	0.0	0.0	0.0	0.0	5.7
PI 602648	BR568-15-4-2-2-2	Bangladesh	5.3	0.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 602629	SHANYOU	China	5.3	0.3	0.0	0.0	0.3	0.0	0.0	0.3
PI 584702	CT10190-10-1-M	Colombia	5.3	0.3	0.3	0.0	0.0	0.0	0.0	0.3
PI 584667	JUMA 61	Do. Republic	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PI 584713	CT10308-19-3-M	Colombia	5.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PI 584714	CT10308-19-4-M	Colombia	5.5	0.0	1.0	0.0	0.0	0.0	0.5	5.5
PI 584722	CT10323-21-6-M	Colombia	5.5	0.5	0.3	0.5	0.0	0.0	0.0	0.0
PI 602641	BG1639	Sri Lanka	5.7	0.0	0.0	0.0	0.0	0.0	1.0	0.0
PI 574670	BR14	Bangladesh	5.7	0.3	0.0	0.0	0.0	0.0	0.0	0.5
PI 584672	C 122CU83-S...-CU-1	Colombia	5.8	0.0	0.3	0.3	0.0	0.0	0.0	5.3
PI 574681	BR25	Bangladesh	5.8	0.5	0.0	0.0	0.0	0.0	0.0	5.5
PI 584725	CT10335-5-3-M	Colombia	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PI 597048	CT6947-1-1-1-7-M	Colombia	6.0	0.0	0.0	0.0	0.3	0.0	0.0	5.3
PI 602645	BOUAKE 189	Cote D'Ivoire	6.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 584692	CT9908-1-15-M	Colombia	6.0	0.0	0.3	0.0	0.3	0.0	0.0	1.0
PI 584734	CNAX 5115-2-1-1	Colombia	6.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
PI 597042	IR47686-18-7B	Philippines	6.3	0.0	0.0	0.0	0.0	1.0	0.0	1.0
PI 602652	ECIA 66	Cuba	6.3	0.3	0.0	0.0	0.0	0.0	0.0	0.3
PI 584733	CNAX 5093-8-1-1	Colombia	6.5	0.0	0.0	0.0	0.0	0.0	0.3	0.0
PI 584717	CT10321-2-2-M	Colombia	6.5	0.3	0.3	0.0	0.0	0.0	0.0	5.5

continued

Table 1. Continued.

PI Number	Name or identity	Country of origin	Sheath blight	*P. grisea* race IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 597081	IR9202-25-1-3	Philippines	6.7	0.3	0.0	0.0	0.0	0.0	0.3	6.3
PI 596944	RP2327-318-869	India	6.8	0.0	0.0	0.0	0.3	0.7	0.5	1.0
PI 602628	SHANHUNG	China	6.8	0.0	0.0	0.0	0.0	0.3	0.0	5.0
PI 584728	CT10343-10-1-M	Colombia	7.0	0.0	0.0	0.0	0.0	0.0	0.3	5.5
PI 597002	H194-27-2-2-2	Argentina	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
PI 602654	ECIA76-S89-1	Cuba	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
PI 602656	IR47310-87-2-1-2	Philippines	7.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
PI 584753	ORYZICA LLANOS 4	Colombia	7.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
PI 584712	CT10306-8-1-M	Colombia	7.0	0.0	0.3	0.5	0.0	0.0	0.3	0.0
PI 602659	IR50404-57-2-2-3	Philippines	7.0	0.3	0.0	0.3	0.0	0.0	0.0	7.0
PI 584695	CT10179-1-1-M	Colombia	7.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PI 597049	CT7244-9-2-1-52-1	Colombia	7.3	0.3	0.0	0.0	0.3	0.0	0.0	1.0
PI 602653	ECIA67-S1-J1-5	Cuba	7.3	0.3	0.0	0.0	0.0	0.0	0.0	0.7
PI 584732	CNAX 5083-1-5-2B	Colombia	7.7	0.0	0.0	0.0	0.0	0.0	1.0	6.0
PI 602625	MIYANG	China	7.8	0.0	0.0	0.0	0.0	0.0	0.0	5.0
PI 584711	CT10284-5-2-M	Colombia	7.8	1.0	0.3	0.0	0.0	0.0	0.0	1.0
PI 584748	CHANCAY	Peru	8.0	0.7	0.0	0.0	0.0	0.0	2.7	0.3
PI 527707	KATY	United States	.	0.0	0.0	0.0	0.0	0.0	5.6	5.7
PI 584757	SAN PEDRO	Bolivia	5.0	0.0	0.0	0.3	0.3	0.0	4.7	4.7
PI 597053	C101A51	Philippines	7.3	0.0	0.0	0.5	0.0	1.0	5.0	0.0
PI 584724	CT10331-7-1-M	Colombia	6.0	0.0	0.3	0.0	0.3	0.0	7.3	7.0
PI 584738	IAC 1278	Brazil	5.8	0.0	0.3	0.0	0.3	.	6.0	6.3
PI 584703	CT10195-52-1-M	Colombia	4.5	0.0	0.0	0.3	5.3	0.0	0.3	0.0
PI 602657	IR49442-9-1-1-1-3	Philippines	5.3	0.3	0.0	0.0	7.5	0.0	5.0	5.3
PI 584680	TAICHUN SEN YU 10	Taiwan	6.0	0.0	0.0	.	8.0	4.0	6.5	6.0

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 560297	SANTA JULIA	Colombia	7.8	0.0	0.0	5.7	0.0	4.7	5.0	0.0
PI 597075	BSI-10	Philippines	7.3	0.0	0.3	0.0	6.3	6.0	6.0	6.0
PI 584697	CT10181-7-9-M	Colombia	5.8	0.5	0.3	0.0	0.5	0.0	6.0	5.5
PI 602633	WAB450-I-B-P-23-HB	Cote D'Ivoire	7.8	0.0	0.3	4.5	7.0	0.3	0.7	1.0
PI 602636	WAB56-57	Cote D'Ivoire	7.5	0.0	0.3	5.5	7.0	1.0	4.7	5.7
PI 602607	HB-15-2	Hungary	7.3	0.0	6.0	6.0	7.7	6.5	6.7	5.0
PI 584715	CT10308-19-6-M	Colombia	5.3	0.3	0.7	0.0	5.7	0.7	0.3	5.5
PI 584752	ORYZICA 3	Colombia	3.5	0.5	0.0	0.0	5.7	.	5.0	5.5
PI 597041	CNA4130	Colombia	6.8	0.5	0.0	0.0	5.0	1.0	0.0	.
PI 602638	WAB56-50	Cote D'Ivoire	8.0	0.5	0.0	0.0	6.0	.	0.0	5.0
PI 574683	PANBIRA	Bangladesh	5.0	0.5	0.0	4.5	0.0	4.0	6.0	5.7
PI 602635	WAB56-104	Cote D'Ivoire	8.3	3.3	0.3	6.0	6.7	3.0	5.3	4.7
PI 584729	CNAX 5037-1-5-2B	Colombia	5.3	4.0	0.0	0.0	0.0	0.0	.	5.7
PI 584744	CEA 2	Paraguay	4.5	4.0	0.0	1.0	0.0	0.3	1.0	5.3
PI 574428	MEDUSA	Italy	7.0	4.0	0.0	5.0	7.3	.	.	6.0
PI 574677	BR21	Bangladesh	5.0	4.3	0.0	0.0	0.0	.	0.0	0.5
PI 574789	JAGLI BORO	Bangladesh	3.0	4.3	0.0	0.5	6.0	4.3	6.0	1.0
PI 584723	CT10323-28-4-M	Colombia	5.3	4.5	0.3	0.0	0.0	0.0	4.7	4.7
PI 584699	CT10184-4-1-M	Colombia	5.0	4.5	0.3	1.0	0.3	0.0	0.0	0.0
PI 597047	CT6196-33-10-4-15-M	Colombia	7.0	4.5	2.5	.	8.0	0.0	0.0	5.5
PI 574671	BR15	Bangladesh	5.5	4.7	0.0	0.0	0.0	0.7	0.0	5.7
PI 584684	ECIA 167-146-S...-3-1	Colombia	4.8	4.7	0.0	0.0	0.0	0.0	0.0	4.7
PI 584721	CT10323-18-3-M	Colombia	4.5	4.7	0.0	0.0	0.0	.	0.0	0.5
PI 597052	C101LAC	Philippines	8.5	4.7	0.0	0.0	4.3	0.3	4.3	5.3
PI 597090	IR52717-2B-4-2B-1-3	Philippines	6.0	4.7	0.0	0.0	0.0	0.0	0.0	6.3

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 597091	IR8866-30-3-1-4-2	Philippines	5.8	4.7	0.0	0.0	0.0	0.0	0.0	6.0
PI 602624	ZHENSHAN-2	China	7.5	4.7	0.0	0.0	0.0	0.0	0.0	0.7
PI 602658	IR50363-61-1-2-2	Philippines	7.0	4.7	0.0	0.0	0.0	0.0	0.0	7.0
PI 597054	C102PKT	Philippines	8.8	4.7	0.5	0.0	7.3	3.0	6.7	7.0
PI 574445	STAR	Italy	8.5	5.0	0.0	0.0	6.0	.	6.0	1.0
PI 574947	JABA HULU	Bangladesh	.	5.0	0.0	0.0	7.0	0.0	0.0	6.0
PI 585043	CIAT CHINAN 8	Colombia	6.3	5.0	0.0	0.0	5.5	5.0	0.0	5.0
PI 602626	MINGHUI	China	6.3	5.0	0.0	0.0	0.0	0.0	0.0	0.3
PI 602655	IR40750-116-3-2-3-2	Philippines	5.0	5.0	0.0	0.0	0.0	0.0	0.0	6.7
PI 584731	CNAX 5072-2-1-2B	Colombia	7.0	5.0	0.0	0.7	5.7	0.0	0.3	5.7
PI 597076	B 4128	Philippines	5.8	5.0	0.0	5.0	6.7	6.0	6.0	6.0
PI 574444	SORRISO	Italy	8.8	5.0	0.0	5.3	6.5	5.0	6.0	6.0
PI 597087	IR62752-06	Philippines	6.0	5.0	0.0	.	6.0	0.3	.	6.5
PI 602623	SZ-978	Hungary	8.3	5.0	0.0	.	7.0	.	0.0	6.0
PI 602632	WAB450-I-B-P-148-2-1	Cote D'Ivoire	7.3	5.0	0.3	0.0	0.0	0.0	0.5	0.3
PI 602639	BG1165-2	Sri Lanka	7.3	5.0	0.3	0.0	0.0	0.0	0.0	6.3
PI 574440	SELENIO	Italy	7.0	5.0	0.3	0.3	7.0	5.7	6.3	6.5
PI 602663	C101PKT	Philippines	8.3	5.0	0.3	0.7	8.0	5.0	5.7	7.7
PI 584676	IRAT 341	Colombia	7.8	5.0	1.0	0.0	0.0	5.5	0.0	.
PI 597056	C105TTP-4-L23	Philippines	8.3	5.0	1.0	0.5	7.3	5.3	6.5	7.0
PI 584689	CT9901-3-3-M	Colombia	5.8	5.0	1.0	1.0	5.0	0.0	0.0	0.5
PI 584679	H 175-13-1-1	Colombia	5.5	5.0	1.0	4.7	7.0	4.5	6.0	6.3
PI 574429	MIARA	Italy	8.3	5.0	1.0	5.0	8.0	.	7.0	5.5
PI 574420	ELVO	Italy	7.5	5.0	6.0	0.0	7.3	7.0	.	5.7
PI 560222	DWARF J. SANNA	India	5.5	5.3	0.0	0.0	6.0	0.7	4.7	6.3

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 574660	BR3	Bangladesh	4.0	5.3	0.0	0.0	0.0	0.0	0.0	6.0
PI 574667	BR10	Bangladesh	3.8	5.3	0.0	0.0	0.0	0.0	0.0	6.0
PI 584736	IR1529-ECIA	Philippines	5.3	5.3	0.0	0.0	0.0	0.0	0.0	6.7
PI 596964	IR43549-56-41-3-1	Philippines	8.0	5.3	0.0	0.0	0.0	0.0	0.0	5.7
PI 597050	SAMGANGBYEO	South Korea	7.3	5.3	0.0	0.0	0.0	0.0	0.0	1.0
PI 602642	BG450	Sri Lanka	4.3	5.3	0.0	0.0	0.0	0.0	0.0	6.0
PI 602643	BG915	Sri Lanka	5.8	5.3	0.0	0.0	0.0	0.0	0.3	7.0
PI 574659	BR2	Bangladesh	6.8	5.3	0.0	1.0	6.0	5.0	4.7	6.3
PI 597038	IRAT 216	Philippines	7.0	5.3	0.0	4.5	5.7	0.0	5.0	4.7
PI 597082	RP1848-216-...(HB 5055	Philippines	7.5	5.3	0.3	0.7	6.5	4.5	6.3	6.0
PI 584674	CT9146-12-1-1E-2-1P	Colombia	6.5	5.3	0.3	4.7	0.0	0.0	0.0	4.7
PI 584756	SAN MARTIN 86	Peru	3.8	5.3	1.0	0.0	0.0	0.0	0.0	7.0
PI 584687	CT9901-1-4-M	Colombia	6.8	5.3	1.0	0.3	5.3	4.7	0.3	4.7
PI 597065	IRBB1 (XA-1)	Philippines	5.8	5.5	0.0	0.0	0.0	0.0	0.0	6.3
PI 597088	IR9884-54-3-IE-P1	Philippines	5.0	5.5	0.0	0.0	0.0	.	0.0	7.0
PI 574658	BR1	Bangladesh	5.5	5.5	0.0	0.5	6.0	6.0	5.7	6.0
PI 584701	CT10184-8-6-M	Colombia	5.5	5.5	0.3	0.0	0.0	0.0	0.0	6.0
PI 597044	KU115	Thailand	6.5	5.5	6.0	0.5	7.0	.	6.7	.
PI 597066	IRBB3 (XA-3)	Philippines	5.8	5.7	0.0	0.0	0.0	0.0	0.0	6.5
PI 584678	HURI 282	Colombia	6.8	5.7	0.3	0.0	0.0	0.0	0.0	5.3
PI 584693	CT9998-21-7-M	Colombia	5.5	5.7	5.7	6.0	7.0	5.0	6.0	6.0
PI 584565	TCHAMPA	Iran	5.8	6.0	0.0	0.0	7.0	0.5	0.7	5.0
PI 584685	TAI SEN WAXY YU 19	Taiwan	4.8	6.0	0.0	0.0	0.0	0.0	0.0	0.3
PI 584726	CT10335-5-10-M	Colombia	5.3	6.0	0.0	0.0	0.3	0.0	0.0	5.7
PI 584742	ARAURE 4	Venezuela	4.5	6.0	0.0	0.0	0.0	.	0.0	5.0

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 597045	HD14	Australia	6.0	6.0	0.0	0.0	0.0	0.0	0.0	4.5
PI 597068	IRBB5 (XA-5)	Philippines	6.8	6.0	0.0	0.0	0.0	0.0	0.0	6.3
PI 597069	IRBB10 (XA-10)	Philippines	6.7	6.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 597071	IRBB13 (XA-13)	Philippines	7.0	6.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 597072	IRBB14 (XA-14)	Philippines	6.5	6.0	0.0	0.0	0.0	0.0	0.0	6.7
PI 597079	TCCP266-2-49	Philippines	6.0	6.0	0.0	0.0	0.0	0.0	4.7	6.0
PI 597093	IR25976-12-2-2-2-1-1	Philippines	6.8	6.0	0.0	0.0	0.0	0.0	0.0	7.0
PI 602611	M-225	Hungary	8.0	6.0	0.0	0.0	8.0	0.3	5.3	6.5
PI 602630	WAB450-11-1-2-P1-HB	Cote D'Ivoire	8.0	6.0	0.0	0.0	0.0	0.5	5.0	0.0
PI 602661	WAB 502-13-4-1	Cote D'Ivoire	8.3	6.0	0.0	0.0	0.5	0.0	0.0	6.0
PI 574735	BURI KATARI(2)	Bangladesh	.	6.0	0.0	0.3	5.7	4.3	6.0	6.0
PI 574790	JAGLI BORO	Bangladesh	.	6.0	0.0	0.3	7.0	5.5	5.5	1.0
PI 584739	CIAT ORYZICA 1-M2	Colombia	4.5	6.0	0.0	0.3	0.0	0.0	0.0	5.3
PI 596813	WIR 3419	Azerbaijan	6.0	6.0	0.0	0.3	8.0	0.0	8.0	6.5
PI 574528	RONCOLO	Italy	7.0	6.0	0.0	5.0	8.0	6.0	6.0	6.0
PI 597074	BSI-15	Philippines	6.5	6.0	0.0	7.0	5.0	.	.	6.0
PI 602613	SANDORA	Hungary	8.5	6.0	0.0	.	7.5	6.0	.	7.0
PI 602662	WAB 501-11-5-1	Cote D'Ivoire	8.5	6.0	0.0	.	6.0	4.5	0.0	6.0
PI 584660	AMISTAD 82	Colombia	5.8	6.0	0.3	0.0	0.0	0.0	0.0	5.7
PI 584708	CT10227-4-7-M	Colombia	6.5	6.0	0.3	0.0	0.0	0.0	0.5	4.7
PI 574759	BOLORUM	Bangladesh	.	6.0	0.3	4.7	0.3	6.0	5.0	6.0
PI 584661	CR1821	Colombia	5.0	6.0	0.3	5.0	5.0	0.0	5.3	6.0
PI 602614	SZ-6	Hungary	7.3	6.0	0.3	5.0	8.0	6.0	7.3	5.5
PI 596847	AS13744	India	6.5	6.0	0.5	0.5	7.7	6.7	7.3	7.7
PI 574959	MURA BAZAL	Bangladesh	.	6.0	0.5	0.7	0.5	6.0	5.7	6.7

continued

Table 1. Continued.

PI Number	Name or identity	Country of origin	Sheath blight	*P. grisea* race IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 584664	EMPASC 102	Colombia	5.0	6.0	1.0	0.0	0.0	0.0	0.0	6.0
PI 596833	GRALDO	Italy	5.0	6.0	1.0	0.0	8.0	.	6.0	5.5
PI 584673	LMNT X DESC/85...1	Colombia	8.8	6.0	1.0	0.3	5.3	0.0	7.5	.
PI 584606	MAINT...OLOTSY 1226	Madagascar	5.8	6.0	1.0	1.0	7.0	0.0	5.0	5.7
PI 584681	7818-TR4-1-1	Colombia	5.0	6.0	4.3	0.0	0.3	0.0	1.0	0.7
PI 575026	LOHAR GURA	Bangladesh	.	6.0	4.5	6.0	7.0	6.0	6.7	6.0
PI 575027	ARAI	Bangladesh	.	6.0	5.0	0.7	7.7	7.0	6.0	7.3
PI 597073	BSI-16	Philippines	6.8	6.0	5.0	7.0	7.3	7.0	6.0	6.0
PI 597077	B 4013	Philippines	5.5	6.0	5.3	0.5	6.3	0.5	5.5	.
PI 584690	CT9905-5-10-M	Colombia	5.0	6.0	5.3	1.0	0.5	5.0	0.0	6.0
PI 574762	CHAKULIA	Bangladesh	.	6.0	5.7	6.0	8.0	7.0	6.3	7.5
PI 584682	7953-TR53-27-1-1-1	Colombia	7.5	6.0	7.0	6.3	8.0	7.0	7.7	7.5
PI 574758	BOWALIA	Bangladesh	.	6.3	0.0	0.0	5.3	5.5	1.0	0.7
PI 597067	IRBB4 (XA-4)	Philippines	5.8	6.3	0.0	0.0	0.0	0.0	0.0	6.3
PI 597092	IR59489-2B-3-2	Philippines	5.8	6.3	0.0	0.0	0.0	0.0	0.0	6.0
PI 574755	DHOLI BORO	Bangladesh	.	6.3	0.0	0.3	0.0	0.0	5.7	6.7
PI 597064	C101TTP-1	Philippines	7.5	6.3	0.0	0.3	6.0	6.5	5.0	7.3
PI 584709	CT10230-8-3-M	Colombia	6.3	6.3	0.3	0.5	0.0	0.0	0.0	6.0
PI 574437	RIO	Italy	7.0	6.3	5.0	0.3	7.7	.	6.0	5.7
PI 574761	AGAUA	Bangladesh	.	6.3	5.7	6.3	7.5	7.0	7.3	7.0
PI 574675	BR19	Bangladesh	3.8	6.5	0.0	0.0	0.0	0.0	0.0	7.5
PI 597089	IR51500-AC11-1	Philippines	5.5	6.5	0.0	0.0	0.0	0.0	0.0	5.3
PI 574439	SAN PETRONIO	Italy	7.5	6.5	0.0	0.5	7.0	7.0	7.0	6.5
PI 574686	BOTESWAR	Bangladesh	.	6.5	0.0	4.5	0.3	5.0	6.3	7.3
PI 574688	KALA MANIK	Bangladesh	.	6.5	0.3	0.0	8.0	5.7	6.7	7.0

continued

Table 1. Continued.

PI Number	Name or identity	Country of origin	Sheath blight	*P. grisea* race IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 602634	WAB450-24-...3-P33-HB	Cote D'Ivoire	8.7	6.5	0.3	0.0	0.3	4.0	0.0	6.3
PI 584557	CHAHORA 144	Pakistan	5.0	6.5	4.7	0.0	7.0	0.0	6.0	6.3
PI 602618	SZ-74	Hungary	8.0	6.5	5.5	0.0	7.0	1.0	6.0	7.0
PI 574796	GORIA	Bangladesh	.	6.5	6.0	0.0	7.7	.	6.3	7.0
PI 602615	SZ-26	Hungary	8.0	6.5	6.0	6.0	7.5	4.0	6.3	7.5
PI 574415	CERVO	Italy	7.0	6.5	6.7	0.0	6.7	6.0	6.5	6.7
PI 574423	IDRA	Italy	5.5	6.5	7.0	6.0	7.3	6.3	6.5	6.7
PI 584735	CT11971F2	Colombia	6.5	6.5	.	.	0.0	0.0	0.0	7.0
PI 597046	CEYSVONI	Suriname	5.5	6.7	0.0	0.0	0.0	0.0	0.0	7.0
PI 574760	PANKIRAJ	Bangladesh	7.0	6.7	0.0	4.7	6.7	7.0	5.7	7.0
PI 560279	H 305-84	Colombia	7.0	6.7	0.0	6.0	6.5	.	7.0	6.0
PI 574757	BOWALIA	Bangladesh	.	6.7	0.0	6.0	6.0	6.3	5.5	7.3
PI 584546	PADI KASALLE	Indonesia	5.0	6.7	0.3	0.0	7.3	7.0	5.3	7.3
PI 584686	CT9901-1-2-M	Colombia	5.0	6.7	0.3	0.0	0.0	0.0	0.0	7.3
PI 584670	RUSTIC	Colombia	7.3	6.7	0.3	0.3	0.3	0.0	0.3	6.0
PI 584700	CT10184-8-5-M	Colombia	6.3	6.7	0.3	.	0.0	0.0	0.0	5.5
PI 584730	CNAX 5067-4-2-4B	Colombia	7.0	6.7	4.7	6.0	0.3	4.3	6.7	7.0
PI 574438	RIVA	Italy	7.7	6.7	5.0	5.0	7.0	6.3	6.7	6.7
PI 574416	DEDALO	Italy	6.3	6.7	6.0	0.0	7.3	0.0	7.7	6.7
PI 574414	BONNET BELL	Italy	5.5	6.7	6.7	7.0	7.7	.	7.7	6.5
PI 574447	TESORO	Italy	6.0	7.0	0.0	0.0	6.3	0.5	.	.
PI 574676	BR20	Bangladesh	4.3	7.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 574680	BR24	Bangladesh	6.0	7.0	0.0	0.0	0.0	0.0	0.0	7.0
PI 597070	IRBB10 (XA-11)	Philippines	7.0	7.0	0.0	0.0	0.0	0.0	0.0	6.3
PI 574674	BR18	Bangladesh	5.5	7.0	0.0	0.3	0.0	0.0	5.3	6.7

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 602634	WAB450-24-...3-P33-HB	Cote D'Ivoire	8.7	6.5	0.3	0.0	0.3	4.0	0.0	6.3
PI 574684	HASHA KUMIR	Bangladesh	.	7.0	0.0	0.3	5.3	5.5	7.7	7.5
PI 602617	SZ-44	Hungary	9.0	7.0	0.0	0.3	7.3	6.0	7.0	7.0
PI 574685	DHALA SAITA	Bangladesh	.	7.0	0.0	0.7	0.0	4.5	5.7	7.3
PI 574853	BALIA BOKRI	Bangladesh	.	7.0	0.0	4.7	0.0	5.0	7.0	7.0
PI 574682	BR26	Bangladesh	5.0	7.0	0.0	6.0	0.0	0.3	8.0	6.7
PI 596809	DEOKJEOKJODO	South Korea	6.5	7.0	0.0	6.0	6.7	6.5	.	6.0
PI 584707	CT10227-4-1-M	Colombia	7.0	7.0	0.3	0.0	0.0	0.0	0.0	5.0
PI 602651	CL SELECCION 56	Brazil	5.3	7.0	0.3	0.0	0.0	0.0	0.0	6.7
PI 574797	JUMA	Bangladesh	.	7.0	0.3	6.0	5.0	5.0	7.7	6.7
PI 560227	RUPSAIL	India	4.8	7.0	0.5	0.5	0.5	0.0	1.0	5.3
PI 560294	P 5446-6-6-2-1	Colombia	3.5	7.0	0.5	5.0	6.0	4.5	5.3	7.0
PI 602610	KARMINA	Hungary	7.3	7.0	1.0	0.0	7.0	.	.	6.5
PI 602622	SZ-958	Hungary	5.8	7.0	1.0	.	8.0	7.0	7.0	6.7
PI 574945	ACHAR DHOG	Bangladesh	.	7.0	5.3	0.0	7.3	0.3	5.7	7.0
PI 584671	X-10	Colombia	5.8	7.0	5.3	7.0	0.0	0.0	5.0	6.7
PI 602605	AGUISTA	Hungary	8.0	7.0	5.3	7.0	7.0	.	.	6.5
PI 574441	SILLA	Italy	7.3	7.0	5.5	0.5	7.5	6.0	7.0	6.0
PI 574793	THUBRI	Bangladesh	.	7.0	5.5	5.3	7.7	7.3	6.7	7.0
PI 602616	SZ-40	Hungary	8.0	7.0	5.7	6.0	7.5	.	.	8.0
PI 584677	DM16-5-1	Colombia	5.3	7.0	6.0	0.0	5.5	0.0	0.0	5.0
PI 602631	WAB450-4-1-1-P23-1-1	Cote D'Ivoire	6.0	7.0	6.0	0.5	6.3	5.3	5.5	6.0
PI 574430	MIDA	Italy	7.3	7.0	6.3	0.0	7.5	0.0	7.3	7.0
PI 602609	HC-11-2	Hungary	7.7	7.0	7.0	.	6.3	1.0	6.0	7.0
PI 585047	K-17082	Thailand	7.7	7.0	.	5.7	6.0	6.0	7.0	6.5
PI 560234	2717	Colombia	6.0	7.0	.	6.0	6.0	1.0	7.7	7.0

continued

Table 1. Continued.

			Sheath	*P. grisea* race						
PI Number	Name or identity	Country of origin	blight	IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 574433	ONDA	Italy	6.5	7.3	0.0	0.0	7.7	0.0	0.5	6.3
PI 584754	PALIZADA A-86	Mexico	5.0	7.3	0.0	0.0	0.0	0.0	0.0	6.5
PI 585045	K-17039	Thailand	4.0	7.3	0.0	0.0	0.0	0.0	0.0	6.3
PI 574434	PEGASO	Italy	7.0	7.3	0.3	1.0	8.0	1.0	5.5	6.3
PI 584570	ARIAS	Indonesia	4.5	7.3	4.7	6.3	6.0	6.7	6.0	5.3
PI 574792	INDA	Bangladesh	.	7.3	6.0	6.0	7.3	6.3	7.3	7.7
PI 602666	PALLAGI 67	Hungary	8.0	7.3	6.3	6.0	8.0	7.0	7.0	6.0
PI 584710	CT10279-2-4-M	Colombia	5.5	7.5	0.0	7.0	5.7	5.3	6.0	6.0
PI 574443	SMERALDO	Italy	7.5	7.5	4.7	6.0	7.0	5.0	6.5	6.0
PI 574435	PREVER	Italy	7.0	7.5	5.7	0.0	7.7	0.0	7.7	7.3
PI 602665	PALLAGI 9	Hungary	7.8	7.5	7.3	6.0	7.5	6.5	7.0	7.0
PI 602660	IR51678-93-2-2-2-1	Philippines	4.8	7.7	0.0	0.0	0.0	0.0	0.0	7.0
PI 584691	CT9905-5-18-M	Colombia	6.8	7.7	1.0	6.0	7.3	0.7	5.0	6.0
PI 574756	KACHILON	Bangladesh	8.0	7.7	6.5	6.0	8.0	.	6.7	7.3
PI 574791	SHADRA DUMRA	Bangladesh	.	7.7	7.0	6.3	8.0	3.3	7.7	7.5
PI 474580	NEWBONNET	United States	.	7.9	6.9	.	7.9	.	.	.
PI 574666	BR9	Bangladesh	4.8	8.0	0.0	0.0	0.0	0.0	0.3	6.7
PI 602627	TESHANAI	China	5.0	8.0	0.0	0.0	0.0	0.0	0.0	6.0
PI 574687	LAKSMI LOTA	Bangladesh	3.0	8.0	0.0	0.3	0.0	.	6.7	7.0
PI 584663	EL PASO L-144	Colombia	6.5	8.0	0.0	6.3	0.0	4.0	6.7	6.7
PI 574944	DAL KAISHA	Bangladesh	3.0	8.0	0.3	0.0	6.7	6.7	5.3	6.7
PI 584683	C 3CU77-1CU-...2CU-S	Colombia	3.8	8.0	0.3	0.0	0.0	0.0	0.0	7.3
PI 584705	CT10204-5-3-M	Colombia	6.0	8.0	0.3	0.0	0.0	0.0	0.0	6.7
PI 574795	KOLA DAMA	Bangladesh	.	8.0	0.3	0.3	0.0	7.0	7.0	7.0
PI 560275	ORYZELLA	Colombia	6.5	8.0	0.5	6.5	7.0	1.0	7.5	7.0

continued

Table 1. Continued.

PI Number	Name or identity	Country of origin	Sheath blight	*P. grisea* race						
				IB-49	IC-17	IG-1	IB-1	IH-1	IE-1K	IB-33
PI 584750	EMPASC 103	Brazil	5.3	8.0	0.7	5.5	0.0	0.0	6.3	6.0
PI 584566	PHUDUGEY	Bhutan	6.3	8.0	1.0	0.0	7.3	0.5	5.0	5.0
PI 602608	HC-7-2	Hungary	7.3	8.0	3.5	0.0	7.3	1.0	7.0	7.0
PI 584665	EMPASC 105	Colombia	7.5	8.0	4.3	6.3	0.0	0.3	6.7	6.0
PI 602621	SZ-951	Hungary	7.7	8.0	5.0	0.5	7.0	.	7.0	7.0
PI 584741	ARAURE 1	Venezuela	5.3	8.0	5.0	6.7	6.3	5.3	7.0	7.3
PI 574446	TARRISO	Italy	7.3	8.0	5.5	0.0	8.0	0.0	7.0	7.0
PI 602619	SZ-79	Hungary	7.5	8.0	5.5	0.0	8.0	1.0	.	6.5
PI 597055	C104PKT	Philippines	8.8	8.0	7.0	7.0	8.0	5.0	7.7	7.3
CI 9980	M201	United States	8.0	7.7	7.5	8.0	8.0	8.0	7.9	.
PI 597033	WIR 911	Russian Fed.	8.0	8.0	8.0	7.3	7.7	8.0	7.7	6.7
PI 597028	80099-TR242-4-1-1	Turkey	7.8	8.0	.	6.0	7.0	6.5	7.0	6.0
PI 574669	BR12	Bangladesh	5.8	.	0.0	0.0	0.0	0.0	0.0	5.0
PI 597086	IR62752-10	Philippines	5.8	.	0.0	0.0	0.3	.	5.0	1.0
PI 602637	WAB462-10-3-1	Cote D'Ivoire	7.5	.	0.0	1.0	7.0	1.0	0.3	1.0
PI 584575	CANELLA DE FERRO	Brazil	6.3	.	0.0	5.0	6.0	4.0	4.7	4.3
PI 602612	RINGOLA	Hungary	7.8	.	6.0	0.0	7.5	1.0	7.0	6.0
PI 574421	EUROSE	Italy	7.0	.	6.5	7.0	7.5	7.0	7.0	6.5

[z] Rating scale: 0 = no disease to 9 - maximum disease.

DISEASE RESISTANCE IN THE NEW RICE CULTIVAR 'WELLS'

F.N. Lee, K.A.K. Moldenhauer, R.D. Cartwright, and J.L. Bernhardt

ABSTRACT

Maintaining and improving disease resistance in high-yielding cultivars released for use in Arkansas rice production areas is an ongoing process using all available disease resistance sources. University of Arkansas breeding program entries are evaluated in inoculated greenhouse and field disease nurseries manipulated to favor disease development and in un-inoculated plots, including those in grower fields. One breeding line identified as having exceptional agronomic potential was recently released as the 'Wells' cultivar. In greenhouse tests, Wells is susceptible to common blast *(Pyricularia oryzae)* races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1_K with disease ratings in greenhouse tests of 4-5, 7, 7-8, 5-6, and 6, respectively. Wells is resistant to races IB-45, IB-54, IG-1 and IH-1. Wells, rated moderately susceptible (MS) to susceptible (S) to blast overall, and exhibited good blast 'field' resistance in all field tests conducted to date. Wells is rated as being moderately susceptible to susceptible (MS-S) to sheath blight, moderately resistant (MR) to kernel smut, S to false smut, MR to leaf smut, resistant (R) to brown spot, and narrow brown leaf spot. In research tests to date, Wells is better than or compares favorably with reference cultivars 'Cypress' and 'LaGrue' and does not appear to be unusually susceptible to the many diseases found in Arkansas.

INTRODUCTION

Cultivar resistance, the most efficient, reliable, and inexpensive disease control method, serves as the mainstay of rice disease control strategies in Arkansas. Conservation and improvement of existing resistance sources and the incorporation of new sources of resistance is a continuous process serving as a cornerstone in cultivar development programs. Considerable effort is expended by the University of Arkansas Agricultural Research and Extension Center rice disease research program to exploit existing resistance levels and to discover and incorporate new resistance sources into agronomically acceptable cultivars as defined in the project *Identification and Utilization of Varietal Resistance for Control of Rice Diseases in Arkansas*, funded by grower check-off monies administered by the Rice Research and Promotion Board (RRPB). To achieve these objectives, standard and improved evaluation techniques are employed to manipulate resistance sources and to delineate disease resistance and liabilities of new varieties prior to release for Arkansas production.

Diseases frequently become limiting factors in Arkansas rice production areas.

Resistant or tolerant varieties are traditionally used to reduce disease losses. However some disease pathogens, particularly *Pyricularia grisea* which causes rice blast and significant yield reductions, quickly adapt to new cultivars especially if resistance is controlled by a single gene. New blast races IB-49 and IC-17, for example, quickly arose to cause substantial yield losses in the blast resistant 'Newbonnet' and other susceptible cultivars. Single gene resistance provides years of effective blast control when it endures, as evidenced by 'Katy' resistance genes presently used in the 'Kaybonnet' and 'Drew' cultivars. Blast 'field' tolerance results through the combined activity of lesser resistance genes to limit disease development. Although susceptible in greenhouse tests and where field conditions are highly favorable for disease, cultivars such as Cypress and LaGrue exhibit sufficient 'field' resistance to reduce blast yield losses. In addition, disease pathogens are much less prone to rapid and dramatic virulence changes to field resistance.

Results presented here reflect the effort to define, maintain, and improve disease resistance in new cultivars being released for use in Arkansas production areas.

PROCEDURES

Disease evaluation data for Wells were collected from several sources. In addition to the considerable testing within the Arkansas program, data were obtained from disease nurseries conducted by researchers in other states. These tests are conducted by the professional and qualified support staff necessary to provide quality disease evaluations and, consequently, ratings within a source are consistent. However, it is not unusual for these data to vary with location due to environmental differences.

Two types of disease nurseries were established. In the first, greenhouse or field plots (usually on University of Arkansas experiment stations) were established under conditions highly favorable for disease. Cultural practices such as row spacing, fertility requirements, flood conditions, etc., are manipulated to predispose the plant to infection. Plots are artificially inoculated at opportune growth stages to insure an adequate uniform disease pressure. In the second nursery type, un-inoculated observation nurseries are established in grower fields to evaluate disease reactions under current production practices (Cartwright *et al.*, 1994). When seed became available in 1997, Wells was included in the monitoring plots and carefully scrutinized for disease susceptibility.

Disease evaluations were made by comparing the performance of Wells with established reference cultivars LaGrue, Cypress, Kaybonnet, and Drew using data obtained either from direct or indirect assays or from visual estimates of disease progress and severity. Visual disease evaluations were made on a standard 0 to 9 rating scale. A rating of 0 indicates complete disease immunity. A rating of 1 to 3 indicates resistance where little yield loss is anticipated and, in the case of rice blast lesions, lesion development is considerably restricted. Conversely, a 9 rating indicates maximum disease susceptibility, which typically results in complete plant death and/or yield loss. Depending upon the disease in question, a disease rating of 4 to 5 is usually indicative of acceptable disease resistance with limited yield reduction under general field conditions slightly favoring the pathogen. Numerical ratings can be converted to universal 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).

Wells was tested for reaction to the most volatile U.S. rice disease, rice blast caused by *Pyricularia oryzae,* in greenhouse seedling tests. These trials are the primary means of screening the large number of breeding lines for susceptibility to common regional blast races. They are quite variable and tend to overwhelm any field resistance present in the entry. Under controlled conditions, however, the tests provide an accurate definition of the fungus-cultivar genetics and, if properly conducted, field resistance can be estimated. Seedling plants near the 3- to 5-leaf growth stage were sprayed with approximately 5 x 10^5 spores of individual blast races. Plants were immediately placed into a humidity chamber for 24 hours then moved to greenhouse benches. When susceptible reference plants exhibited typical lesions (usually about seven days), leaf lesion characteristics were used to visually estimate varietal reaction to the different blast races using the 0 to 9 blast rating scale. Artificially inoculated field nurseries were established to evaluate blast susceptibility under field conditions favoring blast development. Data from inoculated field nurseries and un-inoculated grower production field plots were used to estimate field performance using both leaf lesion characteristics and panicle infection characteristics.

Sheath blight (*Rhizoctonia solani*) evaluations were made in field nurseries. Plots were artificially inoculated with rice strains of *Rhizoctonia solani* when plants reached the beginning internode elongation growth stage. Sheath blight severity and vertical progress on the plants was estimated visually using the 0 to 9 rating scale when grains were physiologically mature. Naturally infected plots in grower observation tests were evaluated using the same rating scale.

Kernel smut (*Tilletia barclayana*) susceptibility was estimated using data collected from grower fields, disease monitoring plots, and artificially inoculated tests. Data from the Arkansas Regional Performance Trials, expressed as percent damaged kernels by weight in brown rice (Bernhardt *et al.*, 1995), also provides a relative susceptibility estimate for kernel smut in addition to kernel discolorations from causes other than the rice stink bug.

Evaluations for other diseases were made by visual examination of test plots located on experiment stations, in grower fields, and in the disease monitoring plots. Often plots were inspected but specific data were not recorded for most diseases unless an unusual level of susceptibility was evident or the disease pressure was abnormally severe. Disease evaluations were also obtained from other states where these diseases occur more frequently and are more severe.

RESULTS AND DISCUSSION

Greenhouse seedling tests indicate Wells is susceptible to blast races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1_k (Table 1) and resistant to races IB-45, IB-54, IG-1, and IH-1. To date, Wells rated MS-S to blast overall, has exhibited good field tolerance to blast in all field tests (Table 2) when exposed to significant blast pressure in inoculated blast field nurseries and in individual grower field observation nurseries. The lack of significant blast damage in these situations suggest Wells ‘field’ tolerance ranks between that of LaGrue and Cypress. However, given that environmental conditions have not generally favored heavy blast development in Arkansas during the period Wells was being developed and the slightly higher greenhouse reaction to races IB-49 and IC-17, growers should manage Wells carefully in the field to avoid significant losses under blast conducive environmental conditions.

Wells is rated as being MS-S for sheath blight relative to that developing in reference cultivars LaGrue (S), Cypress (S-VS), Kaybonnet (MS), and Drew (MS) (Table 3). The MS-S levels of field tolerance suggests some losses will occur in production fields under normal disease situations but fungicide applications likely will not be necessary except under adverse conditions.

Wells is MR to kernel smut (Table 4). Data collected from inoculated tests and from uninoculated yield trials and observation plots in grower fields indicate Wells is significantly more tolerant to kernel smut than LaGrue (VS), Cypress (VS), Kaybonnet (MS), or Drew (MS). Wells is S to false smut (*U. virens*) which dramatically increased to become a significance disease in Arkansas during 1997 and 1998.

Data from the disease monitoring plots and other research programs indicates Wells is MS to stem rot (Table 5). Wells has good resistance to minor diseases such as leaf smut (MR), brown spot (R), and narrow brown leaf spot (R).

SIGNIFICANCE OF FINDINGS

Wells, developed in conjunction with RRPB grower funded research is an extremely high yielding cultivar which will enhance the economic well being of Arkansas rice industry and the state as a whole. Wells has satisfactory disease resistant for use in Arkansas. Smut resistance in Wells is particularly significant in light of an increased kernel smut incidence and severity over the past six to seven years.

ACKNOWLEDGMENTS

Research funding by the Rice Research and Promotion Board was essential for disease evaluation of Wells. Disease data supplied by Drs. M.A. Marchetti USDA, Beaumont, Texas, and D.E. Groth, Louisiana State University Rice Experiment Station, Crowley, Louisiana, are very much appreciated.

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Table 1. Summary leaf blast reactions in Wells and reference cultivars inoculated with rates of *Pyricularia grisea* in greenhouse tests.

	International blast race[z]									
Cultivar	IB-1	IB-33	IB-45	IB-49	IB-54	IC-17	IE-1	IE-1K	IG-1	IH-1
Wells	4-5[y]	7	1	7-8	1	7-8	5-6	6	1	1
LaGrue	6-7	8	3-4	6-7	5	5-6	5-6	6-7	6-7	5
Kaybonnet	1	6	1	1	1	2	1	7	1	1
Cypress	5	7	1	6	1	5-7	6	5-6	3	1
Drew	1	7	1	1	1	2	1	5-6	1	1

[z] Composte leaf blast ratings on the 0 (none) - 9 (maximum) disease scale in multiple comparative inoculated greenhouse tests conducted by Dr. M. A. Marchetti, USDA, Beaumont, Texas, and at the University of Arkansas Rice Research and Extension Center, Stuttgart. Ratings indicate relative susceptibility under conditions favorable for seedling blast.

[y] Disease ratings vary between tests. For conversion of the 0-9 disease scale to symbols R (resistant) = 0-3, MR (moderately resistant) = 3-4, MS (moderately susceptible) = 5-6, S (susceptible) = 7, and VS (very susceptible) = 8-9. Cultivars rated MS may be damaged and those rated S or VS may be severely damaged under favorable blast conditions.

Table 2. Summary composite leaf and panicle blast ratings for Wells and reference cultivars in inoculated field nurseries and non-inoculated grower plots.

	Blast field data source[z]				
	Arkansas		Texas[y] inoculated	Louisiana[x] inoculated	Overall
Cultivar	Inoculated field nurseries	Grower observation plots	field nurseries	field nurseries	rating
Wells	S	S	MS	MS	MS-S
LaGrue	S-VS	S	S	S	S-VS
Kaybonnet	R	R	R	R	R
Cypress	MS	MR	MR	MS	MR-MS
Drew	R	R	R	R	R

[z] Composite leaf and rotten neck blast ratings from field nursery tests at the indicated locations converted from the 0-9 disease rating scale. Ratings indicate relative susceptibility under very favorable blast conditions. For conversion of the 0-9 disease scale to symbols R (resistant) = 0-3, MR (moderately resistant) = 3-4, MS (moderately susceptible) = 5-6, S (susceptible) = 7, and VS (very susceptible) = 8-9. Cultivars labeled MS may be damaged and those labeled S or VS may be severely damaged under favorable blast conditions.

[y] Disease nursery data supplied by Dr. M.A. Marchetti, USDA, Beaumont, Texas.

[x] Disease nursery data supplied by Dr. D.E. Groth, Louisiana State University Agricultural Experiment Station, Rice Research Station, Crowley, Louisiana.

Table 3. Summary sheath blight ratings for Wells and reference cultivars in inoculated field nurseries and non-inoculated grower plots.

	Sheath blight data source[z]				
	Arkansas		Texas[y] inoculated	Louisiana[x] Inoculated	Overall
Cultivar	Inoculated field nurseries	Grower observation plots	field nurseries	field nurseries	rating
Wells	5-7	MS	4-5	6-7	MS-S
LaGrue	5-6	S	6-7	6	S
Kaybonnet	5-7	MS	3-4	6-7	MS
Cypress	7	VS	3-4	7-8	S-VS
Drew	6-7	MS	1	6-7	MS

[z] Composite sheath blight evaluations on the 0-9 disease rating scale from the indicated source. Ratings indicate relative susceptibility under favorable sheath blight conditions. For conversion of the 0-9 disease scale to symbols R (resistant - lesions on or below lower 20% of total plant height) = 0-3, MR (moderately resistant - lesions below 40% of height) = 3-4, MS (moderately susceptible - 50-60% of height) = 5-6, S (susceptible - few infected flag leaf sheaths) = 7, and VS (very susceptible - many lesions on flag leaf sheath and above with significant panicle death) = 8-9.

[y] Disease nursery data supplied by Dr. M.A. Marchetti, USDA, Beaumont, Texas.

[x] Disease nursery data supplied by Dr. D.E. Groth, Louisiana State University Agricultural Experiment Station, Rice Research Station, Crowley, Louisiana.

Table 4. Relative grain discoloration and overall kernel smut rating for Wells and reference cultivars.

	Percent gain by weight[z]			
Cultivar	Kernel smut[y]	Other discolored[x]	Overall kernel smut rating	False smut rating
Wells	0.052	0.384	MR	S
LaGrue	0.268	0.388	VS	S
Kaybonnet	0.042	0.317	MS	S
Cypress	--	--	VS	S
Drew	--	--	MS	VS
Bengal	0.047	1.101	MS	MR
Lafitte	0.166	0.864	S***	

[z] Average percent by weight of damaged kernels found and kernels discolored from undetermined causes in the Arkansas Rice Performance Trials plots from 1996 to 1998 by sorting equipment.

[y] Kernel smut caused by *Tilletia barclayana.*

[x] All other grain discolorations including those confined to the brand layer but excluding those discolorations resulting from rice stink bug feeding.

Table 5. Relative disease reactions observed with Wells and reference cultivars for selected diseases.

Reference cultivar	Disease[z]			
	Stem rot[y]	Leaf smut[x]	Brown spot[yx]	Narrow brown leaf spot[x]
Wells	MS	MR	R	R
LaGrue	MS	R	R	R
Kaybonnet	MS	S	MS	R
Cypress	MS	MR	R	MS
Drew	MS	MS	S	MR

[z] Ratings indicate estimated relative susceptibility under various field conditions. Available data were limited for some diseases. Conversion for the 0-9 disease scale to symbols R (resistant - lesions on or below lower 20% of total plant height) = 0-3, MR (moderately resistant - lesions below 40% of height) = 3-4, MS (moderately susceptible - 50-60% of height) = 5-6, S (susceptible - few infected flag leaf sheaths) = 7, and VS (very susceptible - many lesions on flag leaf sheath and above with significant panicle death) = 8-9.

[y] Disease rating primarily obtained from the 1997-98 Arkansas grower disease monitoring plots.

[x] Disease rating primarily obtained from 1996-98 disease evaluation data provided by Dr. D.E. Groth, Louisiana State University Rice Experiment Station, Crowley, Louisiana with confirmation in the 1997-98 Arkansas grower disease monitoring plots.

THE IMPORTANCE AND CAUSES OF SEEDLING DISEASE PROBLEMS IN RICE

C.S. Rothrock and J. Sherrill

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) on stand problems in rice and determine the importance of soilborne plant pathogens in limiting stand establishment. Results from initial controlled environmental studies support a role for soilborne pathogens in stand establishment problems in specific fields. The removal of soil pathogens by soil pasteurization generally increased plant stands, height, and weight for the soils from the Cooper, Garner, and Pine Tree sites, indicating a role for soilborne pathogens in limiting rice development for these sites. In contrast, soil from the Davis site generally had decreased stand and plant development for pasteurized soils, indicating pathogens were not playing an important role at this site. The disease rating indices used did not reflect the effect of treatments on rice stand and development and should be re-examined. Isolation data for fungal pathogens from plants may be a better assessment of disease development. Pathogenicity tests have indicated a number of Pythium isolates recovered from rice 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 had some level of stand establishment problem, with resulting management difficulties 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 seeding), 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, and thus favoring seedling diseases. Defining the role of each of these factors is critical in 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 resulting in rapid death of the seedlings 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 numerous fungi also occur 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. The overall objective is to develop management practices to reduce stand losses.

PROCEDURES

Soils were collected from sites with a history of stand establishment problems in Poinsett County (i.e., Cooper, Garner, Davis, Newcome) and a site at Pine Tree Branch Experiment Station examining the use of conservation tillage for rice and soybean production under the direction of Rick Cartwright.

A system was designed to examine the relative importance of abiotic and biotic components on rice seedling establishment. Each soil was stored at 39°F and was then divided into two lots. One lot was pasteurized at 140°F for 30 minutes to kill soilborne plant pathogens. The other lot was not treated. Soils were placed in 6-inch pots and placed under different environmental treatments. Soil temperature treatments included 50, 60, and 70°F. After incubating soils for one week, the soils were seeded with 15 seed per pot of the cultivar 'LaGrue'. Soil water treatments were watering as needed or for periodic soil saturation. The experiment for each soil was a 3x2x2 factorial design with three replications. Stand was recorded weekly and plant development and weight assessed after three to four weeks. Seedlings were evaluated for disease symptoms on roots and hypocotyls using a 1 to 5 scale, with 1 being healthy and 5 severe disease. Seedlings were washed in running water for 20 minutes, and roots were disinfested in 0.5% NaOCl for 1.5 minutes. Root systems were plated on water agar amended with the antibiotics rifampicin and ampicillin and the miticide Danitol to isolate fungal pathogens. After three to four days, developing fungal colonies were transferred to potato dextrose agar amended with rifampicin, ampicillin, and Danitol for identification. Pathogenicity assays were run on selected isolates.

RESULTS AND DISCUSSION

Stands were consistently lower at 60°F than 70°F (Table 1). No plant emergence occurred during the period of the experiments at 50°F. The water treatments did not influence seedling emergence. The removal of soil organisms by pasteurization generally increased stand, however, this was significant only for seedlings growing in soil from the Pine Tree site having soybean as the previous crop and occurred only at 60°F.

Plant weight was greater at 70°F than 60°F for all sites (Table 2). Soil pasteurization increased plant weight for the Cooper and Pine Tree sites and the Garner site for the 70°F treatment. At the Cooper and Pine Tree rice site, the response to fumigation on plant weight was more pronounced at 70°F. There was no consistent response for watering regime on plant weight (Table 2).

Plant height was greater at 70°F compared to 60°F (Table 3). Pasteurization increased plant height in soils from the Garner, Cooper, and Pine Tree Sites. This response of pasteurization on plant height was greater at 70°F than 60°F. Plant height was reduced by pasteurization at the Davis site. Soil water treatment did not consistently influence plant height over sites (Table 3).

Disease root ratings generally did not reflect plant growth responses for soils to the treatments. Pasteurization increased the root ratings in soils from Garner, Cooper, and Pine Tree rice sites and decreased root rating for the Davis soil (Table 4). Identification of the fungi isolated from seedlings is continuing. *Pythium* spp. were frequently isolated from seedlings. Separate experiments examining the pathogenicity of Pythium isolates to rice showed some isolates were highly virulent.

Current research is expanding the soils being characterized and repeating the experiments for the soils already examined. The influence of the environment on Pythium damage is being examined.

SIGNIFICANCE OF FINDINGS

Results from initial controlled environmental studies support a role for soilborne pathogens in stand establishment problems in specific fields, with the removal of these pathogens by soil pasteurization generally increasing plant stands, height and weight in soils from most sites (Cooper, Garner and Pine Tree sites). The identification of the relative importance of specific environmental or disease factors in stand establishment will allow the development of effective recommendations for their management.

ACKNOWLEDGMENTS

The authors would like to give special thanks to the Rice Research and Promotion Board for their financial support of this project.

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Table 1. Influence of soilborne pathogens and environment on stand.

					Pine Tree	
Treatment	Garner	Cooper	Newcome	Davis	Rice	Soybean
	(seedlings/pot)					
Pasteurized						
+	7.3 a	9.5 a	8.8 a	7.5 a	9.3 a	9.4 a
–	5.7 a	8.8 a	8.0 a	9.1 a	9.0 a	6.3 b
Temperature						
60	3.9 b	7.0 b	7.6 a	7.5 a	7.1 b	6.4 b
70	8.8 a	11.1 a	9.2 a	9.1 a	11.2 a	9.3 a
Water						
saturated	6.4 a	8.6 a	8.9 a	7.8 a	9.2 a	7.4 a
nonsaturated	6.8 a	9.7 a	8.1 a	8.8 a	9.1 a	8.3 a
Temp*Past		*				*
Temp*Water				*		
Past*Water				*		

Table 2. Influence of soilborne pathogens and environment on plant weight.

					Pine Tree	
Treatment	Garner	Cooper	Newcome	Davis	Rice	Soybean
	(grams/pot)					
Pasteurized						
+	0.13 a	0.15 a	0.10 a	0.09 a	0.14 a	0.08 a
–	0.13 a	0.10 b	0.10 a	0.08 a	0.09 b	0.07 b
Temperature						
60	0.10 b	0.07 b	0.06 b	0.07 b	0.08 b	0.05 b
70	0.16 a	0.17 a	0.13 a	0.11 a	0.16 a	0.10 a
Water						
saturated	0.14 a	0.12 b	0.10 a	0.07 b	0.14 a	0.07 a
nonsaturated	0.12 b	0.14 a	0.10 a	0.10 a	0.10 b	0.08 a
Temp*Past	*	*			*	
Temp*Water	*			*		
Past*Water	*					

Table 3. Influence of soilborne pathogens and environment on plant height.

Treatment	Garner	Cooper	Newcome	Davis	Pine Tree Rice	Pine Tree Soybean
	----	----	----	(cm)	----	----
Pasteurized						
+	12.3 a	14.9 a	5.7 a	4.7 b	11.8 a	10.4 a
–	9.9 b	8.3 b	6.5 a	6.6 a	6.9 b	6.4 b
Temperature						
60	4.4 b	5.0 b	3.0 b	3.3 b	3.5 b	2.7 b
70	16.9 a	17.4 a	8.7 a	8.1 a	15.1 a	14.1 a
Water						
saturated	12.0 a	9.6 b	5.9 a	3.8 b	10.1 a	7.6 b
nonsaturated	10.5 a	13.4 a	6.2 a	7.6 a	8.4 a	9.2 a
Temp*Past	*	*		*	*	*
Temp*Water		*		*		

Table 4. Influence of soilborne pathogens and environment on root rating.[z]

Treatment	Garner	Cooper	Newcome	Davis	Pine Tree Rice	Pine Tree Soybean
Pasteurized						
+	3.9 a	2.7 a	2.5 a	2.3 b	3.9 a	2.1 a
–	2.9 b	2.4 b	2.7 a	3.5 a	2.8 b	2.0 a
Temperature						
60	3.8 a	2.7 a	2.8 a	2.9 a	3.6 a	1.5 b
70	3.1 a	2.4 b	2.4 a	2.9 a	3.1 a	2.5 a
Water						
saturated	3.8 a	2.3 b	2.3 b	3.0 a	3.5 a	1.9 a
nonsaturated	3.0 b	2.8 a	2.9 a	2.8 a	3.2 a	2.1 a
Temp*Past		*				*
Past*Water						*
Temp*Water						*
Temp*Past*Water						

[z]Rating scale 1 to 5, 1 being healthy and 5 being severe disease.

ROLE OF INFESTED SEED IN THE EPIDEMIOLOGY AND CONTROL OF RICE BLAST DISEASE

D.O. TeBeest and C.A. Guerber

ABSTRACT

Rice blast, caused by *Pyricularia grisea*, is a major fungal disease of rice in Arkansas. Recent research has shown that the disease is present each year and can reach epidemic proportions on susceptible cultivars. The origin (sources) of the disease in Arkansas fields is unclear. This study was conducted to determine the presence and to quantify the incidence of seed infection by the fungus on rice seed collected from various sources in Arkansas. Results show that the rice blast fungus was detected on rice seeds of 3 of 28 seed samples grown in Arkansas in 1997 and collected and tested in 1998. The incidence of *P. grisea* on infested rice seed lots ranged from 0 to 1.5%. This research confirms results from 1997 and further suggests that the rice blast fungus can occur on seed produced in Arkansas. Further, additional work with an infested seed lot collected in 1997 confirms that planting infested seed can lead to seedling disease.

INTRODUCTION

Rice grown in Arkansas is used as seed for replanting and for human consumption. Rice blast is one of the most serious of the several rice diseases in Arkansas on many of the high-yielding cultivars. Losses due to blast are significant due to its high epidemic potential, especially when grown under conditions of low night temperatures and high humidity and when rice is grown in dry soil (Anonymous, 1994). Also, there appears to be a substantial connection between the early onset of disease and the amount of disease at harvest, despite a midseason period in which plants appear to be disease-free (TeBeest *et al.*, 1994).

Reducing the amount of disease early in the season while plants are juvenile may be an important and helpful step in reducing the severity of the disease at maturity. However, this requires identifying and quantifying the sources of inoculum. The overwintering sources of inoculum include infected plant debris, other hosts or on rice seed (Chung and Lee, 1983; Lee, 1994). Rice seed infected by *P. grisea* can be a source of primary inoculum for seedlings grown from infected seed (Chung and Lee, 1983; Lamey, 1970; Lee, 1994), however, none of these studies quantitatively related seed infection to subsequent disease levels in the field or directly linked infection of seed to infection in the field.

Inoculum thresholds are fundamental to disease management but they are difficult to establish and have been established only for a few seedborne pathogens (Kuan, 1988; Lee, 1994). The objectives of this research were to quantify the extent to which rice seeds grown in Arkansas were infected with *Pyricularia grisea* and to investigate the quantitative relationship of seed infection to the seedling phase of this important disease.

PROCEDURES

In 1998, 40 seed samples were collected from several sources in Arkansas to assess the level of seed infection. Thirty-three seed lots were tested for the presence of the rice blast fungus. The remaining seven lots consisted of blast resistant cultivars or were treated with an unknown pesticide and were not tested. Seed lots were tested in random order in a blind assay.

Detection of Blast on Rice Seed

Rice blast was detected by direct observation of seeds with a microscope. Two replications of 200 seed from each seed lot were incubated for four days on moistened filter paper in glass petri dishes at 24°C with a 12-hour photoperiod. After four days, each seed was examined microscopically for visible growth of the rice blast fungus (Agarwal *et al.*, 1989) and the percentage of seed infection was calculated. Final percent infection was determined as an average of two replicates of 200 seeds for each seed lot.

Development of Seedling Blast-Greenhouse Experiments

Infested seeds were planted to soil in a greenhouse to quantify seedling infection. In these tests, 200 seeds from a single seed lot collected in 1997 (R25, 'Bengal') were rolled onto the surface of autoclaved field soil in each of six trays. The plastic trays were covered with a clear plastic lid and were placed in a greenhouse for 10 days at 28°C. The trays were divided equally into two treatments: flooded and air-dried. Three of the trays (each tray was a replicate) were planted and maintained in a flooded condition in which soil was irrigated so that the entire surface remained visibly wet at all times. The remaining three trays were allowed to air-dry thereafter.

After 10 days, 100 seedlings were harvested at random from each tray and divided into four categories: seedlings with visible lesions, healthy seedlings without lesions, non-germinated seeds, and dead seedlings. All healthy seedlings, all seedlings with visible lesions, all non-germinated seeds, and all dead seedlings were incubated on moistened filter paper in petri dishes at 24°C with a 12-hour photoperiod to determine the presence of the blast fungus. Each seedling and seed was examined microscopically for visible signs of the rice blast fungus on the day of harvest, each day for four days and again at 10 days. The percentage of rice blast was calculated for each seed lot as the total number of seedlings and seeds infected by the blast fungus divided by the total number of samples collected (100) from that seed lot multiplied by 100.

Development of Seedling Blast-Field Experiments

A single preliminary experiment was conducted in September 1998 to confirm that planting infested seed can lead to seedling blast. In this test, 1000 seeds were planted in field soil in a 14.5 square ft plot at the Arkansas Agricultural Research and Extension Center, Fayetteville. Seeds were planted in rows on the surface of loose, dry soil in rows, then rolled into the soil with plastic tubing to cover any seed. Irrigation was by natural rainfall only.

RESULTS

In 1998, 40 seed lots representing foundation seed and registered seed produced by growers in Arkansas in 1997 were sampled at planting to test for the presence of the rice blast fungus as described above (Table 1). Five foundation seed lots (Table 1, F1 through F5) representing each of the five cultivars currently in the foundation seed program were sampled. Thirty-five seed lots (Table 1, R1 through R35) were collected from several registered seed sources, however, only 28 of the registered seed lot cultivars representing seven cultivars were sampled (Table 1). Seven registered seed lots have not been sampled because three of these lots (R23, R24, R25) were treated with a fungicide while four were seed of the resistant cultivar 'Kaybonnet' (R18, R21, R29, and R34) (Table 1).

Detection of Blast on Rice Seed

The rice blast fungus was not detected on seed of susceptible or resistant cultivars produced in 1997 by the foundation seed program (Table 1). In 1996, foundation seed of susceptible cultivars had very low levels (0.0 to 0.5%) of blast. On the other hand, the rice blast fungus was detected on three seed lots R1 (Bengal), R2 ('Cypress') and R35 ('LaGrue'), collected from registered seed grown in 1997 and being planted in 1998. The level of infestation / infection was very low in each instance ranging from 0.25% to 1.5%. In our tests, 0.50% equals one infected seed in a total of 200 examined. In 1997, we reported detecting the rice blast fungus on 5 of 15 (33%) of the registered seed lots examined (TeBeest and Guerber, 1998). However, we examined a total of 33 seed lots in 1997 and found 11 of the seed lots to be infected with blast with the level of blast ranging from 0.25% to 10.5% (R25).

Seven seed lots (R18, R21, R23, R24, R25, R29, and R34) were collected but were not examined for blast in 1998 because they were either resistant cultivars like R18 (Kaybonnet), or were treated with an unknown pesticide. Several foundation and registered seed lots of resistant cultivars (F4, R5, and R11) were sampled and the blast fungus was not detected.

Development of Seedling Blast–Greenhouse Experiments

A second objective was to determine if infestation of seed by the blast fungus led to measurable levels of seedling disease and to determine the conditions under which the infection was supported. Since seed infestations were very low in the seed collected in

1998 (Table 1) we used a single seed lot (R25) with 10.5% infection, which was collected in 1997 to study seedling infection. Results of the tests indicate that, at least under greenhouse conditions, planting and maintaining seeds under "flooded" conditions consistently reduced the number of seedlings infected by the blast fungus. In three replications, a total of four infected seedlings (0.33%) were detected after 10 days when plants were grown under "dry" conditions while none were detected in seeds maintained in "flooded" conditions. This is very consistent with results reported earlier by Chung and Lee (1983) and by Lamey (1970) although conditions of each test were slightly different.

Additionally, the number of non-germinated, infected seeds found on the soil surface was also greater under "dry" conditions than when the same seed were grown under "flooded" conditions. Only one infested seed (0.083%) was found among the 1200 seeds planted under flooded conditions, whereas 20 seeds (1.67%) were found among the 1200 seeds planted in the three dry replicated experiments.

Development of Seedling Blast–Field Experiments

A preliminary experiment was conducted in September and October of 1998 to determine whether infested seed could cause seedling infections in the field confirming greenhouse experiments. In this test, 1000 seeds from the same seed lot used in the work described in Table 2 were planted in one small plot at Fayetteville. After 14 days, 45 seeds found on the soil surface and 50 seedlings were harvested at random and washed in tap water to remove soil and debris. Washed seeds and seedlings were blotted dry and placed onto filter paper in petri plates and incubated under lights as described above. All samples were observed under a microscope for the presence of the rice blast fungus on the day of harvest, on day 1 through 4 after harvest and on day 10 after harvest. Rice blast was found on dead cotyledonary leaves of 2 (4.4%) of the 45 seedlings sampled and on 1 (2%) of the 50 non-germinated seeds collected 14 days after planting.

DISCUSSION

Seed has been and continues to be an important mechanism for transmitting plant pathogens of all major classes. Accurate estimates of pathogen levels in seed sources are essential to establishing inoculum thresholds, which are critical to effective management of seedborne diseases (Kuan, 1988). Although infestation of rice seed by the blast fungus has been previously reported, the inoculum thresholds that establish or increase the risks for rice blast have not been established (Chung and Lee, 1983; Lamey, 1970; Lee, 1994). However, Long and TeBeest (1998) reported that they were able to induce rice blast epidemics at Pine Tree Branch Experiment Station with as few as one infested seed per 2 sq ft. Furthermore, disease development in their experimental plots accurately reproduced development in producers fields. These results may also explain why blast is often randomly distributed within fields early in the growing season.

For the second consecutive year, we have found the rice blast fungus on rice seed grown in Arkansas. We consider these reports to be the first which quantified the level of percentage of seed grown in Arkansas actually infested by the rice blast fungus. Lee (1994) previously reported finding viable rice blast spores on seed collected from several field grown seed sources but he did not estimate the percentage of the seeds within lots that were infested.

The percentage of the seeds infected by the rice blast fungus was lower in 1998 samples (grown in 1997) than in the 1997 samples (collected from plants grown in 1996). This may reflect the fact that rice blast was less severe in 1997 than in 1996. Rice blast was not a significant problem during the 1998 production year and we might expect the level of seed blast to be reduced as well.

In 1997 and in 1998, the amount of rice blast on seed was usually greater on certain cultivars. This may be related to the level of resistance of any one cultivar to the disease since cultivars like Kaybonnet are generally more resistant to current races of the pathogen and very little, if any, rice blast was found on seed from that cultivar from a number of sources. Conversely, the more susceptible cultivars like LaGrue, Cypress, and Bengal had the highest levels of seed infestation in our samples.

SIGNIFICANCE OF FINDINGS

This study has shown that some rice seed grown in Arkansas quantify the level of rice blast infection or infestation on rice seed produced in Arkansas. It also documents the sequence of events in the development of blast from infected seed to seedlings and confirms the fact that rice seed is an overwintering source of inoculum.

Additional research is required to determine the extent to which seed is a significant source of primary inoculum in Arkansas. It should not be considered as the only potential source. Nevertheless, rice producers growing susceptible cultivars may want to consider planting disease-free seed harvested from blast-free fields or even planting treated seed to reduce the risk of rice blast.

ACKNOWLEDGMENTS

The authors give a special thanks to all those who contributed seed samples and to the Rice Research and Promotion Board for the financial support for this project. We are especially grateful for the assistance of Dr.Cartwright who collected the samples of registered seed tested and without whom this work could not have been completed.

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Table 1. The average number and percentage of seeds grown in 1997 that were infected by the rice blast fungus[z].

Lot	Cultivar	Number	Percent
F1	Bengal	0.00	0.00%
F2	Cypress	0.00	0.00%
F3	Drew	0.00	0.00%
F4	Kaybonnet	0.00	0.00%
F5	LaGrue	0.00	0.00%
R1	Bengal	1.00	0.50%
R2	Cypress	0.50	0.25%
R3	Drew	0.00	0.00%
R4	Jefferson	0.00	0.00%
R5	Kaybonnet	0.00	0.00%
R6	LaGrue	0.00	0.00%
R7	Bengal	0.00	0.00%
R8	Cypress	0.00	0.00%
R9	Drew	0.00	0.00%
R10	Jefferson	0.00	0.00%
R11	Kaybonnet	0.00	0.00%
R12	LaGrue	0.00	0.00%
R13	Alan	0.00	0.00%
R14	Bengal	0.00	0.00%
R15	Cypress	0.00	0.00%
R16	Drew	0.00	0.00%
R17	Jefferson	0.00	0.00%
R18	Kaybonnet	--[y]	--
R19	LaGrue	0.00	0.00%
R20	Drew	0.00	0.00%
R21	Kaybonnet	--	--
R22	LaGrue	0.00	0.00%
R23	Bengal	--	--
R24	Cypress	--	--
R25	Jefferson	--	--
R26	Bengal	0.00	0.00%
R27	Cypress	0.00	0.00%
R28	Drew	0.00	0.00%
R29	Kaybonnet	--	--
R30	Bengal	0.00	0.00%
R31	Cypress	0.00	0.00%
R32	Drew	0.00	0.00%
R33	Jefferson	0.00	0.00%
R34	Kaybonnet	--	--
R35	LaGrue	6.00	1.50%

[z] Two replications of 200 seeds from each of the seed lots were examined after 4 days of incubation at 24°C under 12-hour light/dark photoperiod. Data presented is the average of two replications.

[y] "–" = these samples were not assayed since they either were treated with a pesticide or were from a cultivar resistant to rice blast disease.

Table 2. The effect of flooding or dryland conditions on the number of seeds and seedlings showing infection by the rice blast fungus in greenhouse tests[z].

		Seedlings		Seeds	
Treatment[y]	Replication	Number	Percent	Number	Percent
Flooded	1	0	0%	0	0%
	2	0	0%	0	0%
	3	0	0%	1	0.25%
	Average	0	0	0.3	0.08
Dry	1	2	0.50%	1	0.25%
	2	0	0.00%	14	3.50%
	3	2	0.50%	5	1.25%
	Average	1.33	0.33	6.67	1.67

[z] Four hundred seedlings from lot No. 25 of Bengal cultivar (10.5% infected) seed lot harvested in 1996 were grown in a greenhouse for ten d at 28°C. Non-germinated seeds and seedlings were collected 10 days after planting, placed on filter papers and incubated for up to 10 days at 24°C under a 12-hour light/dark photoperiod. All samples were visually examined under a microscope on the day of harvest, on days 1 through 4 and on day 10 after harvest.

[y] Flooded indicates that soil was kept visibly wet for the entire period. Dry indicates that soil was moistened at planting and then not watered again.

THE EFFECTS OF FALL RICE STUBBLE MANAGEMENT AND WINTER FLOODING ON SUBSEQUENT CONVENTIONAL- AND NO-TILL IRRIGATED AND RAINFED SOYBEANS

Merle M. Anders, Tony E. Windham, John F. Robinson, Ronald W. McNew, and Ken Reinecke

ABSTRACT

A series of field experiments on the effects of rice stubble management combined with different winter flooding strategies on conventional- and no-till irrigated and rainfed soybeans were conducted at the University of Arkansas Rice Research and Extension Center between 1996 and 1998. 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 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 the two years data were combined. None of the rainfed soybean plots resulted in a profit in 1997. Higher overall yields in 1998 resulted in six rainfed soybean plots returning profits. Additional operations necessary to flood fields for winter waterfowl habitat did not result in gains or losses in a following soybean crop yield but did incur an additional expense that made this strategy less profitable than not pumping water on fields.

INTRODUCTION

Arkansas' 1.5 million acres of rice lies in the flight path of 2 to 3 million mallards and other migratory waterfowl and this area 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 it is a common practice for farmers to sow soybeans following a rice crop. 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 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 dollars 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 their fields with minimizing costs and maximizing 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, and
2. To provide wildlife specialists with relevant information on the benefits and problems related to winter flooding for waterfowl habitat.

PROCEDURES

In 1996 and 1997, rice fields used for foundation seed production at the University of Arkansas Rice Research and Extension Center, Stuttgart, were selected for these studies. In both years, the preceeding rice crop was the cultivar 'Cypress'; which was managed as a commercial crop. The soil in the experimental area was a Crowley silt loam (fine, montmorillonitic, thermic Typic Albaqualf) with a hard pan 6 to 8 inches below the soil surface. Following the rice harvest, straw treatments (Table 1) were applied. Winter flooding treatments were initiated the third week of November with a water level of 4 inches maintained in the pumped plots until all plots were drained during the first week of March. The soybean cultivar 'Holladay' was sown into plots 25 ft x 200 ft and managed as indicated in Table 2. At harvest, two sub-plots were collected in each treatment and yields were adjusted to a 12% moisture value. A bushel of soybeans weighs 60 lb.

In 1996-97, a split-split-split plot design was used with three replications. In 1997-98, a split-strip-split design was used with five replications. Data from 1996-97 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 $6.00 soybean price and with no land costs included. The pooled analysis was calculated using 1998 cost data.

RESULTS AND DISCUSSION

In 1997, there were no significant differences in soybean grain yield for the interactions between main treatments and the two treatment comparisons that resulted in a significant difference were the conventional-till vs. no-till and the irrigation vs. rainfed comparisons (table 3). Rice straw management treatments had no effect on the following soybean grain yield either year. There was an increase in soybean grain yield from the rainfall winter flooding treatment in 1998, but this increase was not significant and did not occur in 1997 (Table 4). Soybean grain yield was higher in the conventional tilled plots when compared to the no-till plots in both years. The increase in conventionally-tilled plots over no-till plots was 8 bu / acre in 1997 and 5 bu / acre in 1998. Of all the treatments used, irrigation had the greatest impact on grain yield. Increases in soybean grain yield from irrigation over rainfed plots was 27 bu / acre in both years.

Results to date indicate that farmers can expect the same grain yields from a subsequent soybean crop if they disk, roll, or leave standing rice stubble prior to winter flooding. Farmers decision on which stubble management system to use should not change if a farmer chooses to winter flood over not flooding. This decision could be based on cost or benefits to waterfowl from leaving more grain. The results presented here indicate that farmers should not expect reductions or increases in soybean grain yields if fields are winter flooded. These results support efforts of the North American Waterfowl Management Plan to increase the area under winter flood in that farmers should not expect reductions in a following soybean yield if they participate in winter flooding programs. Results from the tillage comparison indicate that higher yields can be expected from conventional tillage when compared to no-till systems. These results might change if Roundup Ready® (RR) soybeans are used. Observations made on these plots indicated that weed growth was a severe problem in some no-till soybean plots. This is particularly true where the field had been rutted during the rice harvest and soybean plant densities were low. In 1998, some plots had to be abandoned because of a severe grass infestation. These plots could not be included in the later application of Poast Plus® because they were adjacent to rice plots. Significant increases in soybean grain yields in the irrigated plots when compared to the rainfed plots were expected given the shallow soil and dry summer conditions. In 1998, irrigation treatments were modified to a more frequent but less volume strategy because of the extreme heat during the growing season and shallow nature of the soil.

The economic analysis presents a somewhat different picture (Tables 5 and 6). In 1997, none of the rainfed soybean treatments resulted in a profit. Returns for all treatments increased where there was a reduction in field operations with none of the pumped treatments ranking in the top 10 treatments for returns. Combined with the yield analysis, this suggests that while pumping does not effect grain yields it does represent an additional cost and thus could pose a constraint to farmers flooding fields. Increased yields from conventional-tilled plots did not completely offset the costs of additional tillage. There were five each of the conventional-till and no-till treatments in the top 10 treatments for net returns. A narrowing of the soybean grain yield gap between conventional-till and no-till treatments and increased soybean yields in 1998 resulted in increased net returns and a dominance of no-till treatments in the net return rankings. Pumped treatments performed better in 1998 but the question remains as to how these extra costs will be offset. There were six rainfed treatments that resulted in profits in 1998. Of these, five were conventional-till treatments. This result is attributed to the extremely dry conditions and a plant population in the no-till treatments that were considerably higher than the conventional-till treatments. If these trends continue, it would be appropriate to test a narrow-row, no-till planting arrangement.

A pooled economic analysis (Table 7) indicates an overall advantage to not pumping fields, no-till, and irrigation. These results suggest that savings in tillage costs associated with no-till planting of soybeans more than offset the differences in grain yield between the conventional- and no-till planting systems. Additional costs from pumping fields would appear to be an impedance to expanding the area under winter flood.

SIGNIFICANCE OF FINDINGS

These findings provide preliminary guidelines regarding what farmers can expect from adopting winter flooding. They identify constraints to increasing the amount of land under winter flood and identifying a tillage system that results in maximum profits for soybeans grown after rice.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Rice Research and Promotion Board, Arkansas Soybean Promotion Board, U.S. Fish and Wildlife Service, and USGS for their contributions to this work.

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Table 1. Rice stubble, winter flooding, tillage, and irrigation treatments used in 1997 and 1998.

Treatment	1996-97	1997-98
Fall rice stubble	disked standing rolled	standing rolled
Winter flooding	pumped rainfall drained	pumped rainfall drained
Spring tillage (soybeans)	conventional no-till	conventional no-till
Summer irrigation (soybeans)	irrigated rainfed	irrigated rainfed

Table 2. Soybean plot management used in 1997 and 1998.

Management	1997 Conventional	1997 No-till	1998 Conventional	1998 No-till
Field preparation	disked (2) triple K (2) float (2)	none	disked (2) triple K (3) rolled (1)	none
Weed control	Scepter, 1.4 pt/acre Dual, 1.5 pt/acre Poast Plus 1#, 1.5 pt/acre Crop oil, 1 qt/acre	Roundup Ultra, 2 pt/acre Poast Plus 1E, 1.5 pt/acre Crop oil, 1 qt/acre	Scepter, 1.4 pt/acre Dual, 1.5 pt/acre Poast Plus 1D, 1.5 pt/acre Crop oil, 1 qt/acre Cultivated (2)	Roundup Ultra, pt/acre Poast Plus 1E, 1.5 pt/acre Crop oil, 1 qt/acre
Irrigation[z]	3 x 3 inches	3 x 3 inches	6 x 1.5 inches	6 x 1.5 inches
Row spacing	32 inches	7.5 inches	32 inches	7.5 inches

[z] Number of irrigations x acre-inches of each irrigation.

Table 3. Soybean yields (bu/acre) for main effects in the 1997 soybean crop.

Operation	Treatment	Grain yield
		(bu/acre)
Straw management	disked	32
	standing	32
	rolled	34
Winter flooding	drained	33
	rainfall	31
	pumped	33
Tillage	conventional tillage	37[z]
	no-till	29[z]
Irrigation	irrigated	46[y]
	rainfed	19[y]

[z] Treatments were significantly different at the 0.001 level.
[y] Treatments were significantly different at the 0.001 level.

Table 4. Soybean yields (bu/acre) for main effects in the 1998 soybean crop.

Operation	Treatment	Grain yield
		(bu/acre)
Straw management	standing	37
	rolled	38
Winter flooding	drained	37
	rainfall	40
	pumped	35
Tillage	conventional tillage	40
	no-till	35
Irrigation	irrigated	51[z]
	rainfed	24[z]

[z] Treatments were significantly different at the 0.001 level.

Table 5. Net returns for the top 10 treatments in 1997.

Treatments				
Rice straw	Winter flooding	Tillage	Irrigation	Net returns $
rolled	drained	conventional	irrigated	119.99
standing	drained	conventional	irrigated	118.12
rolled	rainfall	no-till	irrigated	115.00
standing	drained	no-till	irrigated	108.66
standing	rainfall	no-till	irrigated	103.19
rolled	drained	no-till	irrigated	100.58
standing	rainfall	conventional	irrigated	63.53
disked	drained	conventional	irrigated	62.88
disked	drained	no-till	irrigated	58.10
disked	rainfall	conventional	irrigated	50.41

Table 6. Net returns for the top 10 treatments in 1998.

Treatments				
Rice straw	Winter flooding	Tillage	Irrigation	Net returns $
standing	rainfall	no-till	irrigated	170.79
standing	drained	no-till	irrigated	169.84
rolled	rainfall	no-till	irrigated	166.80
rolled	drained	no-till	irrigated	163.49
standing	drained	conventional	irrigated	125.46
rolled	pumped	no-till	irrigated	114.97
standing	rainfall	conventional	irrigated	112.65
standing	pumped	no-till	irrigated	87.37
rolled	rainfall	conventional	irrigated	86.43
rolled	pumped	conventional	irrigated	79.03

Table 7. Net returns for the top 10 treatments combining years 1997 and 1998.

Treatments				
Rice straw	Winter flooding	Tillage	Irrigation	Net returns $
rolled	rainfall	no-till	irrigated	140.90
standing	drained	no-till	irrigated	139.25
standing	rainfall	no-till	irrigated	136.99
rolled	drained	no-till	irrigated	132.04
standing	drained	conventional	irrigated	121.79
rolled	drained	conventional	irrigated	99.51
standing	rainfall	conventional	irrigated	88.09
rolled	pumped	no-till	irrigated	59.84
rolled	pumped	conventional	irrigated	54.86
standing	pumped	no-till	irrigated	54.76

WHOLE FARM WATER AND SOIL RESOURCES MANAGEMENT

J.T. Gilmour, L.R. Fry, and N.A. Slaton

ABSTRACT

A demonstration study was located on a 2000 acre farm in the Bayou de View watershed in Monroe County, Arkansas, south of Brinkley. Wells and surface water supplies were sampled one to four times during the summer of 1998. Results showed that evaluation of irrigation water sources on a whole farm basis can lead to much different management strategies than sampling a few water sources and assuming they are representative of the whole farm.

INTRODUCTION

Surface and ground water quality must by protected in the row crop areas of Arkansas and the mid-South. Improving crop yields, protecting aquatic life, assuring acceptable drinking water quality, and minimizing sedimentation in surface water resources are outcomes of implementing best management practices (BMPs) in a whole farm plan that benefit society as a whole.

This study was located on a 2000 acre farm in the Bayou de View watershed in Monroe County, Arkansas, south of Brinkley. The quality of water in Bayou de View is limited by excess sediment and nutrient loads according to the 1992 Water Quality Inventory Report by the Arkansas Department of Pollution Control and Ecology.

The well water on the farm is representative of wells throughout Arkansas that cause saline and calcareous soil conditions to develop. Saline soil slows crop plant growth and depresses yields for soybeans and rice, while calcareous soils provide a poor growth medium for rice. Poor plant growth is accompanied by small plant leaf areas which can lead to increases in erosion and runoff. Fortunately, the farm near Brinkley has other water resources of better quality that can be used in a whole farm water and soil resources management plan to alleviate the saline and calcareous soil conditions. Farms in about 25% of the Delta counties in Arkansas have similar irrigation water and soil problems.

PROCEDURES

Wells and surface water supplies were sampled periodically during the summer of 1998. The sampling protocol was: a) for water from a pump, pump the well at least five (5) minutes if not already running, b) rinse sample bottle three times with water source,

c) fill bottle completely full, no air space, and cap tightly, d) label bottle, e) place sample bottle in cooler with ice, and d) ship the same day to the Arkansas Water Resources Center Water Quality Laboratory at the University of Arkansas, Fayetteville, for analysis. Waters were analyzed for calcium, magnesium, sodium, bicarbonate, chloride, sulfate, and electrical conductivity (EC).

The farm was mapped using a Trimble Ag 132 Differential Global Positioning System (DGPS) coupled to a portable computer using Geolink software to obtain positional data and produce DGPS images and data tables. Images and data tables were then translated to ArcView GIS 3.1 for final presentation. Farm boundaries, well locations, and other features of the farm were georeferenced in this way, and likewise transformed to ArcView GIS 3.1.

RESULTS AND DISCUSSION

Figure 1 presents an aerial photograph of the farm and the location of the 16 irrigation water sources. Table 1 presents additional information on the irrigation water sources. The water sources are presented in three groups in Table 1 and following tables. The first group, consisting of three wells and one surface water source, had the best water quality. These water sources were located in the north central to northwest portion of the farm. The second group of water sources included four wells and two surface waters. The wells in this second group were located along a diagonal band from the northeast to the southwest portion of the farm. The surface water sources were located in the southwest area of the farm. The third group of water sources consisted of six wells. These water sources were also located on a diagonal band from the northeast to the southwest portion of the farm, but the diagonal band was below that for the second group of wells. Each of the wells was removing water from the Quaternary aquifer, while the surface waters were largely irrigation water return flows.

Table 2 presents water quality data for the 16 irrigation water sources, while Table 3 presents an interpretation for the water quality data based on information in Tacker *et al.* (1994). No consistent trends in water quality were found from one sampling time to another, and means are presented in Table 2. None of the irrigation waters had a sodium adsorption ratio (SAR) greater than 10. As a result, these water sources would not be expected to create a sodic soil.

The first group of irrigation waters had concentrations of calcium, magnesium, sodium, bicarbonate, chloride, and sulfate typical of good quality irrigation water in Arkansas. Electrical conductivities were below 1200 µS/cm. In general, these water sources would be expected to cause soil pH increases in the top levees of a field leading to rice nutritional problems because of elevated concentrations of calcium and bicarbonate (Tacker *et al.*, 1994). Increases in soil chloride (chloride > 3 meq/l) or development of soil salinity (EC > 1200 µS/cm) problems in rice are not likely in soils irrigated with these waters (Table 3).

The second group of waters shown in Tables 2 and 3 had poorer water quality than the first group in regard to chloride concentrations and electrical conductivity. Chloride concentrations ranged from 3.5 to 7.5 meq/l with a mean of 5.0 meq/l. Electrical conductivity ranged from 1110 to 1460 μS/cm with a mean of 1240 μS/cm. Thus, these irrigation waters would be expected to increase soil chloride and overall soil salinity to levels that could damage rice (Tacker *et al.*, 1994). Continued use of these waters would cause soil pH increases in upper levees and flow areas to a greater extent than the first group.

The third group of irrigation waters shown in Tables 2 and 3 had the poorest water quality. Mean values for calcium for the first, second, and third groups were 3.9, 4.7, and 6.7 meq/l, respectively. Parallel values for bicarbonate were 6.1, 6.9, and 8.2 meq/l, respectively. Thus, the potential for these waters to increase soil pH in flow areas and upper levees increased from the first to the third group of irrigation waters. The surface waters (MRN, LRE, and MRS) had lower calcium and bicarbonate concentrations than other sources which suggested that calcium carbonate (lime) had precipitated on the soils being irrigated before the water returned to the surface water source.

The chloride concentrations in the third group ranged from 7.4 to 9.0 meq/l with a mean of 8.1 meq/l. These waters could reduce rice seedling stands as well as rice and soybean yields in cases where the chloride remains or concentrates in the crop root zones. The electrical conductivities of these waters ranged from 1560 to 1920 μS/cm with a mean of 1700 μS/cm which could cause salinity damage to rice should the soluble salts remain in the root zone.

The results clearly show that analysis of irrigation water sources on a whole farm basis can present a much different picture than sampling a few water sources. In this case, development of water resources in the north central and northwest portions of the farm, coupled with a water distribution system, could take advantage of the best water quality and lead to increased crop yields. Increased crop yields generally result from earlier and larger crop plants which can more efficiently use nutrients and protect the soil from erosion.

SIGNIFICANCE OF FINDINGS

To date, irrigation water sampling has been on a well by well or surface water basis. Consideration of the water quality across a whole farm has received little attention. Indeed, the number of irrigation water samples submitted each year is very small compared to the water sources used in rice production. The results from the summer of 1998 demonstrate the utility of sampling irrigation water sources on a whole farm basis and using the water quality data to develop a whole farm water management plan.

ACKNOWLEDGMENTS

This project was supported by a United States Environmental Protection Agency 319 Program grant administered through the Arkansas Soil and Water Conservation Commission.

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Table 1. General information on water sources.

Identifier	Type	Depth	Flow rate	Sample dates
			feet	gallons/minute
M1	well	160[z]	1000[z]	6/11, 8/5
M2	well	120	1800	6/11, 7/9, 9/1
M3	well	130	1800	6/11, 7/9, 8/5, 9/1
MRN	surface		600	8/5
L1	well	140	1000	6/18, 7/9, 8/5, 9/1
L2	well	130	1000	6/11, 8/5, 9/1
LRE	surface		600	6/11, 7/9, 8/5
M4	well	120	500	6/11, 7/9, 8/5, 9/1
M5	well	140	1100	6/18, 8/5
MRS	surface		600	7/9, 8/5
L3	well	120	100	6/11, 8/5, 9/1
L4	well	130	900	6/11, 7/9, 8/5, 9/1
L5	well	120	600	6/18, 7/9, 8/5, 9/1
M6	well	120	500	6/11, 8/5, 9/1
M7	well	130	1200	6/11, 7/9, 8/5, 9/1
M8	well	130	1400	6/11, 7/9, 8/5, 9/1

[z] Data obtained from farmer.

Table 2. Mean water quality analyses for irrigation water sources.

Identifier	Calcium	Magnesium	Sodium	Bicarbonate	Chloride	Sulfate	Electrical conductivity
	(meq/l)						(µS/cm)[z]
M1	5.5	2.8	3.5	8.6	2.5	0.3	1180
M2	3.7	2.1	1.5	5.8	1.2	0.5	810
M3	3.9	2.1	2.4	6.2	1.9	2.4	900
MRN	2.4	1.4	1.1	3.7	1.0	0.2	550
L1	5.8	3.0	4.6	8.8	4.4	0.3	1240
L2	5.5	2.9	6.0	9.0	4.4	0.3	1300
M4	5.2	2.8	4.4	7.1	4.7	0.3	1200
LRE	3.8	3.5	6.9	4.9	7.5	0.5	1460
M5	4.3	2.5	3.3	6.4	3.5	0.4	1110
MRS	3.5	3.0	5.0	5.1	5.5	0.4	1150
L3	6.2	3.2	8.7	7.7	8.1	0.1	1610
L4	6.0	3.7	7.7	7.5	9.0	0.4	1740
L5	7.6	4.2	6.9	8.5	7.8	1.4	1640
M6	7.1	4.1	6.3	8.3	7.4	0.9	1560
M7	7.2	4.0	7.9	8.7	7.7	2.1	1700
M8	6.3	3.5	9.2	8.4	8.8	0.7	1920

[z] Equal to mmhos/cm.

Table 3. Interpretation of mean water quality analyses for irrigation water sources.

Identifier	SAR<10	Chloride > 3 meq/l	EC > 1200 μS/cm	Calcium > 3 meq/l and bicarbonate > 5 meq/l
M1	no[z]	no	no	yes[y]
M2	no	no	no	yes
M3	no	no	no	yes
MRN	no	no	no	yes
L1	no	yes	yes	yes
L2	no	yes	yes	yes
LRE	no	yes	yes	yes/no
M4	no	yes	yes/no	yes
M5	no	yes	no	yes
MRS	no	yes	no	yes
L3	no	yes	yes	yes
L4	no	yes	yes	yes
L5	no	yes	yes	yes
M6	no	yes	yes	yes
M7	no	yes	yes	yes
M8	no	yes	yes	yes

[z] No adverse soil conditions expected.
[y] Adverse soil conditions can develop.

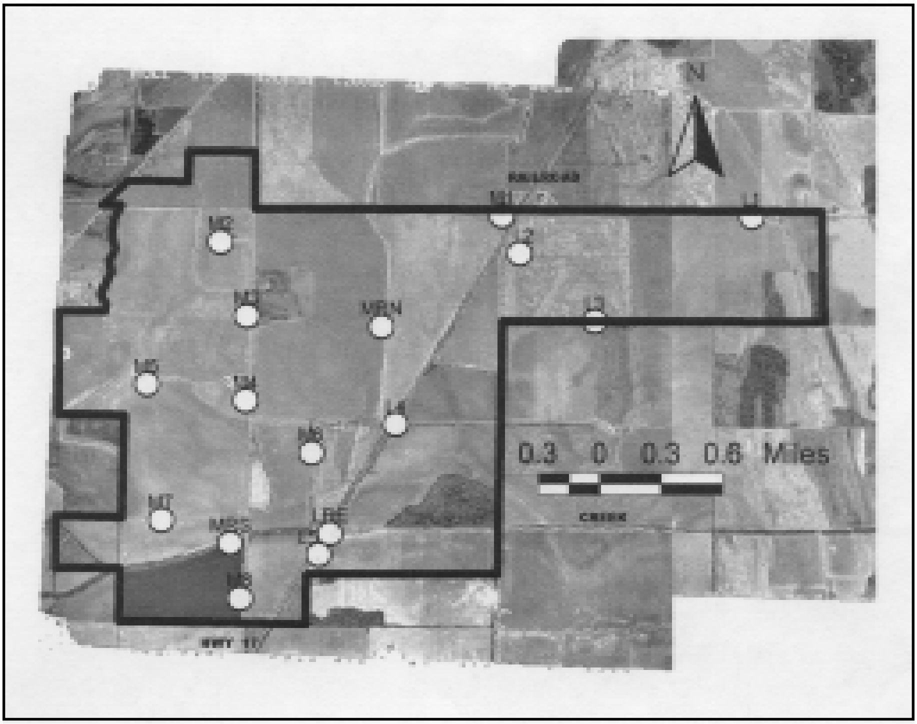

Fig. 1. Aerial images and locations of water sources for irrigation on demonstration farm.

DEVELOPMENT OF THE DD50 DATABASE FOR NEW RICE CULTIVARS

R.J. Norman, N.A. Slaton, and K.A.K. Moldenhauer

ABSTRACT

The DD50 computer program, to be effective, must be continually updated as new rice cultivars are named and released. We conduct studies each year to gather development data for promising cultivars/varieties. Starting in 1998, the water-seeded portion of the study was terminated because of lack of significant difference between water-seeded and dry-seeded rice in DD50 thermal unit accumulations. Thus, all new cultivars/varieties were evaluated in the dry-seeded management system only, but were evaluated over three seeding dates instead of two and grain yield data were collected to determine the influence of seeding date on each cultivar's/variety's grain yield performance. Cultivars/varieties evaluated in 1998 were: 'Anheuser Busch (AB) 647', 'Cocodrie', 'Drew', 'Jefferson', 'Lafitte', 'Litton', 'Madison', 'Priscilla', RU9601053 (Arkansas), RU9601096 (Arkansas), RU9601099 (Arkansas), and RU9602074 (Louisiana). Data from this study will be combined with data from previous years to formulate updated threshold values for the 1999 DD50 computer program.

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 use this program as a management tool in rice production. The program requires data for all cultivars with plant development based on accumulation of DD50 thermal units from date of seedling emergence. This data is developed by conducting studies which include all promising new rice varieties for two to three years prior to naming and releasing the variety as a rice cultivar. When the new cultivar is released to farmers, the data developed from these studies are used to provide threshold DD50 thermal units in the computer program to enable predictions of the dates of 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 varieties, to verify databases for existing cultivars, and to assess the effect of seeding date on DD50 thermal unit accumulations. In 1998, the water-seeded portion of the study was terminated due to very little difference found between the DD50 thermal unit accumulations when rice was water-seeded compared to dry-seeded. Thus, starting in 1998, all new potential rice cultivars/varieties studied were dry-seeded and this portion of the study was expanded from two seeding dates to three. In addition, grain yield was measured to determine the influence of seeding date on a rice cultivar's / varieties' grain yield performance.

PROCEDURES

The 1998 study was conducted at the University of Arkansas Rice Research and Extension Center, Stuttgart, on a Crowley silt loam soil. Twelve rice cultivar / varieties (i.e., AB 647, Cocodrie, Drew, Jefferson, Lafitte, Litton, Madison, Priscilla, RU9601053 [Arkansas], RU9601096 [Arkansas], RU9601099 [Arkansas], and RU9602074 [Louisiana]) were drill-seeded at a rate of 100 lb / acre in nine-row plots (7-inch spacing), 15 ft in length. The seeding dates were 6 April, 11 May, and 10 June. The cultural practices were as normally conducted for drill-seeded rice culture. All plots received 100 lb nitrogen (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 seeding emergence, date of beginning internode elongation, date of inch internode elongation, date of 50% heading, and date of physiological maturity. The temperature data were then 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 (bu) of rice weighs 45 lbs. Statistical analyses were conducted with SAS and mean separations were based upon protected Least Significant Difference (LSD) where appropriate.

RESULTS AND DISCUSSION

Rice seeded in April required 23 days to emerge whereas rice seeded in May and June required only 10 and 8 days to emerge, respectively (Table 1). Days from emergence to flooding were similar for all three seeding dates and thus, the influence of seeding date on the days required from seeding to flooding was most affected by the days required for seedling emergence.

The DD50 thermal unit accumulations for the cultivars / varieties as influenced by seeding date are shown in Table 2 (emergence to 1 / 2 inch internode elongation) and Table 3 (emergence to 50% heading). Usually the days or DD50 thermal unit accumulations required from emergence to 1 / 2 inch internode elongation decreases as seeding date is delayed from April to May and June. This pattern was observed for only a few cultivar / varieties in 1998. In several cases, the largest DD50 thermal unit accumulation from emergence to 1 / 2 inch internode elongation was found for the June seeding date. What was mostly observed was either a similarity or an unrecognizable pattern to the DD50 thermal unit accumulations from emergence to 1 / 2 inch internode elongation for the April, May, and June seeding dates. This phenomenon could possibly be due to the warm erratic weather patterns observed in 1998 from El Niño. Overall, the average number of DD50 thermal unit accumulations required for the cultivars/varieties to reach 1/2 inch internode elongation ranged from 1129 to 1391, with most requiring between 1275 to 1375. Cocodrie, by far, required the fewest DD50 thermal unit accumulations between emergence and 1/2 inch internode elongation of all the cultivars/varieties tested in 1998.

The DD50 thermal unit accumulations required for a rice cultivar/variety to reach 50% heading in 1998 also did not follow the characteristic pattern of less DD50 thermal unit accumulations required as seeding date was delayed. In fact, there were less DD50 thermal unit accumulations required to reach 50% heading for most of the cultivars/varieties when seeded in April rather than from the May and June seeding dates. In general, most of the cultivars/varieties required more DD50 thermal unit accumulations to reach 50% heading when seeded in June rather than May or April. Overall, on average, the cultivars/varieties required between 1909 and 2368 DD50 thermal unit accumulations to reach 50% heading, with most requiring between 2075 and 2200. The two new experimental varieties, RU9601099 and RU9601096, required the fewest DD50 thermal unit accumulations between emergence and 50% heading of all the cultivars/varieties tested in 1998.

Drew and RU9601053 produced the highest yields of all long-grain cultivars/varieties evaluated for the May and June seeding dates (Table 4). Madison produced the highest yield of long-grain cultivars/varieties for the April seeding date. Jefferson produced average to low yields for each of the seeding dates. Cocodrie, a very short season cultivar, produced the third highest overall yield for long-grain cultivars/varieties. Litton, Drew, Cocodrie, and RU9601053 all produced high yields when seeded in June compared to the other long-grain cultivars/varieties. Although few medium-grain cultivars/varieties were included in this study, the Louisiana experimental line RU9602074 produced high yields at all seeding dates. Deep seed placement for the June seeding date resulted in poor stands for RU9601099, RU9601096, Jefferson, and Lafitte. The Madison seed was treated with fungicide and gibberellic acid which aided emergence and stand establishment, whereas seed from all other entries was untreated and thus, provides an estimate of relative seedling vigor.

SIGNIFICANCE OF FINDINGS

The data from 1998 will be used to refine the DD50 thermal unit thresholds for AB647, Cocodrie, Drew, Jefferson, and Litton, and to establish thresholds for Lafitte, Madison, Priscilla, and the experimental varieties. The grain yield data will be used to inform producers as to which cultivar are best to seed when planting in early April and June and which should be seeded at the recommended, optimum time between 15 April and 15 May.

ACKNOWLEDGMENTS

This research was supported 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 1998 at the Rice Research and Extension Center, Stuttgart.

	Seeding date		
Factor	6 April	11 May	10 June
Emergence date	29 April	21 May	18 June
Flood date	19 May	9 June	8 July
Days between seeding and emergence	23	10	8
Days between seeding and flooding	43	29	28
Days from emergence to flooding	20	19	20

Table 2. DD50 accumulations from emergence to 1/2 inch internode elongation as influenced by cultivar/variety and date of emergence in 1998 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ variety	Grain type	Seeding date: 6 April	Seeding date: 11 May	Seeding date: 10 June	Average across seeding dates
		(DD50 thermal unit accumulations)			
RU9601053	Long	1280	1326	1283	1296
Drew	Long	1309	1296	1219	1275
Cocodrie	Long	1157	1169	1060	1129
Madison	Long	1248	1356	1377	1327
Jefferson	Long	1248	1265	1315	1276
Litton	Long	1341	1295	1377	1338
Priscilla	Long	1309	1390	1409	1369
Lafitte	Medium	1309	1304	1409	1341
RU9602074	Medium	1405	1390	1377	1391
AB647[z]	Medium	1309	1326	1283	1306
RU9601099	Short	1280	1273	1441	1331
RU9601096	Short	1248	1212	1409	1290

[z] Anheuser Busch cultivar 647.

Table 3. DD50 accumulations from emergence to 50% heading as influenced by cultivar/variety and date of emergence in 1998 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ variety	Grain type	Seeding date: 6 April	Seeding date: 11 May	Seeding date: 10 June	Average across seeding dates
		(DD50 thermal unit accumulations)			
RU9601053	Long	2056	2170	2116	2114
Drew	Long	2086	2202	2144	2144
Cocodrie	Long	2000	2012	2116	2043
Madison	Long	2027	2264	2227	2173
Jefferson	Long	1906	1949	2052	1969
Litton	Long	2180	2171	2227	2193
Priscilla	Long	2056	2171	2227	2151
Lafitte	Medium	2027	2117	2084	2076
RU9602074	Medium	2148	2235	2172	2185
AB647[z]	Medium	2435	2416	2254	2368
RU9601099	Short	1906	1832	2020	1919
RU9601096	Short	1874	1832	2020	1909

[z] Anheuser Busch cultivar 647.

Table 4. Grain yield performance of twelve rice cultivars/varieties as influenced by seeding date in 1998 at the Rice Research and Extension Center, Stuttgart.

Cultivar/ variety	Grain type	Seeding date: 6 April	Seeding date: 11 May	Seeding date: 10 June	Average across seeding dates
		(grain yield in bu/acre)[z]			
RU9601053	Long	137	158	138	144
Drew	Long	133	158	132	141
Cocodrie	Long	142	139	123	135
Madison	Long	148	138	114	133
Jefferson	Long	115	135	109	120
Litton	Long	123	129	130	127
Priscilla	Long	128	146	95	123
Lafitte	Medium	140	141	108	130
RU9602074	Medium	152	173	122	149
AB647[y]	Medium	167	148	114	142
RU9601099	Short	136	127	97	120
RU9601096	Short	121	131	73	108
C.V.%		8.4	--		
$LSD_{(0.05)}$		5.2*	--		

[z] A bushel (bu) or rice weights 45 lb.

[y] Anheuser Busch cultivar 647.

GRAIN YIELD RESPONSE OF NEW RICE CULTIVARS TO NITROGEN FERTILIZATION

R.J. Norman, C.E. Wilson, Jr., N.A. Slaton, K.A.K. Moldenhauer, 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', 'Jefferson', 'Litton', 'Madison', 'Priscilla', and 'Wells' were the new rice cultivars studied in 1998. Similar to other cultivars released lately, all six of the new cultivars responded equally well or better in terms of grain yield when the N fertilizer was applied in a single preflood application compared to split applications. In addition, all of the cultivars required more N fertilizer to reach full yield potential on the clay soils than on the silt loam soils.

INTRODUCTION

The major strength of the rice-soil fertility research program has been the delineation of N fertilizer response curves for the promising new rice cultivars. This study determines the proper N fertilizer rates for the 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 has the new long-grain cultivar Wells and the Louisiana program has the new semidwarf long-grain cultivar Cocodrie in the study for the first time. The Mississippi program has the new semidwarf long-grain cultivar Litton in the study for the second year and the new semidwarf long-grain cultivar Priscilla in the study for the first time. The Texas program has the new semidwarf long-grain cultivar Jefferson in the study for the second year and the new semidwarf long-grain cultivar Madison in the study for the first time.

PROCEDURES

Locations where the cultivar x N rate studies were conducted and corresponding soils are as follows: Northeast Research and Extension Center (NEREC), Keiser, Sharkey clay (Vertic Haplaquept); Pine Tree Branch Experiment Station (PTBES), Colt, Calloway silt loam (Glossaquic Fragiudalf); Rice Research and Extension Center (RREC), Stuttgart, Crowley silt loam (Typic Albaqualf); and the Southeast Branch

Experiment Station (SEBES), Rohwer, Perry Clay (Vertic Haplaquept). The experimental designs were a randomized complete block design at the RREC and a split-plot design at NEREC, PTBES, and SEBES. Four replications were used with both experimental designs. In the split-plot design, the main plot was application method and the subplot was N fertilizer rate. Nitrogen fertilizer rates were: 0, 60, 90, 120, 150, and 180 lb N/acre. The two N application methods used in both experimental designs were the recommended single preflood (SPF) and the two-way split (2WS) application methods. The 2WS application method has the N fertilizer applied in split applications of preflood-midseason N rates of: 0 (0-0), 60 (30-30), 90 (45-45), 120 (60-60), 150 (90-60), and 180 (120-60) lb N/acre. The midseason N was applied between beginning internode movement and 1/2 inch internode elongation. The rice cultivars studied were: Cocodrie, Jefferson, Litton, Madison, Priscilla, and Wells. The rice was drill-seeded at a rate of 100 lb/acre in nine-row plots (row spacing of 7 in), 15 ft in length. All plots at each location were flooded when the rice was at the four- to five-leaf (lf) stage and remained flooded until the rice was mature. At maturity, 12 ft of the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as lb/acre at 12% moisture. Statistical analyses were conducted with SAS and mean separations were based upon protected Least Significant Difference (LSD) where appropriate.

RESULTS AND DISCUSSION

Cocodrie, a new semidwarf long-grain cultivar from Louisiana, had a better grain yield response when the N fertilizer was applied in a SPF than in a 2WS application on the silt loam soil at the RREC. Yields were similar from the two N application methods on the silt loam soil at the PTBES as well as on the clayey soils at the NEREC and SEBES (Table 1). However, there was a trend at these three latter locations toward higher yields when the N fertilizer was applied in a SPF application, especially at the NEREC and SEBES. Cocodrie had a peak grain yield of 8001 lb/acre at the RREC when 120 lb N/acre was applied in a SPF application, but had not reached that grain yield when up to 180 lb N/acre was applied in a 2WS (Table 2). However, there was no significant interaction between N fertilizer application method and rate for Cocodrie at the PTBES, NEREC, and SEBES. Grain yields of Cocodrie showed no significant grain yield increase when more than 60 lb N/acre was applied at the PTBES and when more than 90 to 120 lb N/acre were applied on the clayey soils at the NEREC and SEBES. The lower N fertilizer rates required at the PTBES to reach peak grain yield is believed to be due to the application of 1000 lb/acre of poultry litter prior to seeding. On average, 1000 lb of poultry litter contains 20 to 30 lb of N. Thus, the observed N rates required for peak grain yields at this location are probably 20 to 30 lb N/acre too low. This should be taken into consideration when examining the 1998 data from the PTBES on all of the cultivars studied.

Jefferson, the new semidwarf long-grain cultivar from Texas in its second year of testing, responded better at the RREC when the N fertilizer was applied in a SPF than in a 2WS application. It responded similarly when the N fertilizer was applied in a SPF or a 2WS application at the other three locations (Table 3). However, again there was an obvious trend at these three locations toward higher yields when the N fertilizer was applied in a SPF application. There was no interaction between N fertilizer application method and rate at the PTBES, but there was an interaction favoring SPF on the clayey soils at the NEREC and SEBES (Table 4). Jefferson reached a peak grain yield of 7408 lb/acre at the RREC when 120 lb N/acre was applied in a SPF application and did not reach a statistically similar grain yield with the 2WS application until 180 lb N/acre was applied. Jefferson reached peak grain yields when 60 lb N/acre was applied at the PTBES and when 150 lb N/acre was applied on the clayey soils at the NEREC and SEBES. It is difficult to pinpoint a preferred N rate at these latter two locations due to the large variation in the data. Similar to 1997, Jefferson required 120 lb N/acre in a SPF application and 150 to 180 lb N/acre in a 2WS application to produce peak grain yields (Norman *et al.*, 1998).

Litton, the new long-grain cultivar released by Mississippi, which was in its second year of our testing, responded better when the N fertilizer was applied in a SPF than to a 2WS application at the RREC. The reverse was true at the PTBES where the poultry litter had been applied. Yields were similar from the two application methods on the clayey soils at the NEREC and SEBES (Table 5). However, similar to Cocodrie and Jefferson, there was a trend at these latter two locations towards higher yields when the N fertilizer was applied in a SPF application. There was no interaction between N fertilizer application method and rate at the NEREC and SEBES (Table 6). Litton showed no significant grain yield increase at the RREC when more than 90 and 120 lb N/acre were applied in a SPF and 2WS application, respectively. At the PTBES, where the poultry litter was applied, Litton showed no significant grain yield increase when more than 60 lb N/acre was applied. Litton displayed no significant grain yield increase at the NEREC when more than 90 and 120 lb N/acre were applied in a SPF and 2WS application, respectively. Litton required slightly more N on the clayey soil at the SEBES by displaying no significant grain yield increase when more than 120 and 150 lb N/acre were applied in a SPF and 2WS application, respectively. These 1998 data for Litton are very similar to the data collected in 1997 (Norman *et al.*, 1998), excluding the data from the PTBES.

Madison , a new semidwarf long-grain cultivar released by Texas, was tested only at two locations in 1998 due to a limited amount of available seed from the Texas breeders. Madison responded better when the N fertilizer was applied in a SPF compared to a 2WS application on the silt loam soil at the RREC as well as on the clayey soil at the SEBES (Table 7). This can be more clearly seen in Table 8, where Madison showed significantly higher yields with the SPF compared to the 2WS application until the peak grain yield was achieved. Madison showed no significant grain yield increase with the SPF application when more than 120 lb N/acre was applied at the RREC and 150 lb N/acre at the SEBES.

Priscilla, a new semidwarf long-grain cultivar released by Mississippi, was also studied at only two locations due to a limited amount of seed from the breeders. Priscilla, like Madison, responded better when the N fertilizer was applied in a SPF compared to a 2WS application at the RREC and SEBES (Table 9). The better response of Priscilla to the SPF method compared to the 2WS method is also evident in Table 10. Grain yields of Priscilla did not significantly increase when more than 90 and 120 lb N/acre were applied in the SPF application at the RREC and SEBES, respectively. When the N fertilizer was applied in a 2WS application, Priscilla required 30 to 60 lb N/acre more than with the SPF method to obtain statistically similar grain yields.

Wells, a new long-grain rice cultivar released by the Arkansas breeding program, responded better when the N fertilizer was applied in a SPF than in a 2WS application at the RREC. It responded somewhat similarly when the N fertilizer was applied in a SPF application compared to a 2WS application at the PTBES and SEBES (Table 11). Grain yield of Wells peaked at the RREC when 120 lb N/acre was applied in a SPF application and did not reach a statistically similar yield with the 2WS method until 180 lb N/acre was applied (Table 12). Wells grain yields appeared to peak and not display statistically higher yields at the PTBES when more than 90 lb N/acre was applied with either application method. At the SEBES, grain yields of Wells did not significantly increase when more than 90 and 120 lb N/acre were applied in the SPF and 2WS application, respectively.

Rice cultivars grown on the clayey soils at the NEREC and SEBES in 1998, as well as in previous years, almost always required more N fertilizer to reach peak grain yields than when they were grown on silt loam soils. This is because the native N released is less on the clay soils compared to the silt loam soils as indicated by the lower yields when no N fertilizer is applied.

SIGNIFICANCE OF FINDINGS

Cocodrie and Jefferson showed no significant grain yield differences when the N fertilizer was applied in a 2WS application compared to a SPF application at three locations and responded better when the N fertilizer was applied in a SPF application at the other location. In general, Cocodrie reached peak grain yields when 90 to 120 lb N/acre were applied and Jefferson when 120 to 150 lb N/acre were applied. Litton displayed no significant grain differences between the two N application methods at two of the four locations and favored the SPF method at the RREC and the 2WS method at the PTBES. Litton had peak grain yields when 90 to 120 lb N/acre was applied at two locations and 120 to 150 lb N/acre at a third location. Madison and Priscilla responded better when the N fertilizer was applied in a SPF compared to a 2WS application at the two locations where they were studied. Madison and Priscilla required 90 to 120 lb N/acre, respectively on the silt loam soil and 120 to 150 lb N/acre, respectively, on the clayey soil to reach peak grain yields. Wells responded better to the SPF application at the RREC, but responded similarly to the two N application methods at the other two locations where it was tested. Wells required 90 to 150 lb N/acre to produce peak grain yields. In general, all of the cultivars required more N fertilizer to reach full yield potential on the clayey soils than on the silt loam soils.

ACKNOWLEDGMENTS

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

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Table 1. Influence of nitrogen (N) application method and location on grain yields of Cocodrie rice in 1998.

Application method	Grain yields			
	RREC[z]	PTBES	NEREC	SEBES
	-----lb/acre-----			
SPF[y]	7452	6835	5947	6302
2WS	6293	6572	5768	5899
$LSD_{(0.05)}$	188**	687	180	509

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 2. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Cocodrie rice in 1998.

	Grain yields							
	RREC[z]		PTBES		NEREC		SEBES	
Application rate	SPF[y]	2WS	SPF	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	----- (lb/acre) -----							
0	4471		5051	5089	2997	3175	3594	2987
60	6380	5242	7149	6298	5676	5417	5762	5660
90	7216	6078	7284	6822	6168	6213	6579	6157
120	8001	6450	7346	6580	6551	6542	6876	6432
150	7921	6874	7668	7471	6759	6550	7201	6776
180	7742	7679	6627	6802	6793	6710	7799	7383
$LSD_{(0.05)}$ w/in N method	207**		1604		602		963	
$LSD_{(0.05)}$ between N methods			1552		543		947	

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 3. Influence of nitrogen (N) application method and location on grain yields of Jefferson rice in 1998.

Application method	Grain yields			
	RREC[z]	PTBES	NEREC	SEBES
	----- lb/acre -----			
SPF[y]	6937	5521	6151	6968
2WS	5819	5296	5758	5972
$LSD_{(0.05)}$	260**	675	677	1057

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 4. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Jefferson rice in 1998.

	Grain yields							
	RREC[z]		PTBES		NEREC		SEBES	
Application rate	SPF[y]	2WS	SPF	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	----- (lb/acre) -----							
0	4136		4762	4529	3125	2907	3600	3326
60	5904	4586	6460	6961	5744	4086	6991	5467
90	6738	4954	5866	6266	6680	6024	7531	5141
120	7408	5798	5878	5568	682	6743	7634	6502
150	7437	6979	4963	5199	7329	7319	8133	7645
180	7200	7619	3846	4603	7202	7467	7918	7752
$LSD_{(0.05)}$ w/in N method	291**		1597		1543		1283	
$LSD_{(0.05)}$ between N methods			1546		1504		1416	

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 5. Influence of nitrogen (N) application method and location on grain yields of Litton rice in 1998.

Application method	Grain yields			
	RREC[z]	PTBES	NEREC	SEBES
	------------	lb/acre	------------	------------
SPF[y]	6382	6525	5754	5533
2WS	5932	6838	5689	5272
$LSD_{(0.05)}$	197**	250*	278	1123

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 6. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Litton rice in 1998.

	Grain yields							
	RREC[z]		PTBES		NEREC		SEBES	
Application rate	SPF[y]	2WS	SPF	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	------------	------------	------------	------------	(lb/acre)	------------	------------	------------
0	4311		5247	5681	3631	3627	3879	3786
60	6379	5234	7665	7402	5721	5566	5377	4876
90	6856	6036	7551	7591	6024	5739	5287	4783
120	6449	6300	6948	7322	6177	6528	6141	5573
150	6514	6438	6411	6907	6626	6308	6316	6330
180	5713	6464	5327	6124	6338	6364	6200	6286
$LSD_{(0.05)}$ w/in N method	220		1105		624		1024	
$LSD_{(0.05)}$ between N methods			985		609		1309	

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; NEREC = Northeast Research and Extension Center, Keiser; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 7. Influence of nitrogen (N) application method and location on grain yields of Madison rice in 1998.

Application method	Grain yields	
	RREC[z]	SEBES
	------------- (lb/acre)	---------------
SPF[y]	7082	6890
2WS	6098	6404
$LSD_{(0.05)}$	606**	331**

[z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 8. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Madison rice in 1998.

	Grain yields			
	RREC[Z]		SEBES	
Application rate	SPF[Y]	2WS	SPF	2WS
(lb N/acre)	------------------------	(lb/acre)	--------------------------	
0	3393		3296	3241
60	6828	4141	6181	5642
90	7458	5581	6701	6290
120	7622	6479	7762	6643
150	8134	6880	8488	8059
180	7211	7408	8911	8549
$LSD_{(0.05)}$ w/in N method	675		1003	
$LSD_{(0.05)}$ between N methods			941	

[Z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer.
[Y] SPF = Single preflood; 2WS = Two-way split.

Table 9. Influence of nitrogen (N) application method and location on grain yields of Priscilla rice in 1998.

Application method	Grain yields	
	RREC[z]	SEBES
	-------------- (lb/acre) ---------------	
SPF[y]	7082	6890
2WS	6098	6404
$LSD_{(0.05)}$	606**	331**

[z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 10. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Priscilla rice in 1998.

	Grain yields			
	RREC[Z]		SEBES	
Application rate	SPF[Y]	2WS	SPF	2WS
(lb N/acre)	------------------------ (lb/acre) --------------------------			
0	3890		3569	3363
60	6282	4765	6315	5738
90	7406	5694	7304	6607
120	7629	6076	7694	7069
150	7417	6842	7137	7973
180	6857	7531	8241	7312
$LSD_{(0.05)}$ w/in N method	337		884	
$LSD_{(0.05)}$ between N methods			815	

[Z] RREC = Rice Research and Extension Center, Stuttgart; SEBES = Southeast Branch Experiment Station, Rohwer.
[Y] SPF = Single preflood; 2WS = Two-way split.

Table 11. Influence of nitrogen (N) application method and location on grain yields of Wells rice in 1998.

Application method	Grain yields		
	RREC[z]	PTBES	SEBES
	----------	lb/acre	----------
SPF[y]	7814	6931	7005
2WS	6118	7036	6302
$LSD_{(0.05)}$	304**	666	813

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

Table 12. Influence of nitrogen (N) fertilizer rate, application method, and location on grain yields of Wells rice in 1998.

	Grain yields					
	RREC[z]		PTBES		SEBES	
Application rate	SPF[y]	2WS	SPF	2WS	SPF	2WS
(lb N/acre)	----------	----------	----------	(lb/acre)	----------	----------
0	3128		5328	4427	3254	3308
60	5745	4334	6908	6987	6593	5313
90	7323	4576	7896	7866	7650	6329
120	8536	6565	7858	7988	7830	7016
150	8680	7878	7833	7162	8663	7619
180	8484	8730	5763	7101	8038	8228
$LSD_{(0.05)}$ w/in N method	339		1142		1242	
$LSD_{(0.05)}$ between N methods			1196		1285	

[z] RREC = Rice Research and Extension Center, Stuttgart; PTBES = Pine Tree Branch Experiment Station, Colt; SEBES = Southeast Branch Experiment Station, Rohwer.
[y] SPF = Single preflood; 2WS = Two-way split.

EFFECTS OF LIME, PHOSPHORUS, AND ZINC APPLICATION ON RICE AND SOYBEAN PRODUCTION

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ABSTRACT

Nutrient deficiencies in the rice crop may be induced by liming fields that include both soybeans (*Glycine max* L.) and rice (*Oryza sativa* L.) in rotation. The objectives of this three-year study were to (1) determine the response to lime by soybeans and rice grown in rotation and (2) measure the effect of phosphorus (P) and zinc (Zn) fertilization, with lime, on yields and nutrient uptake by rice and soybeans in rotation. Lime rates (0, 1, 2, and 4 ton / acre), P rates (0 and 40 lb P_2O_5 / acre) and Zn rates (0 and 10 lb Zn / acre) were main plot, sub-plot and sub-sub-plot factors, respectively. Different cultivars of rice ('Bengal', 'Cypress', 'Drew', and 'Kaybonnet') and soybean ('Delsoy 5500' and 'Holladay') were randomly seeded in strips across the main plot. Lime application increased soil calcium (Ca) levels, but decreased measurable soil P and Zn levels. A trend toward increased dry matter with an increase in lime rate was observed at midtillering (MT) for rice. Similarly, soybean dry matter tended to be numerically higher with 2 and 4 ton / acre of lime at all growth stages. Significant rice and soybean yield responses to lime were obtained in 1996. A trend for increased soybean yield in 1997 and 1998 was observed. Phosphorus and Zn fertilization did not significantly affect grain yield and dry matter of rice and soybeans. Phosphorus concentration in the plant at all growth stages was significantly decreased and increased by liming for rice and soybeans, respectively. Zinc concentration at all growth stages was significantly decreased by liming for both crops. Liming of acid soils may benefit both rice and soybeans; however, P and Zn deficiencies may become nutritional problems especially for rice. Therefore, farmers should apply P and Zn fertilizers directly to the rice crop if lime has been applied to fields having a rice-soybean rotation.

INTRODUCTION

In Arkansas, soybeans (*Glycine max* L.) and rice (*Oryza sativa* L.) are often grown in rotation on alkaline (pH > 7.0) and acidic soils. Rice yields are reduced on alkaline soils (Wilson *et al.*, 1996), but soybean grown in rotation with rice on the same soils produces high yields under good management practices. Several soybean farmers have reported low soybean yields thought to be related to acid soil conditions. In general, soybeans produce best at a pH between 6.0 and 7.0 (Muir and Sabbe, 1991). Lime is recommended for soybeans on soils having pH ≤5.5 (Snyder and Miley, 1987). Liming acid soils to higher pH values decreases the availability of some nutrients and may induce deficiencies of manganese (Mn), zinc (Zn), boron (B), copper (Cu), and phosphorus (P). Whether or not deficiencies appear depends in part upon the initial supply, the pH attained, and the crop. Farmers are reluctant to lime fields that include a soybean-rice rotation for fear of raising the pH and inducing Zn or P deficiencies in seedling rice. Rice yield increases from P fertilization have been obtained on alkaline soils, but seldom occur on acidic silt loams (Slaton *et al.*, 1999). Also, rice yield increases from Zn fertilization on alkaline soils are less common.

The objectives of this experiment were to (1) monitor soil pH and soil test levels as affected by lime, P and Zn application on acidic silt loam, and (2) determine the growth, nutrient uptake, and yield response of both rice and soybeans, grown in rotation, to lime, P and Zn applications.

PROCEDURES

A three-year field study was implemented on a site with a low soil pH (4.9) at the Rice Research and Extension Center, Stuttgart. Four lime (calcium carbonate, 38-40% Ca) rates (0, 1, 2 and 4 ton / acre), two P rates (0 and 40 lb P_2O_5 / acre / year as triple superphosphate) and two soil-applied Zn rates (0 and 10 lb Zn / acre / year as CoZinco™ Zn sulfate) were tested. Lime was applied and mechanically incorporated in the fall of 1995. Field tests were initiated during 1996 to include two rotations including rice (1996), soybeans (1997), rice (1998); and soybeans (1996), rice (1997), soybeans (1998). Soil samples were taken from each plot prior to soil preparation for seeding and extracted with the Mehlich 3 extractant for analysis. Each year P and Zn fertilizers were incorporated before seeding. Management operations for rice and soybeans were described by Ntamatungiro *et al.* (1998).

The experimental design was a split-split-split plot with four replications. The main plots were the four rates of lime. The subplots were the two rates of P. The sub-subplots were the two rates of Zn. The cultivars were randomly superimposed on the fertilizer treatments and seeded side by side in strips. Bengal, Cypress, Drew, and Kaybonnet were the rice cultivars and Delsoy 5500 and Holladay were the soybean cultivars.

Rice and soybean responses to lime, P and Zn were measured from dry matter production, nutrient uptake at two growth stages (midtillering-MT and 50% heading-HD) for rice, vegetative (V_8), and reproductive (R_2) for soybean, and grain yield at maturity.

Analysis of variance was performed to evaluate the treatment effects on the variables measured. Data analyzed do not include nutrient uptake in 1998. Because no significant year differences in dry matter and nutrient concentration data were found, data were pooled over years. However, grain yields were significantly affected by year. Therefore, grain yield was analyzed separately by year. Means separation was done by using the Fisher's protected Least Significant Difference (LSD) at the 0.05 level of probability.

RESULTS AND DISCUSSION

Soil Test Levels

Soil pH and Ca levels were significantly increased by lime application (Table 1). Soil P levels increased up to 2 ton / acre of lime applied, then decreased numerically with 4 ton / acre of lime applied to rice. There was a trend for lower soil Zn with 4 ton / acre of lime applied in 1998 for both rice and soybean plots. Also, soil Zn levels were significantly increased by annual Zn applications (data not shown). However, P application did not affect soil P levels (data not shown).

Dry Matter and Grain Yield

Lime application tended to increase rice dry matter at MT (Table 2). Soybean dry matter response to lime was not significant at vegetative stage V_8. However, there was a trend for dry matter increase with the 2 and 4 ton / acre lime rates. Dry matter production tended to be numerically higher with 2 ton / acre of lime applied at both soybean growth stages.

Grain yield varied from one year to another and tended to increase each year (1996 < 1997 < 1998) for each lime treatment. There was a significant yield increase due to lime application for both rice and soybean in 1996 and a trend for yield to increase for soybean in 1997 and 1998. No significant soybean yield differences were observed among the 1, 2, and 4 ton / acre lime rates. The highest rice yield responses to lime application were 12.7 bu / acre and 6.1 bu / acre in 1996 and 1997, respectively. The highest soybean yield responses to lime application were 9.2, 4.7, and 8.1 bu / acre in 1996, 1997, and 1998, respectively.

Rice and soybean dry matter and yield responses to P and Zn application were not significant (data not shown). This is an indication that rice and soybean did not experience any P or Zn deficiencies. Significant cultivar differences in yield and dry matter accumulation were found. For example, Bengal tended to have the highest dry matter, and Cypress the lowest dry matter at MT. Similarly, Holladay produced significantly more dry matter and grain yield than Delsoy 5500.

Nutrient Concentration

The concentration of Ca, P, and Zn in rice and soybean tissue at all growth stages followed the same pattern as their uptake. Calcium concentration by the rice plant increased with increased lime rate (Table 3). Liming resulted in decreased P concentration for rice, and increased P concentration for soybeans at both growth stages. Soybean P concentration ranged from 0.248 to 0.285% at V_8, and from 0.258 to 0.281% at R_2 growth. Rice P concentration ranged from 0.304 to 0.417% at MT, and from 0.252 to 0.284% at HD. These data suggest that P was taken up in direct proportions to availability for soybeans and not for rice. The decrease or increase in P concentration with liming may indicate that rice and soybeans are using different pools of soil P. The availability of P for rice decreased from liming, whereas the availability of P for soybeans was increased by liming. Calcium phosphates may become the predominant forms of P at the highest lime rates. Usually, reductant soluble P and ferric phosphates are the forms controlling P supply to flooded rice. Sah and Mikkelson (1986) found that calcium phosphates, like ferric phosphates, may increase after flooding.

Soybean P and K concentrations tended to reach a maximum with 2 ton / acre of lime. Significant decreases in Zn concentration with liming were observed for rice at MT and for soybeans at both growth stages. Phosphorus application did not result in significant P concentration changes for rice at either growth stage, nor for soybeans at the V_8 stage (data not shown). Average P concentrations were 0.261% for soybeans at V_8 growth stage. Application of 40 lb P_2O_5 per acre increased soybean P concentration from 0.267% to 0.275% at R_2 growth stage. Average rice P concentrations were 0.358% at MT, and 0.268% at HD.

Significant differences in P concentration among cultivars were observed. Delsoy 5500 tended to have slightly more tissue P than Holladay (Table 4). Bengal and Cypress contained higher tissue P concentrations at MT than Drew and Kaybonnet. Also, Bengal had significantly higher tissue K at HD than the other rice cultivars. Beyrouty *et al*. (1997) and Pulley and Beyrouty (1998) reported that Bengal had the highest maximum rate of K uptake and most frequently exhibited visual K deficiency symptoms under field conditions. They also found that Cypress had a higher rate of P uptake than did 'Lemont', 'LaGrue', and Kaybonnet.

SIGNIFICANCE OF FINDINGS

The 2 and 4 ton per acre lime rates increased the soil pH from 5.1 to 7.2 or higher. Visual symptoms of Zn or P deficiencies were not observed on rice and soybeans. Phosphorus application had no significant effect on rice and soybean yield and nutrient concentration. Zinc application did not increase rice and soybean yields, but significantly increased Zn concentration and uptake for all rice and soybean cultivars. Increasing the lime rate resulted in decreased P concentration for rice and increased P concentration for soybeans. At the 4 ton / acre lime rate, soil pH ranged from 6.9 to 7.2, and at these soil pH levels soil Zn and plant tissue Zn concentration were the lowest. Higher rates of lime (2 to 4 ton per acre) may induce P and Zn deficiencies in flooded rice, and only Zn deficiency in soybeans on this acidic silt loam. Therefore, if lime has been applied in a rice-soybean rotation, P and Zn fertilizers may be required to avoid nutritional problems for soybeans and flooded rice.

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Table 1. Soil pH, soil test levels of selected elements (Mehlich 3) as influenced by lime application and previous crop at the Rice Research and Extension Center, Stuttgart.

		After soybeans				After rice			
Year	Lime rate	pH	Ca	P	Zn	pH	Ca	P	Zn
	ton/acre	------	------ lb/acre	------	------	------	------ lb/acre	------	------
1997	0	5.1	1551	23.4	12.5	5.1	1645	21.0	12.7
	1	5.5	2166	24.4	13.1	5.4	2219	21.0	13.1
	2	6.5	3269	40.9	10.1	6.4	3145	32.2	11.4
	4	7.1	4271	41.9	12.9	7.1	4323	24.6	12.3
	LSD	0.3	235	13.4	2.5	0.3	297	NS[z]	NS
1998	0	5.3	1816	23.6	19.0	5.1	1605	17.0	16.1
	1	5.7	2377	21.9	17.8	5.4	1995	14.7	15.2
	2	6.4	3209	32.6	16.0	5.7	2514	22.6	16.2
	4	7.2	4206	24.1	15.8	6.9	3777	16.2	13.9
	$LSD_{(0.05)}$	0.3	181	NS	NS	0.2	172	NS	NS

[z]NS = Not significant.

Table 2. Rice and soybean dry matter and yield responses tolime application at the Rice Research and Extension Center,Stuttgart, (dry matter data of all years combined).

	Rice dry matter		Soybean dry matter	
Lime rate	MT[z]	HD[y]	V_8[x]	R_2[w]
(ton/acre)	----------------------------------	(lb/acre)	------------------------------	
0	2459	12996	608	1416
1	2541	13339	593	1480
2	2549	13348	705	1832
4	2555	12890	703	1794
$LSD_{(0.05)}$	NS[v]	NS	NS	284

	Rice yield			Soybean yield		
Lime rate	1996	1997	1998	1996	1997	1998
(ton/acre)	--		(bu/acre)	--		
0	107.4	147.6	162.8	39.1	51.9	46.8
1	120.1	149.8	165.2	43.9	57.3	49.5
2	118.2	145.5	154.5	48.3	58.7	47.6
4	115.6	153.7	159.7	47.5	59.6	54.9
$LSD_{(0.05)}$	8.3	6.9	NS	5.1	NS	NS

[z] MT = rice midtillering growth stage.
[y] HD = rice 50% heading growth stage.
[x] V_8 = soybean vegetative growth stage.
[w] R_2 = soybean reproductive growth stage.
[v] NS = Not significant.

Table 3. Soybean and rice nutrient concentrations as influenced by lime application at the Rice Research and Extension Center, Stuttgart (data of two years combined).

Growth stage	Lime rate	Concentration P	K	Ca	Zn
	(ton/acre)	(%)	(%)	(%)	(mg/kg)
V_8[z] Soybean	0	0.248	1.84	1.19	68.3
	1	0.251	1.75	1.35	55.5
	2	0.285	2.09	1.42	34.2
	4	0.267	1.69	1.58	26.8
	$LSD_{(0.05)}$	0.016	0.24	0.07	9.9
R_2[y] Soybean	0	0.258	1.67	1.13	71.7
	1	0.268	1.65	1.26	59.9
	2	0.281	1.79	1.31	32.7
	4	0.279	1.66	1.40	28.2
	$LSD_{(0.05)}$	0.014	NS[v]	0.08	11.4
MT[x] Rice	0	0.417	3.25	0.236	39.7
	1	0.373	3.22	0.251	39.9
	2	0.337	3.30	0.265	32.7
	4	0.304	3.13	0.311	29.8
	$LSD_{(0.05)}$	0.023	0.19	0.021	2.29
HD[w] Rice	0	0.284	1.70	0.212	28.0
	1	0.275	1.62	0.212	25.1
	2	0.259	1.64	0.232	26.0
	4	0.252	1.55	0.249	24.7
	$LSD_{(0.05)}$	0.016	0.11	0.014	NS

[z] V_8 = soybean vegetative growth stage.
[y] R_2 = soybean reproductive growth stage.
[x] MT = rice midtillering growth stage.
[w] HD = rice 50% heading growth stage.
[v] NS = Not significant.

Table 4. Soybean and rice nutrient concentrations as influenced by cultivar at the Rice Research and Extension Center, Stuttgart (data of two years combined).

		Concentration			
Growth Stage	Cultivar	P	K	Ca	Zn
		---------- (%)	----------	----------	(mg/kg)
V_8[z] Soybean	Delsoy 5500	0.264	1.83	1.36	42.4
	Holladay	0.260	1.82	1.41	51.4
	$LSD_{(0.05)}$	NS[v]	NS	0.03	4.8
R_2[y] Soybean	Delsoy 5500	0.275	1.66	1.27	46.0
	Holladay	0.267	1.72	1.31	52.1
	$LSD_{(0.05)}$	NS	NS	NS	4.8
MT[x] Rice	Bengal	0.374	3.17	0.264	32.5
	Cypress	0.371	3.24	0.242	33.7
	Drew	0.344	3.25	0.276	37.7
	Kaybonnet	0.342	3.24	0.28	38.2
	$LSD_{(0.05)}$	0.014	NS	0.011	1.59
HD[w] Rice	Bengal	0.274	1.73	0.234	22.0
	Cypress	0.254	1.60	0.201	22.9
	Drew	0.280	1.59	0.222	30.5
	Kaybonnet	0.263	1.58	1.247	28.5
	$LSD_{(0.05)}$	0.008	0.04	0.011	4.0

[z] V_8 = soybean vegetative growth stage.
[y] R_2 = soybean reproductive growth stage.
[x] MT = rice midtillering growth stage.
[w] HD = rice 50% heading growth stage.
[v] NS = Not significant.

INFLUENCE OF NITROGEN FERTILIZER TIMING AND RATE ON RICE GROWTH

H.J. Pulley, C.A. Beyrouty, and R.J. Norman

ABSTRACT

The rate and timing of nitrogen (N) fertilizers play an important role in achieving higher yields in rice. If N is supplied during critical growth periods of the plant it will stimulate growth. The first year of a proposed multi-year study was initiated using the mini-rhizotron technique to study the influence of N rates and timing on the growth of two rice cultivars. An additional supply of N was provided at booting in an attempt to alleviate N stress during reproductive growth. Results indicate that rate of application may be much more important to shoot growth than timing. A rate of 160 lb N/acre in a single preflood or split application resulted in higher shoot dry weights, leaf areas, and plant heights of both cultivars compared to 80 lb N/acre single preflood or split application. However, root length was most affected by split applications of 160 lb N/acre. Additionally, supplying N at booting had no effect on the growth of rice for any of the treatments. These preliminary results suggest a single preflood application of N is sufficient to maintain healthy rice growth with the cultivars studied, thus alleviating the need for additional N applications after flooding.

INTRODUCTION

Rate and timing of nitrogen fertilizer are two of the most important factors affecting rice growth and yield. However, higher N supply does not always return higher yields, especially in cases where there is an adequate supply of soil N. When there are N deficiencies, the efficiency of N recovery by rice from fertilizer application is critical in alleviating N stress. Typical fertilizer N recovery under field conditions is only 30 to 40% (De Datta, 1981). Split applications of N that coincide with plant needs have been suggested as a way to improve N recovery efficiency. While these split applications generally result in greater N accumulation (Bufogle *et al.*, 1997), little is known about the effect this application has on root growth and distribution. Generally, rice roots grow until they reach a maximum at booting and remain constant until heading, followed by a decline until grain fill (Beyrouty *et al.*, 1988). The present study was initiated to determine root growth patterns of two cultivars subjected to single and split applications of N and booting N applications. This study is intended to determine if split N applications stimulate root growth during this lag period or if adjustments in N timing should be made.

PROCEDURES

A field study was conducted in 1998 on a Crowley silt loam at the Rice Research and Extension Center, Stuttgart. Two cultivars, ‘Cypress’ and ‘LaGrue’, were seeded on 1 June in nine-row plots measuring 15 ft long with 7-in spacing between rows. These two cultivars comprised over 35% of the total rice acreage in Arkansas in 1998. Each cultivar was subjected to five N fertilizer and two boot N fertilizer treatments. The N fertilizer treatments were: 1) 0 lb N/acre, 2) 80 lb N/acre single preflood application (SPF), 3) 160 lb N/acre SPF, 4) 80 lb N/acre split application (40-20-20) with the splits at preflood, 1/2-in. internode elongation (IE), and 5 days after 1/2-in IE, and 5) 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 approximately five days prior to 50% heading, as timed according to the date estimate of 50% heading from the DD50 program.

Immediately after planting, a mini-rhizotron tube was inserted into each plot in the third row at a 45 degree 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: 1/2-in IE, booting (B), heading (HD), and physiological maturity--harvest (H). The growth stages corresponded to 53, 72, 80, and 115 days after planting (DAP), respectively. These images were processed to determine total root length (TRL) and root length density (RLD). Root length density is root length per unit volume of soil. At each sampling date except 115 DAP, plant height (PHT) was measured in the plot and a 1.6 ft length of row was harvested and shoot dry weight (SDW) and leaf area (LA) were measured.

RESULTS AND DISCUSSION

No differences in TRL, SDW, or LA were observed between cultivars for all sampling dates, with the only cultivar difference being in plant height (PHT) (data not shown). Therefore, the shoot-related data presented will be the averages from both cultivars. Shoot growth appeared to be least affected by N treatments. No significant differences were found in SDW, LA, or PHT between treatments at each sampling date. However, the treatments did affect the overall growth of the rice for the entire season. The N treatments resulted in increases of 63, 47, 33, and 27% in SDW for the 160 lb N/acre SPF, 160 lb N/acre split, 80 lb N/acre SPF, and 80 lb N/acre split treatments, respectively, as compared to the control (Table 1). Similar results were seen for TLA and PHT with increases of 124, 85, 68, and 53% for LA and 22, 22, 16, and 15% increases in PHT for the same treatments, respectively. The addition of boot N applications did not affect SDW, TLA, or PHT for any of the N treatments, suggesting that the plants did not require, or could not use additional N during reproductive growth.

In contrast to shoot growth, there were differences in root growth response to N fertilization at the four sampling dates. Total root length was most influenced by the split application of 160 lb N/acre (Fig. 1). However, there were no differences between the 160 lb N/acre SPF application and the control at any date, and an apparent decrease in TRL for the 80 lb N/acre split application at booting, heading, and harvest as compared to the control. These findings generally agree with previous work by Barber (1995), who reported that roots are not influenced by additions of N when there is adequate N present to support 80% optimal grain yield. These additions reduce the total yield of roots while increasing shoot growth.

Root length density followed the same pattern as TRL. The average RLD was most affected by the 160 lb N/acre split application, with little differences found between the other treatments (Fig. 2). By depth, N treatments had the greatest affect on root growth in the 10 to 20 cm depth increment (Fig. 3). In previous work by Beyrouty *et al.* (1988) and Slaton *et al.* (1990), > 98% of rice roots were measured in the top 40 cm of the Crowley soil with the greatest densities in the 10 to 30 cm range. The lack of increased root distribution by N treatment at lower depths suggests that either the increased N was not available at those depths or that the plant was attaining adequate assimilates in the upper regions and did not need to develop deeper roots. As with shoot growth, additional N supplied at booting did not alter root growth.

SIGNIFICANCE OF FINDINGS

These results suggest that N application rate had an accumulative effect on shoot growth during the season and that the effects were more rate dependent. Root growth did appear to be more influenced by timing, as observed by increased root growth from split applications of 160 lb N/acre. Additionally, the N applied at booting did not affect root or shoot growth. This is expected since the majority of shoot and root growth occurs prior to booting. These data suggest that a single application of N to these two cultivars would be sufficient to support healthy rice growth throughout the season. Work is continuing to determine what effect these treatments have on N uptake and yield.

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Table 1. Average shoot dry weight, total leaf area, and plant height for the growing season.

N Treatment	Shoot dry weight	Total leaf area	Plant height
---lb N/acre---	----g----	----cm^2----	--cm--
0	38.0 a[z]	2237a	60.8 a
80 Split	48.3 b	3417b	70.0 b
80 SPF	50.3 bc	3748bc	70.7 b
160 Split	55.9 c	4127c	74.4 c
160 SPF	61.9 d	5002d	74.1 c

[z] Means within the same parameter followed by the same letter are not significantly different at P=0.05.

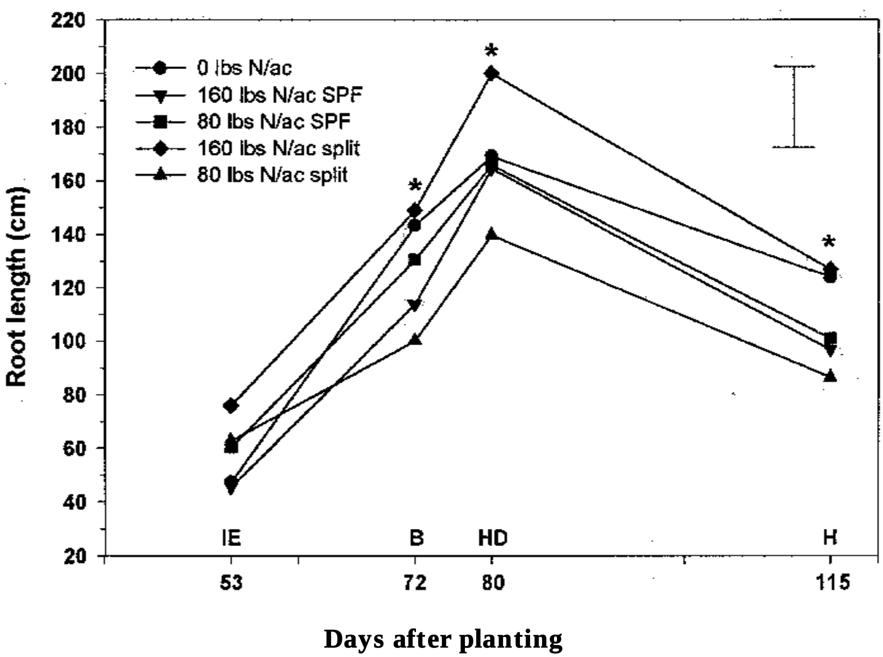

Fig. 1. Average total root length at different growth stages of two cultivars at vaying N application treatments (IE = internode elongation, B = booting, HD = heading, H = harvest). Bar represents LSD (0.05) = 26.0. Asterisk indicates dates when significant differences were observed between N treatments.

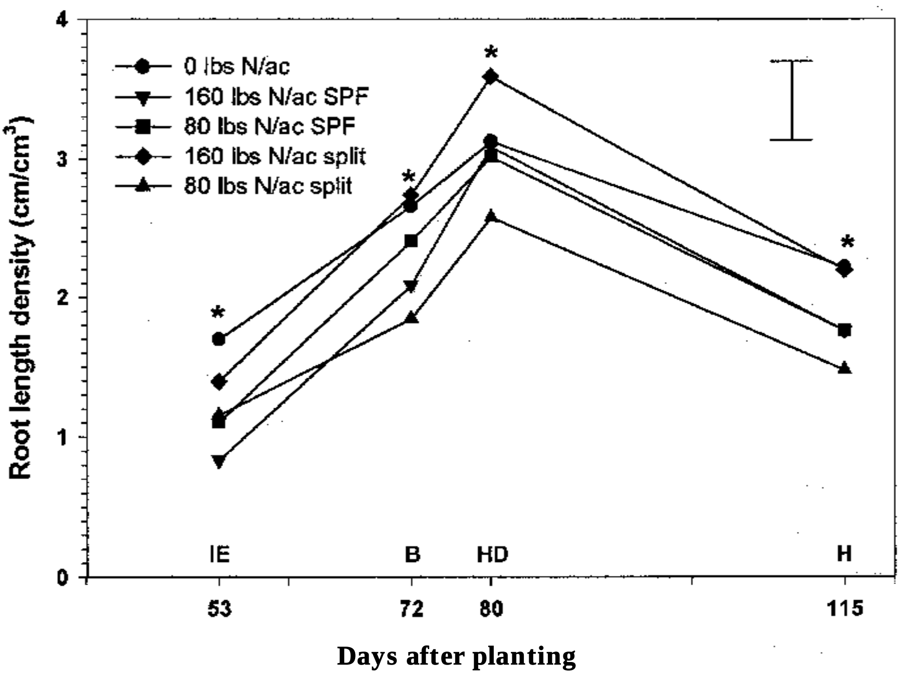

Fig. 2. Average root length density at different growth stages of two cultivars at varying N application treatments (IE = internode elongation, B = booting, HD = heading, H = harvest). Bar represents LSD (0.05) = 0.54. Asterisk indicates dates when significant differences were observed between N treatments.

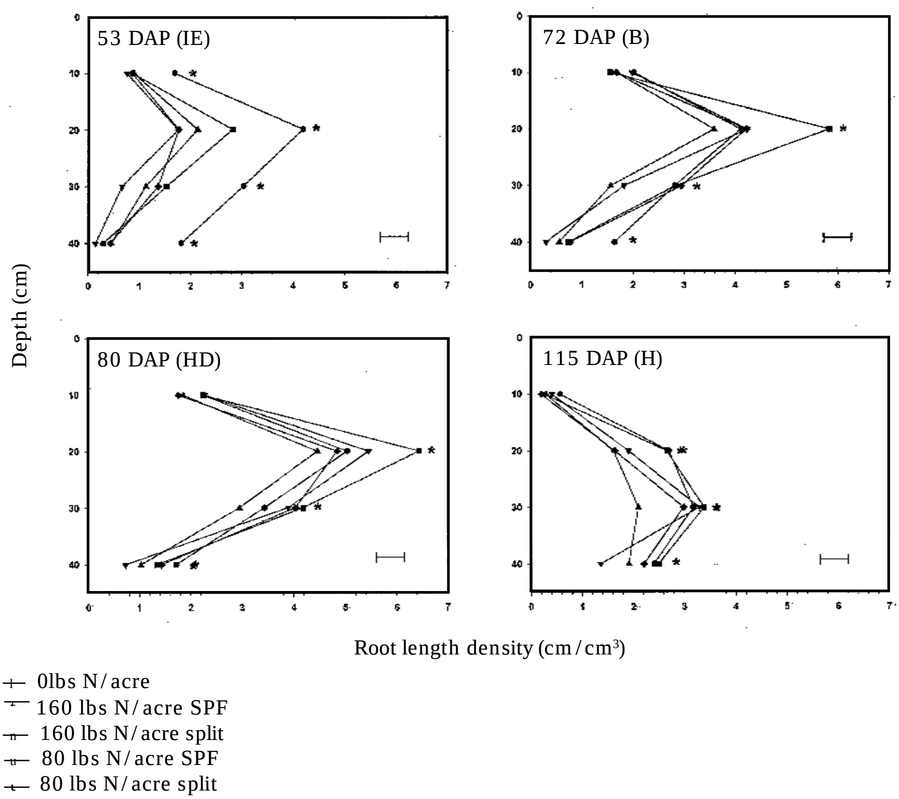

Fig. 3. Average root length density by depth for two rice cultivars. Dates are shown as days after planting (DAP) corresponding to the growth stage (IE = internode elongation, B = booting, HD = heading, H = harvest). An asterisk indicates depths at which significant differences were found between N treatments. Bars represent LSD (0.05) = 0.54.

HEAT AND WATER MOVEMENT IN A CALLOWAY SILT LOAM CROPPED TO FLOODED RICE

F. Renaud, H.D. Scott, and D.M. Miller

ABSTRACT

Soil volumetric water content, soil temperature, and climatic factors were monitored over two rice growing seasons in the Delta region of Arkansas. Measurements were taken every half hour and sensors placed at eight depth increments in the soil profile. Preliminary results on heat transfer for the 1998 season are presented here. Daily soil temperature variations were completely damped at approximately 60 cm but average soil temperatures increased at every depth increment throughout the season. The soil thermal conductivity varied from 1.1 to 1.7 J / msK and soil heat fluxes were negative for most of the locations in the soil profile indicating that the temperature in the soil profile increased during rice cropping.

INTRODUCTION

The Delta region of Arkansas is a major rice and soybean growing area. These two crops require large amounts of water from irrigation which is supplied for the most part by groundwater sources. In some locations, groundwater salinity is increasing (Baker *et al.*, 1996) which can be detrimental to crop productivity. Tracking the movement in the soil of salts that can damage crops should allow for the prediction of critical levels of such ions at different crop development stages. It would also aid in the development of alternative land and crop management strategies should critical levels be exceeded. In order to predict the fate of solutes and contaminants within the vadose zone, soil water and heat distributions as a function of time and location in the soil profile need to be characterized. To achieve this objective, a study was initiated to measure soil volumetric water content, soil temperature, and climatic factors at very short time intervals throughout two rice growing seasons.

PROCEDURES

The procedures were reported by Renaud *et al.* (1998). Briefly, the crop chosen was rice which is more sensitive to excess salinity than soybean and the soil was a Calloway silt loam (fine, silty, mixed thermic Glossaquic Fragiudulfs) which is a common agricultural soil in the region. The study was implemented on Mr. Darryl Schlenker's farm in Cross County and the parameters of interest were monitored during the 1997 and 1998 cropping seasons (April to September). Soil volumetric water content was measured using time domain reflectometry (TDR), and soil temperature with thermistors (TH). Relative humidity, net solar radiation, air and flood water temperature, wind speed, and rainfall were also measured with a Campbell Scientific weather station. In 1998, TDR and TH probes were placed at 5, 9, 14, 26, 45, 60, 80, and 100 cm below the soil surface in three replications. These depth increments corresponded to horizons and horizon boundaries of the soil profile (Table 1). Two additional TH probes were placed on the soil surface. Measurements of all the probes and sensors were taken every 30 minutes and the data were stored using dataloggers.

The field was flooded on 23 May 1998 but the water was removed by Mr. Schlenker on 31 May due to yellowing of the rice leaves. The field was reflooded on 13 June and water remained ponded until the final drainage on 20 August.

RESULTS AND DISCUSSION

Soil volumetric water contents as a function of depth and time in 1998 were similar to those in 1997 as reported by Renaud *et al.* (1998). The soil chemical and physical properties were also similar. Results will therefore not be repeated here. Infiltration of floodwater in the soil was successfully modeled using the logistic equation and comparison with other, more 'traditional' models is currently under way. In 1997, soil temperature measurements failed due to unknown reasons. The thermistors used then were replaced with new ones (Campbell Scientific sensors) and measurements of temperature were successful during the 1998 season. These measurement results and their preliminary analyses follow.

Average Daily Soil Temperature

Average soil temperatures at all depths increased during most of the season and began to decrease in August. Increases and decreases of these soil temperatures were in direct response to fluctuations of air temperatures (Fig. 1). The magnitude of the average soil temperature rise and its day-to-day variation decreased with depth (Figs. 2a and 2b). The effects of relatively cold air temperatures that lasted from 4 to 9 June were apparent throughout the soil profile, even one meter below the soil surface (Figs. 2a and 2b). This 'cold spell' took place between two flood events.

The large changes in average soil temperatures at the 1 m depth are not surprising. Depending on the soil thermal conductivity, Sellers (1965) reported that no temperature variations were observed at depths ranging from 4.6 to 16 m (soil information not provided) for an annual temperature cycle. It would, therefore, be expected to observe temperature variations over a period of several months at a depth of 1 m.

Soil Temperature Distribution Before and After Flooding

Daily soil temperature distribution in the soil profile before flooding indicated that the soil surface was colder than the layers of soil immediately beneath it during nighttime (Fig. 3a). The process is reversed during daytime since heat, when transported via conduction, moves from regions of higher to regions of lower temperatures. Colder surface soil temperatures at night are expected because the soil transmits heat to the air surrounding it in the form of long wave radiation. Once the soil receives short wave radiation during daytime, the soil surface warms up first and transmits heat by conduction to the lower soil layers. The range of soil surface temperatures was approximately 23°C to 35°C before and after the second flood was applied (Figs. 3a and 3b). The range decreased with increasing depth and no temperature variations were observed at a depth of approximately 60 cm. This depth corresponds to 4.6 times the damping depth (*D*), the latter being the depth at which the temperature amplitude is reduced to 0.37 times its surface value (Van Wijk and De Vries, 1963; Sellers, 1965).

The only significant difference between the two temperature profiles shown in Figs. 3a and 3b is that once the flood is applied, it takes more time for the soil surface to warm. This can be explained by the fact that before heat can be directed towards the soil surface, the water above it needs to be warmed. This process takes a relatively long time due to the high volumetric heat capacity of water relative to soil particles. Once the water is warmed and a temperature gradient develops between the water and the soil surface, heat can be transmitted toward the soil by conduction.

From Figs. 3a and 3b, it can finally be observed that the average temperature is slightly warmer after flooding than before. Heat was probably transmitted by convection (i.e. carried by water) into the soil profile upon irrigation. However, having traveled for three days before reaching the study plot, the irrigation water was already at 'ambient' temperature and did not affect the soil temperature distribution dramatically.

Soil Thermal Properties

In order to quantify heat movement in the soil, soil thermal properties need to be characterized. With soil temperature measurements taken every half hour, it was possible to determine the daily temperature range at each depth of measurement. Then, the amplitude equation could be used (Sellers, 1965) to relate the temperature range at the soil surface, the temperature range at some other depth, and the soil thermal diffusivity α. The amplitude equation is taken from one of the solutions to the transient-heat flow equation which assumes that the soil is homogeneous and isotropic. This is, of course, not the case in the Calloway soil. Thermal diffusivities were nevertheless measured for every day of the study period for all the depth ranges (i.e., 0 to 5 cm, 0 to 9 cm ...0 to 100 cm). The daily values of α were lognormally distributed and the mean α varied depending on the depth range used (Table 2). Up to a depth range of 0 to 26 cm, values of α were comparable with those reported in the literature for similar soils (van Wijk, 1963; Horton and Chung, 1991). Beyond this depth range, the α became unrealistic probably because of increased soil heterogeneity. In order to obtain a representative α, another equation relating the damping depth and α was used. The value of α calculated in this way was 5.2×10^{-7} m^2/s, which is close to the value obtained for the 0 to 5 cm depth range (Table 2). This new value of α is, however, only a preliminary estimate due to the fact that the damping depth will vary slightly from day to day.

The parameter of interest to determine soil heat transfer is the soil thermal conductivity (*k*). Thermal conductivity is the product of α and the volumetric heat capacity

(*Cv*) of the medium, which itself is a function of soil bulk density (ρ_b) and soil volumetric water content (θv). Measurements of ρ_b were available and θv was determined on a half hour basis. Therefore, for every day of the study period and at every depth increment, *Cv* and *k* could be calculated. The thermal conductivities obtained ranged from 1.1 to 1.7 J / msK.

Finally, the thermal conductivities were used to characterize soil heat transfer at every depth increment. In order to determine the direction and rate of heat transport, the soil heat flux density (*H*) was calculated. Soil heat flux density is the product of *-k* with the temperature gradient between two depth increments ($\Delta temp / \Delta depth$). When *H* is positive, heat moves towards the soil surface, if it is negative it moves down into the soil profile. Daily *H* had different patterns at different depths in the soil profile (Fig. 4). Close to the soil surface, *H* varied significantly from day to day and the amplitude was high relative to lower depths in the soil profile. Heat was transferred into and out of the profile, depending on the atmospheric conditions prevailing on any single day. For instance, the cold air temperatures, as recorded on 4 to 9 June, induced heat movement towards the soil surface for soil depths to 60 cm. The amount of heat transferred during that period was larger for the surface soil horizons than it was for the subsurface ones. Starting at a depth of 9 cm, heat was transferred downwards for most of the study period ($H < 0$). This was reversed towards the end of the rice cropping and harvest seasons, in September. The implication is, that outside exceptional climatic events, the soil profile was warming constantly throughout rice growth and development, regardless of the amount of water that was ponded on the soil surface.

SIGNIFICANCE OF FINDINGS

The data collected to this point will now be analyzed in more detail by using the 30-minute readings instead of average daily temperatures. However, preliminary results allow for a good understanding of heat transfer in the soil which can then be related to cropping practices. The ultimate objective of the study is to develop adequate models of heat and water transfer in order to estimate salt transfer. This will be achieved by comparing model outputs with salinity readings made with the TDR probes.

ACKNOWLEDGMENTS

We thank the Rice Research and Promotion Board and the Soybean Promotion Board for financing this project. We also thank Mr. Darryl Schlenker for allowing us to work on his farm and for his constant support and interest.

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Table 1. Brief soil profile description of the Calloway silt loam.

Horizon	Description
Ap1	Dark yellowish brown silt loam; weak fine subangular blocky structure; 13% clay; bulk density: 1.4 Mg/m^3
Ap2	Dark yellowish brown silt loam; moderate fine platy structure; 14% clay; bulk density: 1.58 Mg/m^3
E	Pale brown silt loam; moderate medium subangular blocky structure; 19% clay; bulk density: 1.51 Mg/m^3
Btx	Yellowish red and yellowish brown silty clay loam; moderate medium subangular blocky structure; 36% clay; bulk density: 1.5 Mg/m^3
Bt1	Pale brown silty clay loam; moderate medium subangular blocky structure; 32%clay; bulk density: 1.59 Mg/m^3

Table 2. Average thermal diffusivity (α) for various depth ranges.

Depth	Geometric mean[z]	Standard deviation	CV[y]	Mean
(cm)		(ln [α])	(%)	(α [m^2/s] x 10^{-7})
0-5	-14.5	0.78	5.4	5.13
0-9	-14.7	0.56	3.8	4.19
0-14	-14.6	0.43	2.9	4.66
0-26	-14.2	0.33	2.3	6.51
0-45	-13.9	0.39	2.8	8.85
0-60	-13.9	0.34	2.5	9.53
0-80	-13.5	0.34	2.5	14.03
0-100	-13.2	0.29	2.2	19.04

[z] Geometric mean is the average of the log transformed data.
[y] CV = coefficient of variation.

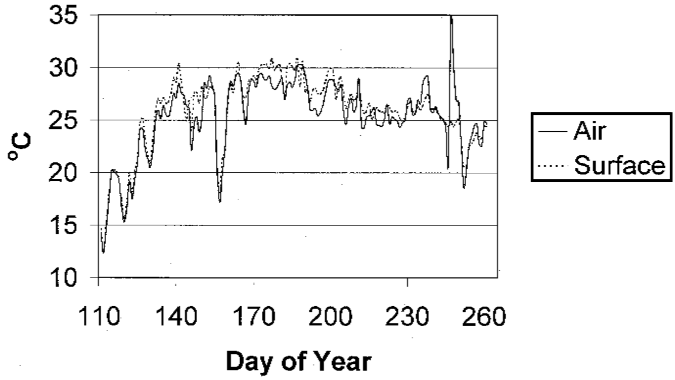

Fig. 1. Average daily temperatures of air and soil surface.

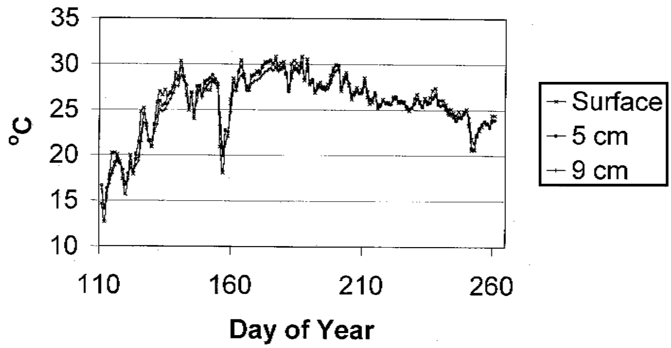

Fig. 2a. Average daily temperature of surface soil.

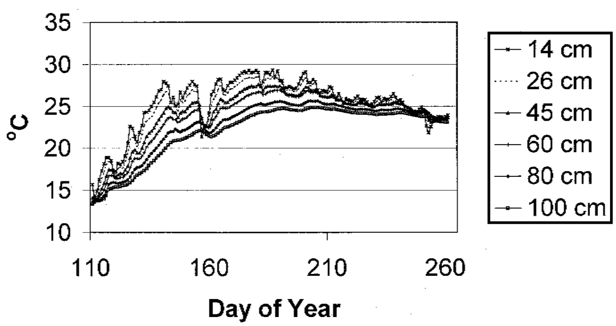

Fig. 2b. Average daily temperatures of subsurface soil horizons.

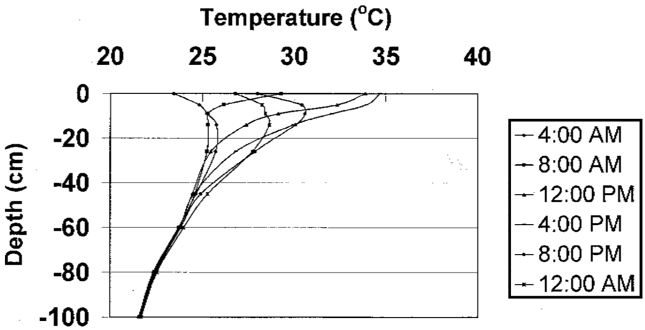

Fig. 3a. Daily soil temperature distribution prior to flooding, 12 June 1998.

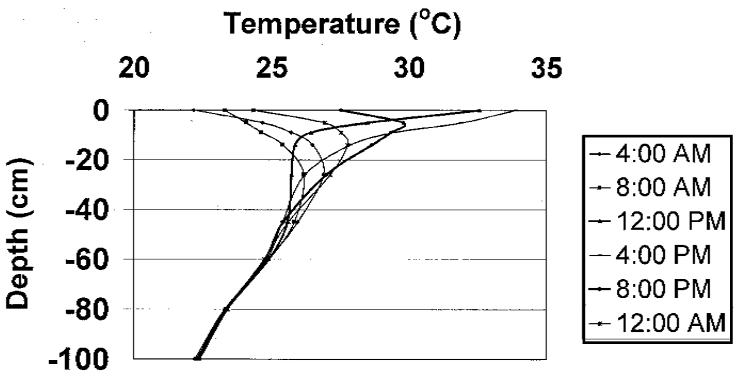

Fig. 3b. Daily soil temperature distribution after flooding on 15 June 1998.

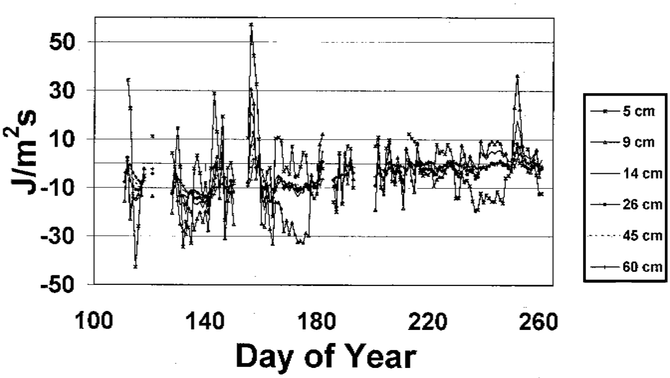

Fig. 4. Daily soil heat flux density at various depths.

EVALUATION OF GRANULAR AND FOLIAR ZINC SOURCES FOR RICE

N.A. Slaton, S. Ntamatungiro, C.E. Wilson, Jr., and R.J. Norman

ABSTRACT

Research indicates that granular zinc (Zn) fertilizers should contain at least 40 to 50% of the total Zn in the water soluble form to supply adequate Zn nutrition for rice. Recent field studies and observations suggest that rice yield responses to Zn fertilization occur less frequently compared to 25 years ago. Therefore, research is needed to develop better or alternative methods of supplying Zn, develop a list of recommended Zn sources, and improve soil test recommendations for Zn application. Two field studies were initiated in 1998 to evaluate four granular fertilizers applied at three rates (0, 5, and 10 lb Zn / acre) and various liquid Zn fertilizers for their effectiveness in increasing grain yield and supplying Zn to seedling rice plants. Results indicated that a significant Zn fertilizer source by rate interaction occurred for granular fertilizers effect on grain yield showing that differences among sources and application rates exist. Although liquid Zn sources did not significantly influence grain yield or tissue Zn concentration, there was a trend for some liquid Zn sources to increase numeric grain yields compared with the untreated check.

INTRODUCTION

Zinc (Zn) is the only micronutrient recommended for rice production in Arkansas. Current recommendations are to apply 10 lb Zn / acre prior to seeding in the form of an inorganic fertilizer such as Zn sulfate when soil pH is > 6.5 and the soil texture is silt or sandy loam. An alternative is to apply 1 lb Zn / acre as a liquid Zn chelate to foliage at the 3- to 5-leaf (lf) stage prior to flooding. The soil applied Zn recommendation requires 10 lb / acre to obtain adequate spatial distribution of Zn fertilizer since Zn is relatively immobile in the soil. Recently completed research at the University of Arkansas found that granular Zn fertilizers should contain 40 to 50% of the total Zn content as water soluble Zn to be effective in supplying rice with adequate Zn nutrition. The objective of these research studies was to evaluate several granular and liquid Zn sources for their ability to increase seedling tissue Zn concentration and grain yield compared to an untreated check.

PROCEDURES

Evaluation of Granular Fertilizer Sources

In 1998, a field study was initiated at the Rice Research and Extension Center (RREC) near Stuttgart to evaluate four Zn fertilizer sources applied at 5 and 10 lb Zn / acre compared to an untreated check on rice grain yield, dry matter production, and seedling Zn concentration. Plots were located on a DeWitt silt loam (fine, montmorillinitic, thermic, Typic Albaqualfs) that had received a 2 ton / acre lime application in 1996. Soil chemical properties are listed in Table 1. Rice grown in this field in 1997 suffered from Zn deficiency after flood application. Plots were seeded on 12 May 1998 with the rice cultivar 'Drew'. Zinc fertilizers, including CoZinco 31% $ZnSO_4$, NS-Zn (an experimental Zn fertilizer from Stoller, 7% Zn), Frit 36% Zn oxy-sulfate, and Stoller 36% Zn oxy-sulfate, were applied by hand and mechanically incorporated before seeding. Phosphorus and potassium fertilizers were broadcast on the plot area at a rate equal to 0-40-60 prior to ground preparation. Nitrogen in the form of urea was applied to a dry soil at the rate of 135 lb N / acre immediately before flooding at the 5-lf growth stage. Fourteen days after flooding, plants in a 3-ft section of the second inside row were cut at ground level in each plot for total dry matter (TDM) production. Tissue samples were immediately washed in deionized water, 0.1 M HCl, and finally in deionized water prior to drying to remove possible sources of contamination from soil. Samples were dried at 60°C to a constant weight, weighed for TDM and ground in a Wiley mill to pass through a 20-mesh sieve. Ground tissue (0.5 gram sample) was later digested with concentrated HNO_3 and 30% H_2O_2 for determination of whole plant elemental composition. At maturity 28 ft^2 from the center of each plot was harvested for grain yield. Reported grain yields were adjusted to 12% moisture by weight and reported in bu / acre, where a bushel is equivalent to 45 lb of rice. Elemental analysis of whole plant rice tissue was performed using an inductively coupled argon plasma unit.

Shoot TDM, tissue Zn concentration, and grain yield data were arranged as randomized complete block design with a 2 x 4 factorial treatment structure with four replications and compared to an untreated check. Data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fishers protected Least Significant Difference (LSD) test at the 0.05 significance level.

Comparison of Liquid Zn Sources

A second field study was initiated to compare five liquid Zn sources applied at 1 lb Zn / acre in 10 gal water / acre to an untreated check and two other fertilizer treatments. Liquid Zn sources included Zince10 (10% Zn), Super-Tel-Zn ($ZnSO_4$), Stoller SS (4% Zn), Terra 9% Zn (EDTA chelate), and Keylate (9% Zn). Seeding date, soil series, N-P_2O_5-K_2O fertilizer rates, and sampling methods were identical to the granular Zn study described above. Liquid Zn was applied to 4-lf rice three days before flood application. The two other treatments included in this study were 1) 100 lb $(NH_4)_2SO_4$ / acre preplant incorporated and 2) 100 lb $(NH_4)_2SO_4$ / acre plus 10 lb CoZinco $ZnSO_4$ / acre preplant incorporated. These two treatments were included to provide insight concerning the benefits of preplant ammonium sulfate applications on alkaline silt loam soils and compared to foliar Zn applications.

For shoot TDM, tissue Zn concentration, and grain yield analysis, treatments were arranged as a randomized complete block design having four replications. Data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fishers protected LSD test at the 0.05 significance level.

RESULTS

Granular Fertilizer Sources

Total dry matter production and whole plant Zn concentration 14 days after flooding were not affected by Zn fertilizer source (averaged across application rates) except for NS-Zn, 7% (Table 2). However, the 10 lb Zn / acre application rate did significantly (at the 0.05 probability level) increase TDM compared to the untreated check (Table 3). Although a significant Zn fertilizer x Zn rate interaction occurred for grain yield, the untreated check was not significantly different from any Zn rate or product (Table 4). Yield data from this study are similar to data from other Zn studies in the fact that the untreated check often produces higher numerical yields than some Zn treatments (Slaton *et al.*, 1995). This is partially due to the absence of severe Zn deficiency in these studies which prevents true expression of yield increases from Zn fertilization. Although tissue Zn concentration was not significantly influenced by Zn fertilizer or rate a trend did exist for tissue Zn concentration to increase with application of Zn fertilizer (Tables 3 and 4). Data in Table 4 suggest that tissue Zn increased as Zn fertilizer application rate increased for zinc products Frit 36% and NS-Zn 7% and decreased for products CoZinco Zn sulfate and Stoller 36%.

Comparison of Liquid Zn Sources

Grain yield and TDM were not significantly influenced by any treatment (Table 5). However, the treatment that included both ammonium sulfate and CoZinco Zn sulfate did tend to increase TDM compared to other treatments. This trend was also observed in the granular study with the NS-Zn product (Table 2). Wells *et al.* (1973) also found that ammonium sulfate applied with Zn sulfate fertilizers tended to increase rice seedling Zn concentration compared to urea as the source of N. Nitrogen research has demonstrated that preplant N applications do not contribute to increased grain yield. This study supports this since the two treatments that received preplant ammonium sulfate applications did not produce yields higher than other treatments (Table 5). However, there may be a management benefit from preplant ammonium sulfate application to alkaline silt loam soils if increased early growth aids growers in the ability to permanently flood rice at the 5-lf stage on problem fields. Tissue Zn concentration suggests that fertilizer Zn uptake increased when ammonium sulfate was applied with preplant Zn fertilizers. Again, the NS-Zn fertilizer in the granular Zn study tended to have the highest tissue Zn concentration compared to treatments that did not receive preplant N. Additional research is needed to examine the synergism between Zn and preplant N and determine what management benefits if any exist.

SIGNIFICANCE OF FINDINGS

Rice response to Zn fertilization by soil or foliar application were limited in studies conducted during 1998 due to lack of Zn as indicated by lack of deficiency symptoms after flooding. This may be partially attributed to relatively low soil pH and moderate soil test Zn levels in the test area. Data suggest that differences among Zn fertilizer sources do exist. Some fertilizers tend to increase rice yields compared to the untreated check, however, others tend to reduce yields. All granular fertilizers also tended to increase tissue Zn concentrations but to varying levels. Preplant application of ammonium sulfate with or without Zn application failed to increase grain yield, but when applied with preplant Zn it did significantly increase tissue Zn concentration. Foliar application of a quality Zn EDTA chelate continued to provide higher numerical grain yields compared to other Zn treatments and the untreated check.

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Table 1. Selected soil chemical properties in zinc source study as determined with the Mehlich III and Diethalenetriaminepentaacetic methods.

	Soil test level	
Chemical property	Mehlich III	DTPA
pH-water pH 1:2, soil:water	6.4[z]	--
P, lb/acre	26	--
K, lb/acre	302	--
Ca, lb/acre	2500	--
Mg, lb/acre	214	--
Na, lb/acre	174	--
SO_4-S, lb/acre	18	--
Fe, lb/acre	303	42.2[y]
Mn, lb/acre	301	83.3[y]
Zn, lb/acre	6.6	3.0[y]
Cu, lb/acre	2.8	1.4[y]

[z] pH of individual plots ranged from 6.3 to 7.3.

[y] Average value of 12 samples taken from individual plots.

Table 2. Influence of granular soil applied zinc (Zn) fertilizers on rice grain yield, total dry matter production, and whole plant tissue Zn concentration 14 days after flooding, averaged across Zn application rates.

Product	Grain yield	Total dry matter production	Tissue Zn concentration
	(bu/acre)[z]	(lb/acre)	(mg/kg)
Frit 36 %	145	724	21.1
CoZinco 31 %	142	577	23.3
Stoller 36 %	138	687	22.3
Control - No Zn	136	633	16.3
NS-Zn, 7 %	128	787	26.3
P-value	0.03	0.33	0.27
LSD(0.05)	11	255	9.2
C.V., %	6.6	32.8	23.4

[z] A bushel of rice weighs 45 lb.

Table 3. Influence of granular soil-applied Zn fertilizer rate on rice grain yield, total dry matter production, and whole plant tissue Zn concentration 14 days after flooding, averaged across products.

Zn fertilizer rate	Grain yield	Total dry matter production	Tissue Zn concentration
(lb Zn/acre)	(bu/acre)[z]	(lb/acre)	(mg/kg)
0	136	633	16.3
5	140	624	22.6
10	137	764	23.9
P-value	0.18	0.09	0.51
LSD(0.05)	10	233	8.4

[z] A bushel of rice weighs 45 lb.

Table 4. Influence of granular soil-applied Zn fertilizers and application rate on grain yield and whole plant tissue Zn concentration 14 days after flooding, averaged across Zn application rate.

Zn fertilizer product	Zn rate	Grain yield	Tissue Zn concentration
	(lb Zn/acre)	(bu/acre)[z]	(mg/kg)
Control - No Zn	0	136	16.3
Frit 36 %	5	144	18.0
	10	145	24.3
CoZinco 31 %	5	148	25.8
	10	134	20.0
Stoller 36 %	5	133	22.8
	10	142	21.8
NS-Zn, 7 %	5	133	23.8
	10	123	28.8
P-value	--	0.04	0.16
LSD(0.05)	–	14.5	NS[y]

[z] A bushel of rice weighs 45 lb.
[y] NS means not significantly different at the 0.5 or 0.1 probability level.

Table 5. Influence of Zn fertilizer treatment on rice grain yield and total dry matter production and whole plant tissue Zn concentration 14 days after flooding.

Product	Grain yield	Total dry matter production	Tissue Zn concentration
	(bu/acre)[z]	(lb/acre)	(mg/kg)
Control	136	633	16.3
$(NH_4)_2SO_4$, 100 lb/acre[y]	131	666	18.8
$ZnSO_4$ + $(NH_4)_2SO_4$[y]	134	866	30.5
Super-Tel-Zn	137	573	17.8
Stoller SS, 4% Zn[x]	131	526	18.8
Zince10, 10% Zn[w]	139	700	18.0
Terra 9% Zn EDTA	150	765	17.8
Keylate, 9% Zn[x]	141	732	13.8
P-value	0.33	0.58	0.0004
LSD(0.05)	16.3	352	5.7
C.V., %	7.9	35.1	20.5

[z] A bushel of rice weighs 45 lb.
[y] Treatments were preplant incorporated.
[x] Zn derived from termary amine carboxylate.
[w] Label states Zn in chelate form.

EVALUATION OF ZINC SEED TREATMENTS FOR RICE

N.A. Slaton, S. Ntamatungiro, C.E. Wilson, Jr., and R.J. Norman

ABSTRACT

In the 1970s, zinc (Zn) seed treatments were evaluated as an alternative to soil or foliar Zn applications. However, recommendations for or against seed treatments were never clearly made. Therefore, two studies were initiated in 1998 to evaluate the utility of Zn seed treatments for supplying Zn to seedling rice plants. Although not statistically different, Zn applied either to seed or soil tended to increase grain yields in both studies. Additionally, application of Zn to rice seed significantly increased seedling tissue Zn concentration compared to that of the untreated check in one study and resulted in a numerical increase in the other study. Preliminary data suggests that Zn seed treatments may be an effective, economical alternative to preplant Zn application. However, seed treatments need to be evaluated under severe Zn deficiencies to establish confidence in performance relative to current recommendations.

INTRODUCTION

In the 1970s, researchers evaluated zinc (Zn) seed treatments as an alternative to soil or foliar Zn applications (Haghighat and Thompson, 1982; Mengel *et al.*, 1976; Rush, 1972). However, recommendations for or against Zn seed treatments were never made. Current Zn recommendations are based on soil pH and soil texture. Therefore, Zn 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) found soil pH to best predict rice response to Zn fertilization during the early 1970s. However, much of this research was conducted before Zn recommendations were available to growers. Since this time, the once low native soil Zn levels on high pH loamy soils have increased appreciably due to broadcast applications of inorganic Zn sources to each rice crop. Consequently, the frequency of both Zn deficiency symptoms and rice yield responses to Zn fertilization have declined during the past 30 years. Work is currently being conducted to establish a critical soil test Zn level for rice that will account for previous Zn applications that have increased soil test Zn. Until a critical soil test Zn level is established and incorporated into recommendations, we are evaluating alternative methods of supplying Zn to the rice crop on high pH soils. Since application of small amounts of Zn to rice seed would be more economical than soil or foliar application, research was initiated in 1998 to evaluate the effect of Zn seed treatments on dry matter production, grain yield and tissue Zn concentration of rice.

PROCEDURES

Two field studies were initiated during 1998 to evaluate the effect of Zn seed treatments on rice grain yield, total dry matter (TDM), and whole plant tissue Zn concentration. Plots were located on a DeWitt silt loam (fine, montmorillinitic, thermic, Typic Albaqualfs) that had received a 2 ton / acre lime application in 1996. Soil chemical properties are listed in Table 1. Rice grown in this field in 1997 suffered from Zn deficiency after flood application. 'Cypress', 'Drew', and 'Jefferson' seed treated with Vitavax and a Zn starter fertilizer was obtained from Garrett Seed Farms (Danbury, Texas). Untreated seed was also obtained from Garrett Seed Farms for the three cultivars. Elemental analysis of the Zn treated seed indicated that 100 lb of seed contained approximately 0.25 lb of Zn. This seed treatment will be referred to as 0.25 lb / cwt for the duration of this manuscript. An additional Zn seed treatment, designated 0.5 lb Zn / cwt, was applied to seed in the laboratory using reagent grade Zn sulfate (36% Zn). After Zn application and drying, seed contained approximately 0.5 lb Zn / cwt. Seed treatments were compared to seed that received no seed Zn applications and was fertilized with either 0 or 10 lb Zn (CoZinco™ Zn sulfate) / acre. The first of two studies was seeded on 12 May 1998 with the four Zn treatments described. A second study was seeded on 23 June with only three treatments, which excluded the 0.5 lb Zn / cwt seed treatment. Plots were seeded at 100 lb / acre and were nine rows wide by 15 ft in length with a 7-inch row spacing. Nitrogen in the form of urea was applied to a dry soil at the rate of 135 lb N / acre immediately before flooding at the 5-lf growth stage. Fourteen days after flooding, plants in a 3-ft section of the second inside row were cut at ground level in each plot to determine TDM production. Tissue samples were immediately washed in deionized water, 0.1 M HCl, and finally in deionized water prior to drying to remove possible sources of contamination from soil. Samples were dried at 60°C to a constant weight, weighed for TDM, and ground in a Wiley mill to pass through a 20-mesh sieve. Ground tissue (0.5 gram sample) was later digested with concentrated HNO_3 and 30% H_2O_2 for determination of whole plant elemental composition. At maturity, 28 ft^2 from the center of each plot was harvested for grain yield. Reported grain yields were adjusted to 12% moisture by weight and reported in bu / acre, where a bushel rice weighs 45 lb. Elemental analysis of whole plant rice tissue was performed using an inductively coupled argon plasma unit.

For shoot TDM, tissue Zn concentration, and grain yield analysis from each study, treatments were arranged as a randomized complete block factorial design with four replications. Data were analyzed using the PROC GLM procedure of SAS. Differences among treatments were identified using Fishers protected Least Significant Difference (LSD) test at the 0.05 significance level.

RESULTS

Since a significant (*P-value* < 0.05) cultivar x Zn seed treatment interaction did not influence rice grain yield or TDM, for either the May or June study, TDM data are not presented. The primary objective of this study was to evaluate Zn seed treatments on rice grain yield and tissue Zn concentration. The lack of an interaction indicates all cultivars responded similarly to Zn seed treatments or soil applied Zn. A cultivar x Zn seed treatment interaction did not occur for tissue Zn concentration. Drew and Cypress tended to produce higher yields in both studies than did Jefferson (Table 2).

At both seeding dates, treatments that received either soil- or seed-applied Zn tended to produce higher grain yields compared to the control (Table 3). Tissue Zn concentration 14 days after flooding tended to be higher for all treatments receiving Zn in the May seeded test. Both soil- and seed-applied Zn significantly increased tissue Zn in the June seeded study. From this one year of field data, it appears that Zn seed treatments may be an effective alternative to soil- or foliar-applied Zn fertilizers. Rush (1972) found significant grain yield increases from Zn seed treatments. He also observed that some Zn sources and application rates reduced stand or seedling emergence. Although stand reduction did not occur in either of our studies, additional research is needed to establish the best Zn rates and products that can be used to treat seed. Research conducted by Rasmussen and Brown (1969) suggested that Zn seed treatment of beans (*Phaseolus vulgaris*) was not an adequate alternative to fertilizer Zn applications to the soil since Zn deficiency symptoms occurred. Zinc seed treatments for rice also need to be tested under severe Zn deficiency conditions to ensure their effectiveness.

SIGNIFICANCE OF FINDINGS

Rice response to Zn fertilization by soil or seed was limited in studies conducted during 1998 as indicated by the absence of Zn deficiency symptoms despite low soil test Zn levels. This may be partially attributed to relatively low soil pH in the test area. Initial studies evaluating Zn seed treatments suggest that Zn application to seed may be adequate for supplying rice nutritional Zn requirements on soils marginally deficient in Zn. Although significant grain yield increases from Zn application were not found, data does support current University of Arkansas recommendations for Zn fertilization by showing increased tissue Zn concentrations with Zn fertilizer application.

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Table 1. Selected soil chemical properties in zinc source study as determined with the Mehlich III and Diethalenetriaminepentaacetic (DTPA) methods.

	Study			
	May Zn seed study		June Zn seed study	
Factor	Mehlich III	DTPA	Mehlich III	DTPA
pH - water pH 1:2, soil:water	6.5[z]	--	6.5[z]	--
P, lb/acre	27	--	26	--
K, lb/acre	268	--	287	--
Ca, lb/acre	2396	--	2386	--
Mg, lb/acre	211	--	190	--
Na, lb/acre	154	--	187	--
SO_4-S, lb/acre	14	--	21	--
Fe, lb/acre	314	49.2[y]	323	45.4[y]
Mn, lb/acre	279	78[y]	264	99[y]
Zn, lb/acre	5.1	1.7[y]	2.6	0.5[y]
Cu, lb/acre	2.9	1.9[y]	2.5	1.1[y]

[z] pH of individual plots ranged from 6.3 to 7.3.
[y] Average value of twelve samples taken from individual plots.

Table 2. Effect of cultivar, averaged across zinc (Zn) treatments, on grain yield in Zn studies conducted during 1998 at the Rice Research and Extension Center, Stuttgart.

	Grain yield	
Treatment	12 May Seeding	23 June Seeding
	------------------- (bu/acre)[z] -------------------	
Drew	154	96
Cypress	153	88
Jefferson	146	62
P-value	0.107	0.0001
LSD(0.05)	15.4	7
C.V., %	9.6	10.7

[z]A bushel of rice weighs 45 lb.

Table 3. Effect of Zn seed treatment (averaged across cultivars) on rice total dry matter (TDM) production and tissue Zn concentration 14 days after flooding, and grain yield at maturity for two Zn seed treatment studies conducted during 1998 at the Rice Research and Extension Center, Stuttgart.

Treatment	May seeding date			June seeding date		
	Yield			Yield		
	TDM	Grain	Zn	TDM	Grain	Zn
	(lb/acre)	(bu/acre)[z]	(ppm)	(lb/acre)	(bu/acre)	(ppm)
Control	1387	140	18.3	291	78	20.4
Soil Zn	1364	156	19.9	272	82	31.6
0.25 lb Zn/cwt seed	1443	155	23.9	340	85	24.0
0.5 lb Zn/cwt seed	1468	149	20.3	--	--	--
P-value	0.95	0.76	0.13	0.24	0.16	0.0001
LSD(0.05)	589	18.4	5.5	84	7	2.5
C.V., %	30.5	9.0	19.4	33.0	10.7	11.0

[z]A bushel of rice weighs 45 lb.

1998 RICE RESEARCH VERIFICATION PROGRAM

N.A. Slaton, C.E. Wilson, Jr., T.E. Windham, and W.B. Koen

ABSTRACT

Seven fields in seven Arkansas counties were enrolled in the 1998 Rice Research Verification Program (RRVP). The counties participating were Arkansas, Crittenden, Jackson, Jefferson, Phillips, St. Francis, and White. Agronomic and economic data for specified operating costs were collected for each verification field. The seven fields totaled 491 acres with and an average field size of 70 acres. Yield, reported at 12% moisture, averaged 140 bu / acre with a range of 124 to 166 bu / acre. Three different cultivars were seeded ('Drew', 'Cypress', and 'Bengal'). Economic analysis suggests that 1998 RRVP total specified production costs were less than production costs proposed in extension crop budgets for 1998. Additionally, net returns from 1998 RRVP fields averaged $101.62 / acre above total specified operating and land costs.

INTRODUCTION

The RRVP, which was initiated in 1983, has had 155 commercial rice fields enrolled in the program to date. The RRVP is an interdisciplinary approach that stresses management intensity to maximize net returns. The program objectives are to verify current research based on recommendations for 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 agents and producers.

PROCEDURES

Each RRVP field 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.

Data were gathered from seven fields in the 1998 RRVP on 491 acres. Counties participating included: Arkansas, Jefferson, Phillips, Jackson, St. Francis, Crittenden, and White. Three different cultivars (Drew, Cypress, and Bengal) were seeded in the verification fields (Table 1). Six fields were drill-seeded and one was water-seeded. Additional agronomic information for soil test data, seeding rates, fertilizer applications, pesticide applications, and important dates during the growing season are listed in Tables 1 through 4.

RESULTS AND DISCUSSION

Grain yield in the 1998 RRVP averaged 140 bu / acre with a range of 124 to 166 bu / acre. This yield was 11 bushels higher than the reported state average of 129 bu / acre. The Arkansas County field of Cypress averaged 166 bu / acre which was the highest recorded yield in the 1998 RRVP. The second highest yield was produced at St. Francis County which averaged 152 bushels / acre despite a treatment threshold of rice water weevil larvae infestation shortly after flooding. Rice water weevil larvae were not controlled since the growers could not obtain Furadan (carbofuran) 3G. Additionally, several areas in the field had been previously leveled and could be identified after flooding by foliage color, thickness, and plant height. The lowest yield was recorded in the White County field (Table 1). Although stand density at this location was the lowest of any RRVP field, the stand was uniform and stand, soil test nutrients, and management should not have been a significant yield limiting factor (Tables 2 and 3). Disease, insect, or grassy weed competition / damage were also minimal. The primary yield limiting factor at White County which could easily be identified was red rice competition. Kernel smut may also have reduced yields in this and several other RRVP fields. Yield potential in all Drew fields appeared better than the final yield. Yield component data are needed to provide insight into reasons why some fields produce only average yields. Field observations at harvest also suggest that many fields producing “average” yields have a high percentage of blanks. Replicated research data and samples are needed to verify or refute these field observations and provide possible reasons (i.e., physiology, insect damage, disease, etc.) for the blanking. Other agronomic data are also needed to verify or compare the effectiveness of extension recommendations in RRVP fields. All fields were seeded in April, except Jackson County which was seeded in late May.

Grass was controlled in four RRVP with a single delayed pre- or early post-residual herbicide application (Table 4). Additional herbicide applications were made for broadleaf or aquatic weed control in several fields prior to reproductive growth. The average number of herbicide applications per acre was 1.76.

The new disease False Smut was observed only in the Jackson County field at significant levels. This may be due to the later seeding date compared to the other northeast or central Arkansas RRVP fields. Verification fields were not treated with foliar fungicides for sheath blight or blast control since treatment thresholds, based on current treatment thresholds and scouting procedures, were not reached.

ECONOMIC ANALYSIS

The cost of herbicides ranged from $17.01 to $79.37 / acre with an average of $44.91 / acre. The average cost of a single herbicide application (excluding application costs) was $25.52 / acre. The average RRVP costs for fertilizer, insecticides, and custom application were $49.93, $2.97, and $25.43 / acre, respectively. Total specified operating costs (herbicides, application, fuel, drying, etc.) ranged from $194.35 to $335.34 / acre and averaged $266.76 / acre (Table 5). Estimates of total specified operating costs ranged from $40.39 to $54.63 / acre and averaged $49.91 / acre. Total specified (direct and fixed) expenses averaged $320.15 / acre. University of Arkansas rice production budget estimates for total specified expenses ranged from $344.46 to $361.88 / acre. Estimated operating costs in 1998 RRVP fields were 7 to 12% lower than operating expenses estimated in 1998 rice production budgets. The average breakeven price assuming a 25% crop share rent was $3.03 / bu. Based on $4.00 cash price all fields showed a net profit which averaged $101.62 / acre.

SIGNIFICANCE OF FINDINGS

Grain yields in the 1998 RRVP reflect the general trend of average to slightly above average yields for Arkansas growers during 1998. Extremely hot and dry weather made water management difficult for most of the year. Many growers did not have enough pumping capacity to deliver water to the required acreage in the absence of rainfall. The RRVP will begin to examine water use requirements (quantity) by use of flow meters and water quality by sampling wells for bicarbonates and chlorides. Despite the hot dry weather, residual weed control programs used in the RRVP fields provided excellent grass control. Economic analysis showed that the 1998 RRVP average grain yield was higher than the state average yield, production costs were below estimated production costs (compared to extension service crop budgets), and showed positive net returns above total specified operating expenses and land costs.

Table 1. County, acreage, soil series, previous crop, grain yield, cultivar, and seeding method of the 1998 RRVP.

County	Field size	Soil series	Previous crop	Grain yield	Cultivar	Seeding method
		(acres)			(bu/acre)	
Arkansas	78	Crowley silt loam	Soybean	166	Cypress	Drill
Crittenden	80	Sharkey clay	Soybean	127	Drew	Drill
Jackson	80	Jackport silty clay loam	Rice	134	Cypress	Water
Jefferson	56	Roxana silt loam	Rice	143	Cypress	Drill
Phillips	38	Henry silt loam	Rice	130	Drew	Drill
St. Francis	80	Calloway silt loam	Edible Soybeans	152	Bengal	Drill
White	79	Jackport silty clay loam	Soybean	124	Drew	Drill
Average	70	-------	-------	140[z]	-------	-------

[z]Weighted average (the sum of individual yields x individual acreage divided by total acreage.

Table 2. Soil test results from the 1998 Rice Research Verification Program fields.

County	Soil pH	Phosphorus	Potassium	Zinc	Calcium
		---------- (lb/acre) ----------			
Arkansas	7.1	41	213	8.4	2841
Crittenden	6.6	28	323	8.2	5562
Jackson	6.3	15	462	2.1	3337
Jefferson	6.9	35	190	4.8	2536
Phillips	7.4	33	260	3.6	3839
St. Francis	6.9	31	220	3.2	3336
White	5.4	35	326	8	3376

Table 3. Stand density, seeding rates, fertilizer rates, and important dates of the 1998 RRVP.

County	Stand density	Seeding rate	Nitrogen applications urea (45%)[z]	Fertilization $N-P_2O_5-K_2O_5-Zn$	Seeding date	Emerge date	Harvest date
	(plants/ft^2)	(lb/acre)	(lb urea / acre)	(lb/acre)	---------------	(month/day)	---------------
Arkansas	26	113	80[y]-200-65	155-36-72-4	4/14	4/26	8/25
Crittenden	16	124	100[z] -175-100	169-0-0-0	4/9	4/29	9/17
Jackson	32	135	235-130-0	164-0-0-0	5/28	6/2	10/9
Jefferson	25	124	300-47-0	156-92-0-0	4/4	4/17	8/25
Phillips	14	90	225-90-0	142-0-0-0	4/15	4/28	9/21
St. Francis	24	113	250-65-50	164-45-60-4	4/23	4/29	9/10
White	12	80	225-100-0	146-0-0-0	4/30	5/12	9/23
Average	21	111	-----	-----	-----	-----	-----

[z] Values represent the split in N applications.
[y] First application of urea flushed in prior to permanent flood.

Table 4. Pesticide treatment, rate/acre, and dates of application on the 1998 Rice Research Verification Fields.

County	Pesticide, Rate/Acre and date of Application[z]
Arkansas	Propanil (Stam) 4 qt + Quinclorac (Facet®) 0.25 lb (5/1), Propanil 3 qt + Bensulfuron (Londax®) 1 oz (5/20)
Crittenden	Propanil + Molinate (Arrosolo®) 3 qt + Quinclorac 0.5 lb + Pendamethalin (Prowl) 2.4 pt (5/17), Propanil 1 qt + Triclopyr (Grandstand®) 0.5 pt (6/5)
Jackson	Thiobencarb (Bolero®) 4 pt (5/22), Bensulfuron 1 oz (6/14), Furadan (carbofuran) 20 lb/A (6/21)
Jefferson	Propanil + Molinate 4 qt + Quinclorac 0.5 lb (4/21), Propanil + Molinate 3 qt. + Bensulfuron 1 oz (5/15)
Phillips	Quinclorac 0.375 lb + Pendamethalin 2.4 pt (4/18)
St. Francis	Quinclorac 0.25 lb + Pendamethalin 2 pt (5/4); 72 acres, Propanil (Superwham) 4qt (5/7); 8 acres
White	Propanil + Molinate 4 qt + Bensulfuron 0.5 oz (5/14), Propanil 4 qt (5/28)

[z]Dates of treatments are in ( ). If only a portion of a field was treated, the acreage is given; otherwise assume that the entire field was treated.

Table 5. Selected economic information for the 1998 Rice Research Verification Program.

County	Total specified operating cost[z]	Total specified ownership cost[y]	Breakeven price[x]	Breakeven price with land cost[w]	Returns above total cost[v]
	($/acre)				
Arkansas	309.08	52.08	2.18	2.90	136.84
Crittenden	254.42	46.49	2.37	3.16	80.09
Jackson	275.58	54.63	2.46	3.29	71.79
Jefferson	335.34	50.94	2.70	3.60	42.72
Phillips	194.35	40.39	1.81	2.41	155.26
St. Francis	261.65	53.81	2.08	2.77	140.54
White	236.89	51.01	2.32	3.10	84.10
Average	266.76	49.91	2.27	3.03	101.62

[z] Specified out-of-pocket expenses, such as seed, fertilizer, herbicides, irrigation, etc.
[y] Ownership cost such as depreciation and interest on equipment, taxes and insurance.
[x] Price/bushel required by the farmer to equal total operating and ownership cost.
[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 $4.00 (average September and October cash price as reported in the Grain and Livestock Market Newsletter) selling price was assumed. No cost sharing was assumed.

PHOSPHORUS FERTILIZER MANAGEMENT FOR RICE PRODUCED ON ALKALINE SOILS

C.E. Wilson, Jr., N.A. Slaton, S. Ntamatungiro, and R.J. Norman

ABSTRACT

Optimum response by rice to phosphorus (P) fertilizer has been shown to be affected by soil pH. The optimum soil pH range for P fertilizer application is between 6.0 and 6.5. While flooding generally increases P availability to rice when the soil pH is less than 6.5, flooding has no effect on P availability on alkaline soils (those with pH > 7.0). The current study was conducted to determine the effects of application timing on optimum P fertilizer response by rice. Studies were conducted at three locations in 1997 and three locations in 1998. A positive yield response was observed due to P fertilizer at two locations in 1997 and two locations in 1998. A significant application timing effect was also observed at these locations. As the fertilizer application becomes closer to mid-tillering, there is a tendency to result in better grain yields. Applications made at midseason were generally better than no fertilizer but were not optimum. Relationships between relative yields and either soil test P levels or soil pH were evaluated from data collected from 33 field studies. The results indicate that soil pH is a better indicator of P fertilizer response than the Mehlich III soil test P level.

INTRODUCTION

Alkaline soils are probably the most important soil problem affecting rice production in Arkansas. When soils have pH levels that exceed 7.0, the potential exists for both zinc (Zn) and phosphorus (P) deficiencies. While the potential for P fertilizer response exists on alkaline soils, the inability of soil test procedures to adequately predict P response by rice resulted in no P recommendations for rice for several years.

Phosphorus is most available to the plant when the soil pH is between 6.0 and 6.5. When the soil pH is less than 6.0, the potential for pH deficiency for most crops increases. The soil P is bound in compounds such as iron phosphates that are not available to the plant. However, when these soils are flooded, the iron phosphate compounds convert to a soluble form, which makes the P available to plants. Since rice is flooded, P deficiency by rice produced on acid soils has been relatively non-existent. It has been common to see increased vegetative growth from P fertilizer applications in these situations, but not increased grain yields. As the result, P was not recommended for rice production in Arkansas for many years.

The first rice yield response to P fertilizer in Arkansas in recent years was observed during 1990, which led to the development of P fertilizer recommendations for rice based on the Mehlich III soil test procedure (Beyrouty *et al.*, 1991). Further work has resulted in the hypothesis that rice response to P fertilizer is also dependent upon soil pH (Wilson *et al.*, 1997). While P availability increases with flooding on acid soils, the compounds that make P unavailable in alkaline soils are not influenced by flooding. Therefore, on alkaline soils, if the available P is insufficient before flooding, then it will likely remain insufficient after flooding.

The objectives of the current study were 1) to evaluate rice yield reponse by rice to P fertilizer as a function of soil test P levels and soil pH and 2) to evaluate the optimum time of application of P fertilizer to rice.

PROCEDURES

Phosphorus Application Timing Study

Application timing studies were conducted in three production fields during 1997 and three production fields during 1998. Selected soil chemical properties taken from untreated areas of the plot area are illustrated in Table 1. During 1997, the studies were located on the Brooks farm in Poinsett County, the Davis farm in Arkansas County, and the Wimpy farm in Poinsett County. During 1998, the studies were located on the Davis Farm in Arkansas County, the Roberts farm in Poinsett County, and the Wimpy farm in Poinsett County. 'Bengal' rice was drill-seeded at approximately 90 lb / acre with a 7-inch row spacing at each location by the grower. After each field emerged, plots were defined by creating alleys between plots with mops previously soaked in Roundup® herbicide.

Phosphorus fertilizer (triple superphosphate, 0-46-0) was applied at four rates consisting of 0, 20, 40, and 80 lb P_2O_5 / acre. The fertilizer was applied at one of four different times in the growing season. The application times were preemergence, preflood, seven days after flooding (postflood), or at 0.5 in internode elongation (PD). The plots were managed by the producer according to management practices for the remainder of the field. Above-ground plant samples were collected from 3 ft of row three weeks after heading. Grain yields were measured by harvesting the four center rows with a small-plot combine and are reported at 12% moisture.

Soil Test Correlation Studies

Phosphorus studies have been conducted between 1993 and 1998 evaluating factors such as rates, sources, and application timing. Data from each of these 33 phosphorus studies were summarized to evaluate the relationship between Mehlich III soil test P levels, soil pH, and rice grain yields. To standardize the response of rice across all locations, relative yields were calculated for each study. Relative yields are calculated by dividing yield for the untreated control by the yield for the highest yield treatment receiving P fertilizer and multiplying by 100 to express yield on a percentage basis. Therefore, each study location has a maximum relative yield of 100 and, as an example, a relative yield of 85 indicates that P fertilizer increased yields by 15%.

RESULTS AND DISCUSSION

Phosphorus Timing Studies

Significant yield increases resulting from application of P fertilizer were observed only at the Davis farm in both 1997 and 1998 (Fig. 1). A trend for increased yields was observed at the Wimpy farm in 1997 and the Roberts farm in 1998. However, the Wimpy farm showed no response to P fertilizer during 1998. The Brooks farm in 1997 showed only a trend for decreasing yields with increasing P fertilizer rates. Since this farm had the lowest soil pH of the six locations in the study, it would be expected to have the least probability of expecting yield responses to P fertilizer.

Rice grain yields were numerically improved by P fertilizer application at four of the six locations (Fig. 2). Highest grain yields at these four locations was either when the P fertilizer application was delayed until preflood or postflood. At the Davis farm in both 1997 and 1998, the highest yields were obtained by the postflood application. PD applications on this farm provided some improvement over the control, but were not adequate compared to P applications made prior to the mid-tillering growth stage. While not significantly different, similar trends observed at the Davis farm were also observed at the Wimpy farm in 1997 and the Roberts farm in 1998.

Application of P at either preemergence, preflood, or postflood resulted in significantly higher yields than at PD at the Davis farm in 1997 (Fig. 2). A similar trend was observed at the Roberts farm in 1998. No significant differences in yields irrespective of application time were observed at the Wimpy farm in 1998 as expected since application of P did not influence yields (Fig. 1). In three of the five locations, the highest yielding treatment was when the P was applied postflood (Wimpy-97,Davis-97, Davis-98).

Although the PD application generally resulted in lower grain yields than earlier application times, it was significantly greater than the control in two locations (Davis-97, Davis-98). This indicates that a salvage application made after P deficiency occurs may be made and still obtain some benefit during the current growing season. In contrast, it did not appear to provide much improvement over the control at the Wimpy farm in 1997 or the Roberts farm in 1998. Thus, it is best to apply the P earlier to obtain maximum benefits to the rice.

Soil Test Correlation Studies

To evaluate the effectiveness of the Mehlich III soil test for available P as a predictor of rice yield response, the relative yields from 33 studies were plotted against the soil test P level corresponding to each study (Fig. 3). When regression analysis was performed, an r^2 of 0.0039 was obtained with a significance probability of 0.7351. This indicates that there was no relationship between soil test P levels and rice grain yields. Thus, the Mehlich III soil test procedure for P was not an adequate measure of P availability to rice.

When the relative yields from these 33 studies were plotted against soil pH, an r^2 of 0.22 was obtained with a significant probability of 0.0069 (Fig. 4). This indicates a highly significant relationship between relative yields and soil pH. Thus, pH was a better predictor of P fertilizer response by rice than were the soil test P levels. Multiple regression of both soil pH and soil test P levels increase the ability to predict fertilizer response slightly (r^2=0.23, p=0.0065) (data not shown).

While these results seem to discount the importance of soil analysis due to the lack of effectiveness of the Mehlich III soil test, in fact, the opposite is true. The Mehlich III is a very effective soil test procedure for potassium fertilizer needs for rice. It is also very effective for upland crops. However, because of the flooded conditions, the availability of P is dynamic in the rice soil environment. Soil sampling is therefore more important to evaluate, not only soil test P levels, but also soil pH levels. This research is intended to highlight the need for a rapid soil test procedure that can adequately assess P availability to rice, even as the availability of P to rice changes with the establishment of the permanent flood.

SIGNIFICANCE OF FINDINGS

Rice produced on alkaline soils continue to show response to P fertilizer. As the result of the research in this study, the P fertilizer recommendations for rice have been modified, effective for the 1999 growing season (Table 2). The recommended P fertilizer rates have incorporated both Mehlich III soil test P and soil pH. This should allow a better estimation of the soils that are most responsive to P fertilizer by rice. An addition to Table 2 includes those soils that have recently been precision leveled. These soil continue to respond to P fertilizer, usually independent of soil pH. Also, the timing studies have shown that P fertilizer may be applied at any time prior to mid-tillering and still receive optimum grain yields.

ACKNOWLEDGMENTS

We would like to express our appreciation to the Arkansas Rice Research and Promotion Board, the Arkansas Soybean Promotion Board, the Phosphate and Potash Institute, and the Arkansas Fertilizer Tonnage Fees for providing funding to support this research. Also, gratitude is extended to Ms. Donna Frizzell and Mrs. Nancy Wolf for their assistance with sample preparation and analysis.

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Table 1. Selected soil characteristics from sites used for phosphorus timing studies in 1997 and 1998.

Location				Soil test P
Farm	County	Year	Soil pH	(Mehlich III)
				(lb/acre)
Brooks	Poinsett	1997	6.6	28
Davis	Arkansas	1997	7.6	20
Wimpy	Poinsett	1997	8.0	56
Davis	Arkansas	1998	6.8	34
Roberts	Poinsett	1998	7.5	20
Wimpy	Poinsett	1998	7.7	40

Table 2. University of Arkansas P fertilizer recommendations for rice effective in 1999.

	Mehlich III soil test P level		
Soil pH	< 30 lbs P/acre	30 - 50 lbs P/acre	>50 lbs P/acre
<6.5	0-20-0	0-0-0	0-0-0
>6.5	0-60-0	0-40-0	0-0-0

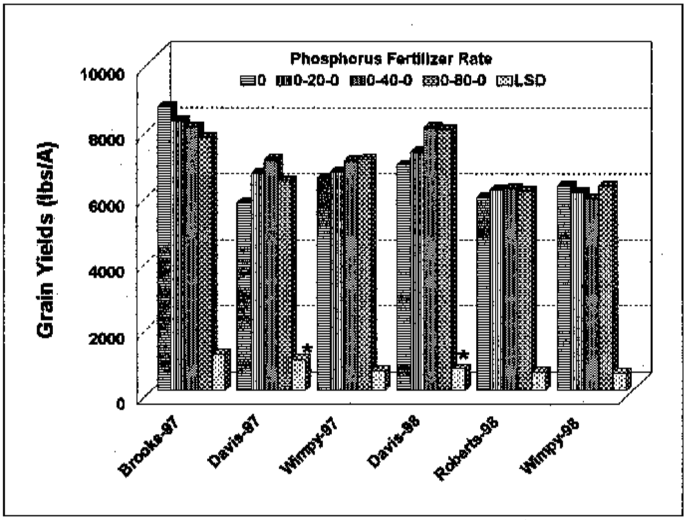

Fig. 1. Influence of phosphorus fertilizer rate on rice grain yields at six study locations during 1997 and 1998.
(* indicates means for this location significantly different at $\alpha = 0.05$)

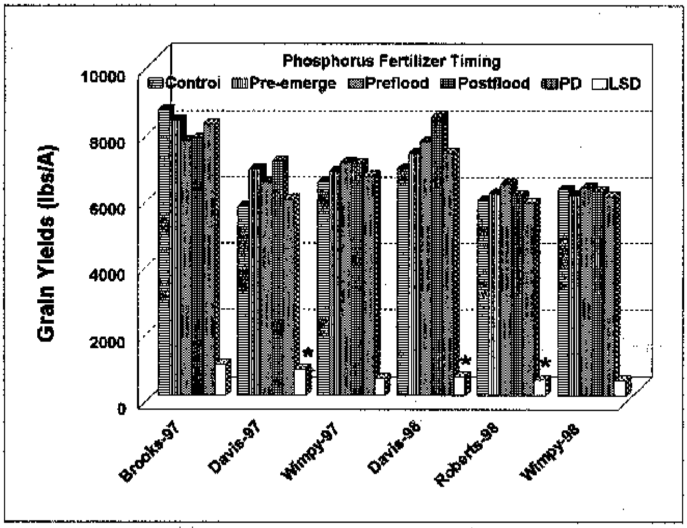

Fig. 2. Influence of phosphorus fertilizer application timing on rice grain yields at six study locations during 1997 and 1998.
(*indicates means for this location significantly different at $\alpha = 0.05$).

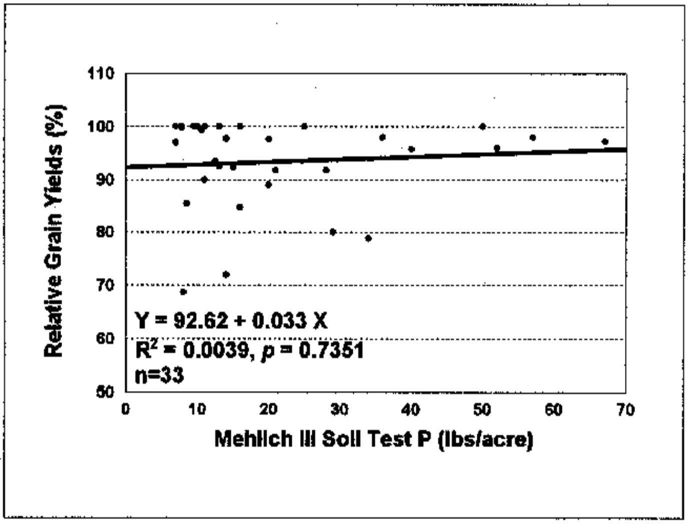

Fig. 3. Relationship between relative grain yields from 33 studies and their respective Mehlich III soil test P level.

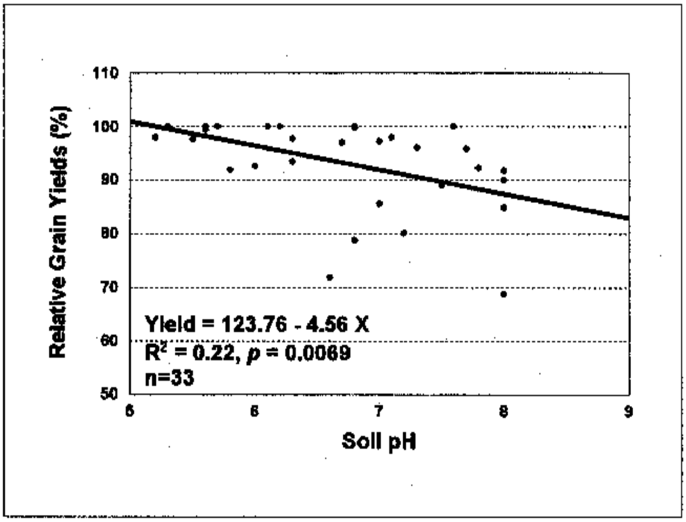

Fig. 4. Relationship between relative grain yields from 33 studies and their respective soil pH levels.

CHARACTERIZATION OF INDIVIDUAL RICE KERNEL MOISTURE CONTENT AND SIZE DISTRIBUTIONS AT HARVEST

R. C. Bautista, T. J. Siebenmorgen, and P. A. Counce

ABSTRACT

Moisture content (MC) and size distributions of individual kernels of rice in a panicle were measured from three rice cultivars ('Bengal', 'Cypress', and 'Drew') harvested at two locations (University of Arkansas Rice Research and Extension Center, Stuttgart and the Northeast Research and Extension Center, Keiser) during the fall of 1998. The objective was to characterize the MC and size distributions of individual kernels of rice in a panicle as a source of fundamental information for optimizing post harvest processes, specifically drying and milling. Moisture content distributions were found skewed to high MCs and were multi-modal. The standard deviation of kernel MC's in a panicle generally decreased with decreasing harvest MC. Individual kernel size distributions for rough and brown rice were also multi-modal. The average kernel size (length, width, and thickness) distributions were also skewed. The results of this study will provide useful information in improving the efficiency of dryers as well as in maintaining the inherent quality of rice during drying.

INTRODUCTION

Large variation in kernel MCs can exist among kernels on a plant and among plants in a field (Chau and Kunze, 1982; Desikachar *et al*., 1973). Chau and Kunze (1982) found that average MC differences ranged from 21 to 29% wet basis (w.b.) for groups of grains harvested from the top of 10 of the most mature panicles and from the bottom of 10 of the least mature panicles on a given day during the normal harvest season. They concluded that the longer rice is left in the field, the greater the probability that the lower MC rice will fissure before these kernels are harvested. Kocher *et al.*(1990) measured the individual MC of kernels in a panicle and found that kernel MC variance decreased as the average MC decreased. Desikachar *et al.* (1973) recommended harvesting rice (two Indian cultivars) at an average MC of 25%. This was based on their conclusion that rice at the top 1/4 of the panicle would be at a lower MC and would have head rice yield slightly lower than maximum. Rice on the remaining part of the panicle would be at slightly higher MC and would have maximum head rice yield. This work indicates that MC variation of the rice kernels in the field has an impact on the optimum average MC at which to harvest if the effect of re-wetting due to mixing of high and low moisture kernels is considered.

Kernel thickness has been found to affect kernel MC distributions and kernel mechanical strength. Wratten *et al.* (1969) showed that the average thickness of rough rice kernels decreased with a decrease in equilibrated MC. Wadsworth *et al.* (1982) in their studies on medium-grain rice ('Nato') and long-grain rice ('Lebonnet' and 'Labelle'), reported that the average MC of thin kernel fractions were significantly greater than those of the corresponding thick kernel fractions. The difference in MC between the thick and thin fractions ranged from 0.6 to 3.5%. For freshly harvested samples, the thinner kernels had a higher average MC than the thicker ones. They suggested that kernel thickness could be an effective basis for separating rice kernels so that the MC variation within the separate portions would be greatly reduced. This could possibly improve rice drying by minimizing fissure formation in kernels.

Matthews *et al.* (1981) found that the thickest and thinnest kernels had a significantly higher percentage of cracked and broken kernels than did the kernels of intermediate thickness. The thinner kernels were probably less mature and broke as a result of low kernel strength. The thicker kernels probably had the lowest MC and were susceptible to breakage from re-wetting of kernels at MCs below the safe re-wetting threshold.

Individual kernel MC and size distribution studies of different rice cultivars are needed to generate fundamental information useful in optimizing drying operation and maintaining the inherent quality of milled rice by understanding which kernels fissure and break during the drying process.

PROCEDURES

Panicles of Bengal, Cypress, and Drew were collected from foundation seed fields at the University of Arkansas Research and Extension Centers at Keiser and Stuttgart, at different harvest MCs that ranged from 12 to 26% w.b. during the fall of 1998. Sample collections were done by hand at approximately every two percentage points of drop in MC. For each harvest, 21 panicles were picked. Immediately after harvest, the panicles were stripped by hand, and samples cleaned to remove empty kernels and chaff. The individual kernel MC distributions were measured using a Shizuoka Seiki CTR800A individual kernel moisture meter. Each treatment representing harvest date and cultivar consisted of three replications with each replication consisting of 300 kernels. Each replication took only about five minutes to complete; thus minimal kernel to kernel contact and resultant moisture exchange took place during measurement.

For size measurement, sets of rough and brown rice samples were prepared for each harvest lot. Brown rice samples were prepared by manually removing the hulls of rough rice with a tweezer. Three replications, consisting of 100 kernels in a replication, were made for each treatment. Individual kernel size distributions were measured using a Satake Image Analysis System which measures the length, width, and thickness of the individual kernels.

Samples in bulk (harvested using a plot combine) were also obtained at three different approximate MCs (22, 20, and 18%). Individual kernel MC and size distributions of samples from the bulk were determined in the same way as samples of individual kernels in a panicle were measured.

RESULTS

Moisture Content Distribution

The mean MCs for the individual panicles on each harvest date were different (Table 1). The standard deviation of kernel MCs in a panicle generally decreased with decreasing harvest MC. This is an indication that as the panicle decreases in MC, an increasing number of the thin, high MC kernels mature and decrease in MC to a more similar, overall average MC for the kernels.

Figure 1 shows the individual kernel MC distributions of Cypress rice harvested at Stuttgart at average MCs of 22.7, 20.5, 18.9, and 14.2% w. b. The individual MC distributions were found to be multi-modal. Similar observations were found for Bengal and Drew. This observation was explained by Holloway *et al.* (1995) and was due to individual kernel MC plateaus observed during kernel development. Thus a greater number of kernels, at a given time, would exist at the plateau MCs than at other MC levels. Another observation from Fig. 1 was that the average MC distributions were skewed, with a greater number of kernels at MCs lower than the mean.

Size Distributions

Individual kernel size distributions for rough and brown rice (Fig. 2) samples of Cypress harvested at 20.4% MC are shown. Rough rice kernels had multi-modal distributions in length, width, and thickness. Higher variability was found in the length distributions of rough rice than of brown rice samples. Brown rice kernel size distributions were less varied than rough rice size distributions, except for the kernel thickness. The average kernel size (length, width, and thickness) distributions were slightly skewed to lower dimensions and thus, there was a greater number of kernels with dimensions higher than the mean.

SIGNIFICANCE OF FINDINGS

Individual kernel moisture content and size distributions of rice kernels at harvest and during drying presents a significant impact in rice processing particularly in increasing drying efficiency and maintaining or improving the quality of milled rice. This study can provide fundamental information that will be useful in implementing a mathematical model currently available that is capable of predicting stresses and fissure formation in rice kernels during the drying process. By knowing which kernels are expected to fissure, drier operation can ultimately be optimized.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the U of A Rice Processing Program Industry Alliance Group, and the Institute of Food Science and Engineering for the financial support of this project. We gratefully acknowledge the help of Mr. Jerry Fendley, Mr. Dale Cox, and Mr. P. A. Shockley during the field phase of this work.

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Table 1. Mean[z] moisture content distributions of three rice cultivars (Bengal, Cypress, and Drew) at different harvesting dates (Stuttgart, 1998). Values in parentheses are the mean of standard deviations of the MC distributions making up the mean.

Harvest Date	Bengal	Cypress	Drew
26 August 1998	26.3 (4.9)	22.7 (3.7)	
31 August 1998	24.2 (4.9)	20.5 (4.7)	22.6 (4.1)
4 September 1998		19.2 (4.3)	
8 September 1998	22.7 (3.9)		20 (5)
9 September 1998	20.7 (4.2)	15.9 (2.8)	
10 September 1998	19.4 (4.6)		18.5 (4.6)
18 September 1998	18.2 (3.4)		
20 September 1998	16.9 (3.6)	15.1 (1.8)	14.8 (2.1)
24 September 1998	14.7 (3.2)	12.5 (0.9)	
14 October 1998			12.8 (0.6)

[z] The mean is from 900 individual kernel measurements.

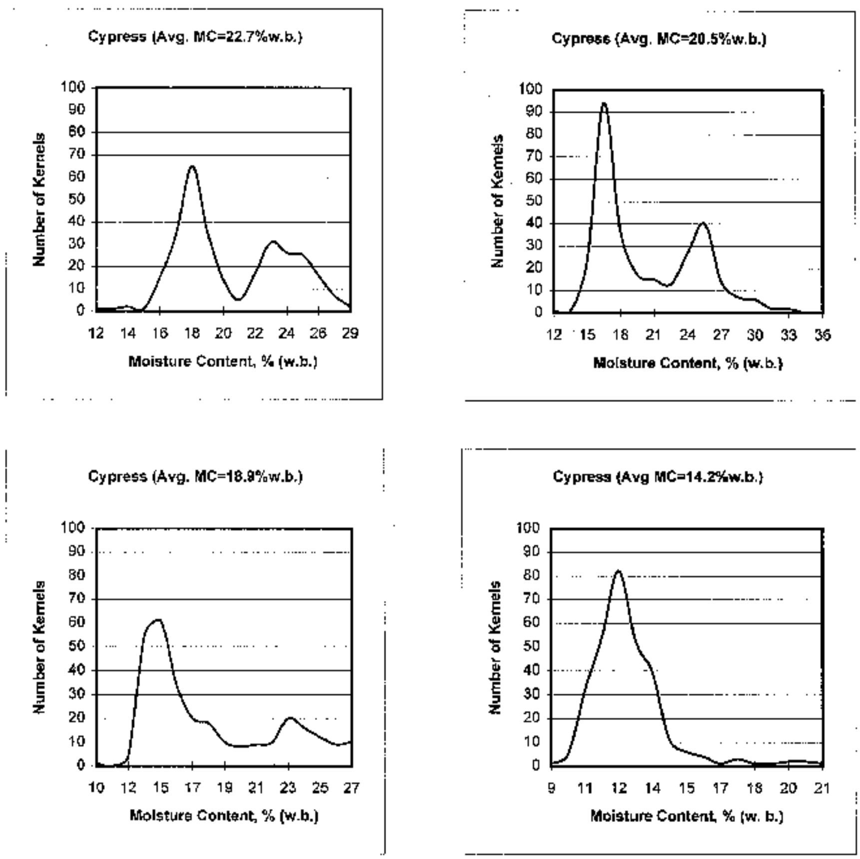

Fig. 1. Individual rough rice kernel moisture content distributions in a panicle of rice (Cypress) at four harvest moisture contents (Stuttgart, 1998).

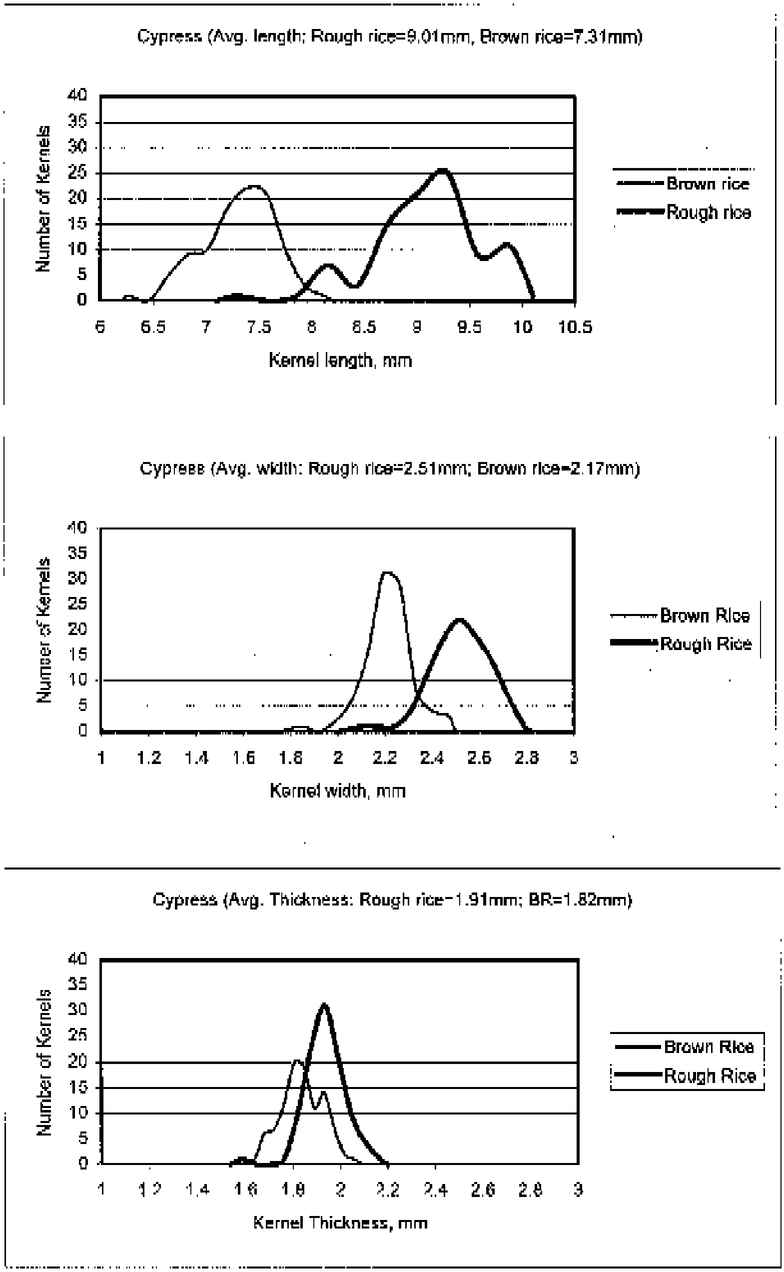

Fig. 2. Size (length, width, and thickness) distributions of individual kernels of rough and brown rice (Cypress) at an average harvest MC of 20.4% w.b. (Stuttgart, 1998).

NONDESTRUCTIVE QUANTIFICATION OF INTERNAL DAMAGE IN ROUGH RICE CAUSED BY AN INSECT AND FUNGI

A.J. Cardarelli, Y. Tao, J.L. Bernhardt, and F.N. Lee

ABSTRACT

A machine vision system was developed to inspect and estimate the internal damage of rough rice. A modified dark field illumination technique was used to direct light through the rice kernels without saturating the CCD camera. Under modified dark field illumination, the good portions of the rice kernels appeared translucent, while the damaged portions as well as some portions of the hull and the germ of the kernel appeared opaque. A combination of thresholding and morphological operators were used to segment the dark areas and to approximate the actual damaged area. The rice was visually separated into categories of undamaged, spot damaged, and damaged by trained entomologists and plant pathologists. The machine vision system was 91.5% successful overall for correctly categorizing a test sample of rice kernels.

INTRODUCTION

The Arkansas Rice Breeding and Varietal Development Program currently screens rice lines for susceptibility to discoloration around the seventh year after the initial cross. The current screening methods are performed on de-hulled rice, which is no longer viable for planting. This method of evaluating rice for discoloration uses a box with an incandescent light in it and a glass window in the top, where a single layer of kernels are placed in a petri dish for inspection (Swanson and Newsom, 1962). The endosperm and hulls of normal kernels appear translucent, while the damaged portions appear opaque. The damaged kernels are then separated and inspected to determine the cause of the damage. This screening technique is slow, laborious, and subjective, thus a modern machine vision system is needed to aid in the critical screening process. By using machine vision, researchers could not only automatically separate good kernels from bad kernels, but they could also simultaneously obtain accurate kernel dimensions and objective measurements of the amount of damage.

Machine vision techniques have been applied throughout the agricultural and food processing industry to inspect and sort food materials. Machine vision provides a reliable and objective means for evaluating products based on visual features. Machine vision systems have been applied to rice to measure the degree of milling (DOM) (Fant *et al.*, 1994; Liu *et al.*, 1998), but not to classify damaged rough rice kernels.

A new non-destructive machine vision system was developed to sort out damaged from undamaged grains of rough rice. The new method would enable rice breeders to non-destructively evaluate rice lines for insect and disease resistance or susceptibility. The separated bad grains could then be hulled to determine the types of damage to which the rice line/cultivar was susceptible. An automated version would allow rice breeders to drastically reduce the amount of labor involved in screening rice lines and thereby allow the breeders to non-destructively evaluate the rice lines earlier in the breeding process, thereby shortening the amount of time required to release new rice lines as cultivars or breeding stocks.

PROCEDURES

An imaging system was developed to identify internal damages of rough rice grain. The system consisted of a computer with a Matrox Meteor/RGB PCI frame grabber, which was connected to a Sony XC711 CCD RGB camera. The camera was connected via C-mount to a Tokina 1:1.8 / 12.5-75mm TV lens with a 10mm extension tube. The camera was mounted inside of a light, excluding imaging chamber, at a fixed focal distance of 5.0 cm above the surface of a 45.7cm circular tempered glass turntable. Four viewing windows were created by covering the glass turn table with black paper and cutting four equidistant 1.9 cm square holes near the edges. A fiber optic ring light with a diameter of 8.25 cm (Cuda Products Corp. model CR360-8) was placed approximately 4.6 cm beneath the imaging surface of the glass turn table and centered directly under the camera. The distance between the fiber optic ring light and the glass table was related to the "focal" point of the ring light. The fiber optic ring light was connected to 250 W fiber optic light source (Cuda Products Corp. model I-250). A picture of the illumination system is shown in Fig. 1.

The illumination system directed the light through a viewing window at an angle, thus the ring light itself was invisible and the viewing window appeared dark. This had an advantage over direct back lighting, which often saturates CCD cameras. In order to remove background noise such as dust or scratches on the surface of the glass, a diffuse plastic film was used to cover the square viewing windows, thereby changing the background from black to solid white. Figure 2 shows typical images of different damaged areas on or in the kernel itself, obtained with the experimental setup.

SAMPLES AND EXPERIMENTAL PROCEDURE

The rice used for this study consisted of three samples of hand sorted medium-grain rice (cultivar 'Bengal') representing a range of damage: undamaged, spot, and damaged kernels. The images of 50 kernels from each of the three samples were collected using the imaging system described in the previous subsection. These images were used as exemplars for each category to calibrate the system. The ring light intensity was adjusted to provide the highest contrast between the undamaged and damaged portions of the kernels. To ensure repeatability in the measurements, a photocell was used to monitor the light intensity. The photocell was placed directly on top of the glass surface above the ring light and connected to a regulated 12 V power supply and a digital current meter. A constant current reading was maintained throughout the experiment.

In order to test the effectiveness of the imaging system, a mix of the three samples of kernels were used as a test set. The test set consisted of 34 undamaged kernels, 20 spot damaged kernels, and 28 damaged kernels. The images from this set were collected in the same manner as the training set and were classified using threshold values acquired from the training set.

The data extraction method used morphological processes, performed by Matrox Inspector® Windows-based imaging software, to extract the true damaged area from the segmented dark portions. The red layer of the original RGB image (Fig. 3a) was thresholded at 150, less than 150 was set to 0 and above 150 was set to 255, and converted to a binary image (Fig. 3b). This binary image represented the segmented dark areas of the kernel.

In order to separate the actual damaged areas from the dark portions of the rice hull, such as the overlap of the two halves of the hull (the lemma and palea), morphological operators were used to eliminate the inessential pixels. Since the image consisted of a black area on a white background, a closing operation was performed on the dark objects to close all the holes or small separations in the binary image (Fig. 3c). To compensate for the additional information, an opening operation was performed on the image (Fig. 3d). Assuming that all damaged areas were shaped like rounded blobs and not thin pointed slivers, five consecutive erosion operations were performed to eliminate any thin or non-significant dark areas (Fig. 3e). Any non-significant damaged portions were eroded to extinction, while any damaged segments that remained indicated the presence of a significant amount of damage in the kernel. Any remaining significant damaged areas where then dilated five times to approximate the original true damaged area and shape (Fig. 3f).

The approximated percent damage (APD) was calculated by dividing the approximated damaged area by the whole kernel area. The APD was then used to categorize the rice samples by selecting the optimum threshold levels between the three categories. The images from the independent test set were then analyzed using these preselected threshold values and the success rates were calculated.

RESULTS AND DISCUSSION

The distribution of the APD values for the training set is displayed in Fig. 4. As expected, the undamaged category was much more consistent in range of APD values than either the spot or damaged categories.

The maximum number of correctly classified kernels in the training set was achieved with threshold values set at 5.6% and 42.5% APD. Table 1 shows the results of the APD method of classification. The classification success for the training set for the undamaged, spot, and damaged categories were 100%, 92.0%, and 98.0% respectively. For the test set, the separation success was 97.0%, 95.0%, and 82.1% for the undamaged, spot, and damaged categories respectively, and 91.5% successful overall.

Although the physical structure of rough rice made internal inspection possible, it was also the major obstacle toward the goal of 100% correct categorization and quantification of damage in the kernels. The actual cause of error in this experiment was primarily attributed to the natural variations in rice. The rice hulls varied greatly in shades from dark to light colored kernels. The relative shade of the kernel mainly affected how much area was included in the binary image.

SIGNIFICANCE OF FINDINGS

A machine vision system can be used to objectively quantify the amount of internal damage in rice grains. To complete this system for rice breeders, the final classification algorithm will be improved to automatically measure the dimensions of each kernel as well as automatically compensate for variations in intensity so that a more precise approximation of the damaged area can be made. The system will also require an automated material handling system to singulate and present the kernels to the imaging system for categorization. After the imaging system categorizes the kernels, the material handling system will then separate the kernels into their respective categories.

Overall, the machine vision system developed was successful in separating good kernels from bad kernels, which met the primary objective of the project. This system combined with an automated material handling system could be used to save a great deal of tedious manual labor in rice line evaluation. This system could save time and money by allowing rice breeders to non-destructively evaluate potential new rice cultivars earlier in the breeding program.

ACKNOWLEDGMENTS

We gratefully acknowledge the Arkansas Rice Research & Promotion Board for their financial support of this project.

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Table 1. Results of kernel classification

			Predicted (T1 = 5.0% and T2 = 43.0%)			
		Total	Good	Spot	Bad	Accuracy (%)
	Good	50 (34)	48 (33)	2 (1)	0 (0)	96.0 (97.0)
Actual	Spot	50 (20)	2 (1)	46 (19)	2 (5)	92.0 (95.0)
	Bad	50 (28)	0 (0)	2 (0)	48 (23)	96.0 (82.1)
				Total Accuracy		94.7 (91.5)

* Values in each column represent training of the model. Values in parenthesis represent testing of the model.

Fig. 1. Imaging setup for identification of internal damage in rice kernels. The system is contained in an imaging chamber.

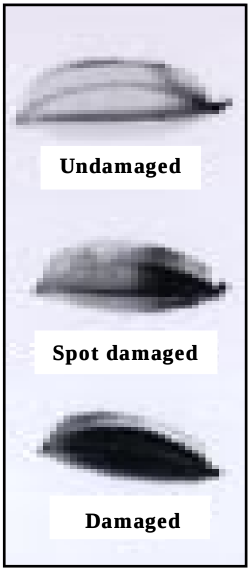

Fig. 2. Categories of rice kernel images taken with imaging system.

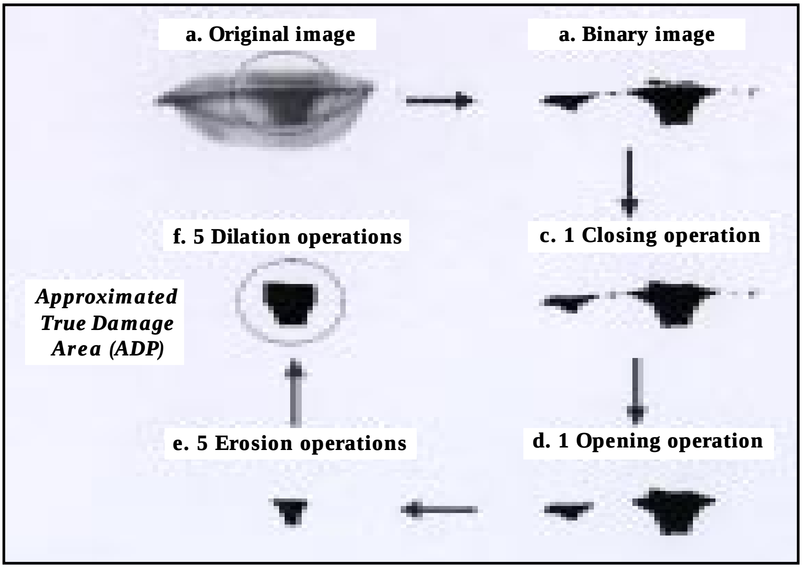

Fig. 3. Algorithm for approximating the true amount of damage in rice kernels. Designed to eliminate dark portions caused by rice hull and germ end. This area divided by the total area is the kernel APD value.

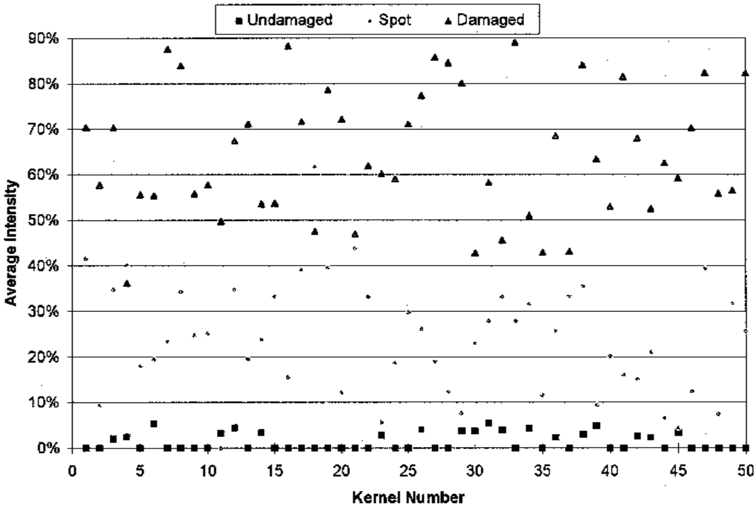

Fig. 4. The distribution of the training set using APD algorithm.

CHARACTERIZATION OF FISSURE OCCURRENCE AND KERNEL SIZE AND MOISTURE CONTENT DISTRIBUTIONS OF MILLED RICE

A.G. Cnossen, T.J. Siebenmorgen, and J.D. Reid

ABSTRACT

'Bengal' and 'Cypress' rice from the 1998 harvest season harvested over a range of moisture contents (MCs), was dried under various conditions and tempered for different durations. The different treatments resulted in varying head rice yield (HRY) levels. Size distributions (length, width, thickness, and circumference) of milled rice samples were measured from the different HRY levels using a Satake image analyzer. Individual kernel MC distributions of the 1998 milled rice samples were measured using a Shizuoka-Seiki CTR-800 individual kernel moisture meter. The number of fissured kernels in 100-kernel samples was counted for four size fractions to relate fissure occurrence to kernel size. Statistical analyses are currently being conducted. Preliminary results indicate that the shorter and thicker kernels are the most prone to fissure formation and subsequent breakage during milling.

INTRODUCTION

Rice breakage during processing is one of the major concerns of the U.S. rice industry. Considerable research has investigated the causes of rice fissuring (Mossman, 1986). A complete understanding of rice fissuring, however, not only involves determining the causes of fissuring; it also requires characterization of (changes in) the physical properties of the kernel itself during subsequent processing, such as milling. Within a rice sample, kernel size and MC distribution can vary widely (Bautista *et al.*, 1999). Matthews *et al.* (1981) concluded that kernel thickness distribution should be taken into account for a complete understanding of rice fissuring.

Rice Thickness

Several researchers found relationships between rough rice kernel thickness fraction and fissuring, breakage, and HRY. Both Wadsworth *et al.* (1982a) and Matthews *et al.* (1981) found higher percentages of fissured and broken kernels in rough rice for the thinnest and thickest fractions. HRY increased with increasing kernel thickness, but leveled off for the thickest fractions. Sun and Siebenmorgen (1993) found similar trends of increasing HRY with increasing rough rice kernel thickness, even after HRYs were corrected for degree of milling. Jindal and Siebenmorgen (1994) concluded that thicker (>1.98 mm and 1.98 - 1.93 mm) rough rice fractions produced dramatically higher

HRY than did thinner (< 1.78 mm) fractions, when samples were dried to 12.5% MC in a conditioning chamber. Wadsworth and Hayes (1991) found significant differences among rough rice thickness fractions for HRY, processing losses, and quantities of damaged kernels.

Fissuring can occur in the field or during harvest, or during drying and milling. Matthews and Spadaro (1976) reported that breakage in rough rice was related to that in milled rice. The ratio for breakage of unfractionated samples was about 1:2 between rough and milled rice. The thinnest fractions had the highest breakage in rough rice, and with a ratio of 1:3 between percent brokens in rough to milled rice, an even higher percent brokens in milled rice.

Moisture Content Distribution

Between thickness fractions, both MC and MC variability differs (Wadsworth and Matthews, 1985). Wadsworth *et al.* (1982b) found a greater variation in MC for the thinnest kernels. Sun and Siebenmorgen (1993) measured higher MCs for the thinnest and thickest fractions compared to the intermediate fractions. A higher MC and larger variability in MC for the thinnest and thickest fractions may result in a larger MC gradient during drying, which makes these kernels more susceptible to fissuring.

Individual rice kernels, when exposed to the same air conditions, dry to different equilibrium moisture contents (EMCs) and have different drying rate constants (Banaszek and Siebenmorgen, 1993). These differences in EMC and drying rate constant indicate that the physical properties of individual kernels can differ dramatically within a rice batch.

In most of the previously mentioned research, rough rice was separated by kernel thickness. Characterizing the kernel length, width, and circumference distributions for milled rice at varying HRY levels could help to more fully understand rice fissuring and breakage. The objectives of this study are to determine, from a kernel size and MC distribution perspective, which kernels break during drying, tempering, and milling of rice. Subsequently, fissure occurrence will be correlated to kernel size.

PROCEDURES

Drying Tests

Both Bengal (medium-grain) and Cypress (long-grain) rice, with harvest MCs ranging from 22 to 19%, were harvested during 1998 from the University of Arkansas Rice Research and Extension Center at Stuttgart, and the Northeast Research and Extension Center at Keiser. After each harvest the individual kernel MC distribution of the rice lot was measured with a Shizuoka-Seiki CTR-800 individual kernel moisture content meter. Brown rice size distributions (length, width, thickness, and circumference) of each lot were measured using a Satake image analyzer.

Each rice lot was dried under three different air conditions (60°C and 50% RH; 60°C and 16.9% RH; 40°C and 12% RH) for four durations, removing 1.5, 3, 4.5, and 6% MC. After drying, the rice samples were tempered for varying durations, ranging from zero to four hours in 40-minute increments. After equilibrating to 12.5% MC, the rice was milled for 30 seconds in a McGill no. 2 mill, and HRY was plotted against tempering duration for each drying run (drying air condition / duration combination). Figure 1 illustrates the experimental design.

Kernel Size and MC Distribution Measurement

The different drying treatments and tempering durations resulted in different HRY levels. Drying runs with the highest HRY differences across tempering durations were used for the image analysis and MC distribution work presented in this article. Within each drying run selected, the samples with the highest and lowest HRY were used.

Two sets of 300 whole kernels were selected from each milled rice sample. Size distributions were then measured using the Satake image analyzer. Subsequently, the MC distribution of each 300-kernel sample was measured using the individual kernel MC meter.

Fissure Counts

Correlating fissure occurrence after drying to thickness fraction can help determine which kernels break during milling. For each lot (harvest location / cultivar / harvest MC combination), the distribution of the circumference of a 1000-kernel sample was measured with the Satake image analyzer. The samples used for fissure counting were than split into four size fractions, setting the quartiles of the distribution of the circumference as the limits for the size fractions. For each size fraction, the number of fissured kernels was counted for a 100-kernel sample. Due to lack of space, this part of this project will be further discussed in future publications.

RESULTS AND DISCUSSION

Data are currently being collected and statistical analyses are being conducted. Length, width, thickness, and circumference distributions of 600-kernel samples were plotted and compared between HRY levels. Table 1 gives preliminary distribution means and standard deviations for cultivar Cypress samples having varying HRYs. The data show a significant ($\alpha = 0.05$) increase in kernel length and a decrease in thickness for decreasing HRY, indicating that the short and thick kernels are the first kernels that break. The 3% sample, however, had a significantly lower average length than the 1.5, 4.5, and 6% samples. More data are needed to investigate if this trend is due to experimental error or if it is a significant change in distribution.

SIGNIFICANCE OF FINDINGS

Rice breakage during drying and subsequent milling is one of the major concerns of the U.S. rice industry. A complete understanding of rice fissuring, and subsequent breakage, not only involves determining the causes of fissuring, but also the characterization of the physical properties, such as size and MC distributions, of the kernel itself. Characterization of distribution changes of these properties as HRY decreases during drying and milling, could help more fully understand which kernels break during drying and milling. This will reduce quality losses, and will ultimately allow for optimizing drier operation and design.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the U of A Rice Processing Program Industry Alliance Group, and the Institute of Food Science and Engineering for the financial support of this project.

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Table 1. Size distributions for several HRY levels. Numbers are based on the distribution of 600 kernels of cultivar Cypress rice with 20.5% harvest MC dried with 60°C, 16.9% RH air.

Moisture content removed[z]	Head rice yield	Length		Width		Thickness	
		Mean	SD[y]	Mean	SD[x]	Mean	SD[w]
(%)							
0	65.2	6.50	0.33	1.978	0.105	1.641	0.086
1.5	62.3	6.55[v]	0.37	1.980	00.101	1.630[v]	0.087
3.0	60.1	6.49[v]	0.39	1.975	0.113	1.633	0.086
4.5	55.1	6.54[v]	0.38	1.980	0.105	1.637	0.081
6	52.1	6.55	0.32	1.980	0.105	1.625	0.084

[z]Percentage points of moisture content removal.
[y]Standard deviations are significantly different (P < 0001).
[x]Standard deviations are significantly different (P = 0.05).
[w]Standard deviations are equal (P = 0.52).
[v]Mean significantly different than the mean of the previous head rice yield level.

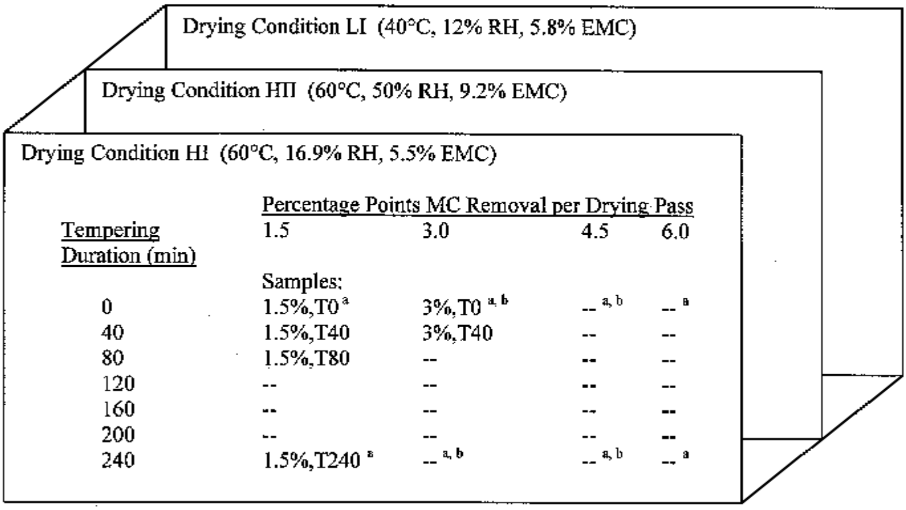

Fig. 1. Design for drying experiments conducted in 1998. Layout represents sampling routine for each harvest location/cultivar/harvest moisture content lot.

[a] Samples within a drying run used for size and MC distribution measurements.
[b] Samples used for fissure counts.

INCORPORATING THE GLASS TRANSITION TEMPERATURE IN RICE DRYING AND TEMPERING TO OPTIMIZE MILLING QUALITY

A.G. Cnossen, T.J. Siebenmorgen, and J.D. Reid

ABSTRACT

Drying and tempering tests were conducted during the 1998 harvest season on 'Bengal' and 'Cypress' rice from two locations in Arkansas, harvested over a range of moisture contents (MCs) (22 to 18%). The rice was dried with three different air conditions, two with drying air above 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) that relates milling quality reduction to T_g. Samples were dried under each condition for durations resulting in 1.5, 3, 4.5, and 6% MC loss. After drying, the samples were tempered for varying time periods ranging from zero to four hours at the same temperature as the dryer. Subsequently, samples were gently dried to 12.5% MC, and milled for head rice yield (HRY) determination. Results indicate that tempering duration after a drying pass has a significant influence on HRY.

INTRODUCTION

Commercial rice dryers use multi-pass procedures to remove moisture from the grain. Between drying passes the rice is held in bins for a certain period of time; this holding process is referred to as tempering. 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 large, causes the kernel to fissure. Moisture migration also improves the energy use of subsequent drying passes. In commercial rice drying, tempering times vary widely. Tempering times between 6 and 24 hours are used in the United States (Mossman, 1986; Steffe and Singh, 1980). By determining the minimum tempering time required to reduce kernel moisture gradients, the drying process can be optimized.

Tempering Research

Numerous researchers have studied the tempering process in rice drying. The emphasis in most of the studies was on the effect of tempering duration on drying performance (i.e., drying rate, energy use). Few researchers, however, have studied the effect of tempering on kernel quality reduction.

A theoretical model based on initial MC and drying parameters, to predict tempering time for rough rice was developed by Steffe and Singh (1980). According to the model, tempering, which was based on the relative humidity response of the interkernel air, was 95% complete in less than two hours and fully complete in less than five hours, when using a 35°C drying air temperature. This work was conducted using a short-grain variety of rice. Steffe *et al.* (1979) concluded that a 35-minute tempering duration was sufficient to equalize the moisture gradient in the rice kernel, when drying high MC medium-grain rice for 20 minutes using 38°C air. Three hours was sufficient when drying for 35 minutes using 38°C air, or drying for 20 minutes using 50°C air. Tempering did improve HRY, but HRYs were equal for any length of tempering considered. Chen (1997) found optimum tempering durations, for the major variety grown in Taiwan, of two to three hours for rice with an initial MC of 18 to 20 %, using 40°C and 50°C air.

High tempering temperatures have shown to be effective in maintaining high HRYs and decreasing tempering duration. Beeny and Chin (1970) dried rice with an initial MC of 24% using 54.4°C air. HRY increased with prolongation of tempering durations up to five hours. Cnossen *et al.* (1998) showed increasing HRYs for tempering durations up to 150 minutes. 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% higher for rice tempered warm (40.6°C) compared to rice tempered cold (23.8°C). Samples tempered at 40.6°C required four hours of tempering while samples tempered at 23.8°C required six. Steffe and Singh (1980) found similar trends of decreasing tempering duration with increasing temperature.

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 glass transition temperature (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 (Fig. 1).

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. Tempering is performed to reduce these temperature and MC gradients. If the tempering environment is one that produces a change of state, differential stresses within the kernel due to widely different material properties resulting from the MC and temperature gradients could result in kernel fissuring. This theory is explained in more detail by Perdon and Siebenmorgen (1999) and Cnossen *et al.* (1998).

Based on the material property considerations discussed and the hypothesized fissuring theory by Perdon and Siebenmorgen (1999), the following objectives were formulated for this study:

1. Minimizing overall drying time by determining the minimum tempering duration required between drying passes, while maintaining high HRYs.
2. Investigate the effects of glass transition on HRY reduction during tempering.

PROCEDURES

In 1998, both Bengal (medium-grain) and Cypress (long-grain) rice at two harvest MCs, high (21 to 22%) and low (18 to 19%), were harvested from the University of Arkansas Rice Research and Extension Center at Stuttgart, and the Northeast Research and Extension Center at Keiser. Immediately after harvest, the rice was shipped to the rice processing labs of the University of Arkansas and cleaned with a Carter-Day Dockage tester.

The experimental design was based on the material property considerations explained in the introduction of this paper. Figure 2 illustrates the experimental design for the drying and tempering experiments. The samples were dried at three different air conditions, two with drying air temperatures above (drying condition HI: 60°C, 16.9% relative humidity [RH], 5.5% equilibrium moisture content [EMC]; and drying condition HII: 60°C, 50% RH, 9.2% EMC) and one with drying air below (drying condition LI: 40°C, 12.9% RH, 5.8% EMC) the T_g temperature line (Fig. 1). Samples were dried for four different durations to create different magnitudes of moisture gradient, resulting in 1.5, 3, 4.5, and 6% MC loss. After these drying durations, the samples were tempered for varying durations ranging from zero to 4 four hours. Varying tempering durations created varying levels of MC equilibration in the kernels, i.e. a tempering duration of zero minutes resulted in maximum MC gradient while extended tempering resulted in minimizing gradients. After tempering, the samples were placed into an EMC 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 different levels of MC gradients due to the varying tempering durations. Our hypothesis would indicate that this state transition will create HRY reduction if there is a sufficient MC gradient inside the kernel.

The samples were held in storage for three months. Samples were subsequently milled for 30 seconds 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

Since kernels were cooled to below T_g immediately after tempering, the increasing tempering durations should provide information relating to the level of MC gradient allowable in kernels during the transition from the rubbery to the glassy state without fissuring.

Milling tests are currently being conducted. After milling, HRY will be plotted against tempering duration for each drying run (drying air condition / duration combination). Figure 3 shows a typical HRY vs. tempering duration curve, showing an increase in HRY with increasing tempering duration. Preliminary results indicate a higher HRY for any tempering duration compared to the sample (T0) that was cooled to below T_g immediately after drying. Statistical analyses will give insight as to the magnitude of HRY increase for the different treatments.

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 help further improve the drying process.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the U of A Rice Processing Program Industry Alliance Group, and the Institute of Food Science and Engineering for the financial support of this project.

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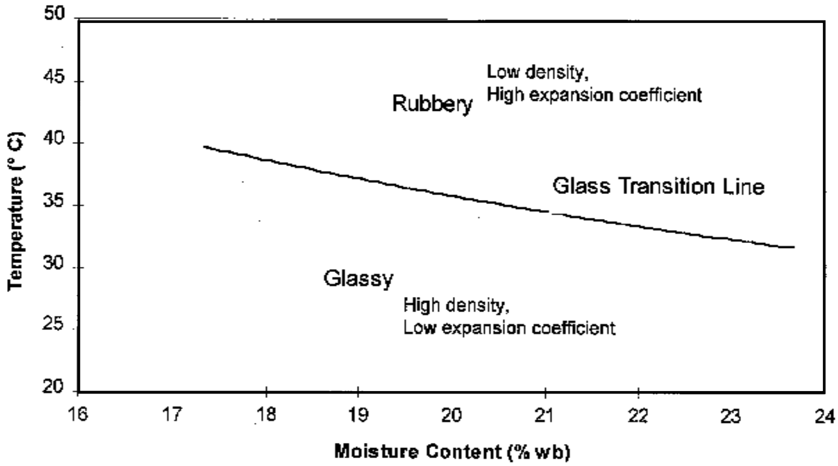

Fig. 1. Glass transition relationship and material properties for rice starch at a given temperature and moisture content, as measured by Perdon and Siebenmorgen (1999).

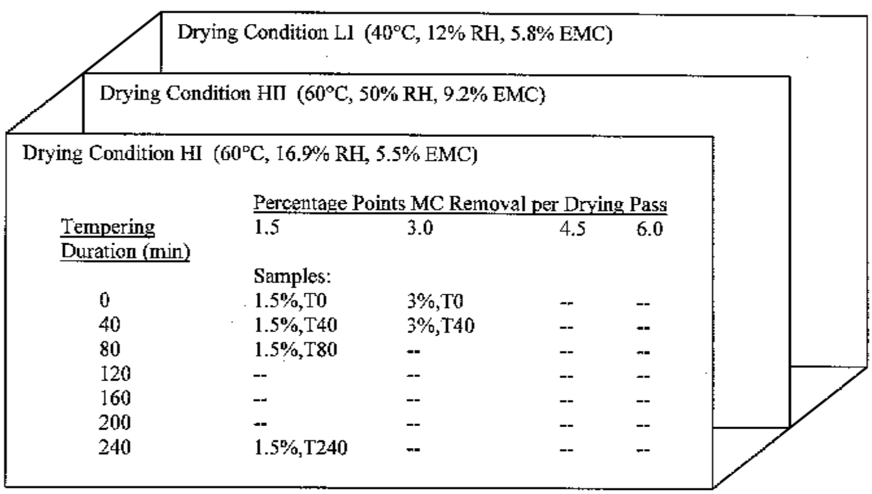

Fig. 2. Design for drying and tempering experiments conducted in 1998. Layout represents sampling routine for each harvest location/variety/harvest moisture content lot.

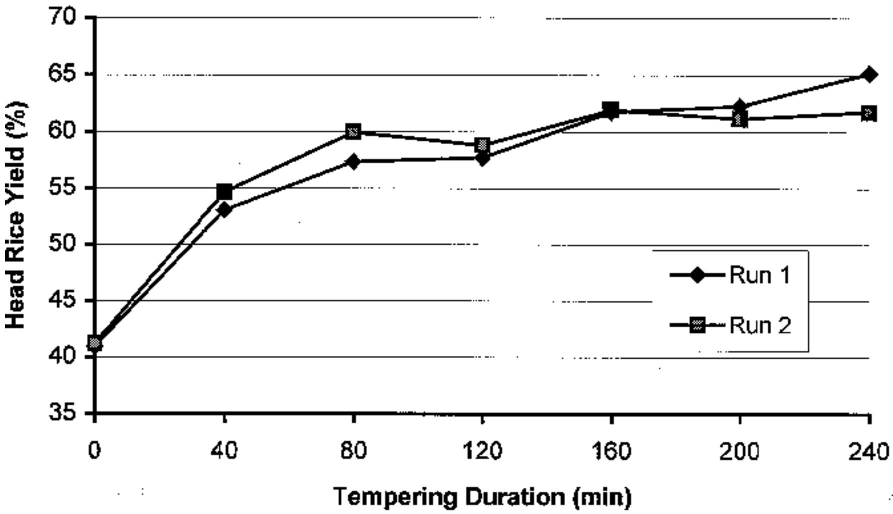

Fig. 3. Head rice yield (HRY) vs. tempering duration for cultivar Bengal rice dried from 19.5% to 15% MC at 60°C and 16.9% RH. The HRY of the control sample, which was gently dried to 12.5% MC in an equilibrium moisture content (EMC) chamber, was around 67%.

EFFECT OF MOISTURE CONTENT ON THE RESPIRATION RATE OF RICE

A.L. Dillahunty, T.J. Siebenmorgen, and R.W. Buescher

ABSTRACT

One cause of yellowing or "stackburn" of rice may be high rates of respiration caused by storage at high moisture content (MC). As the first phase of a project designed to study this problem, the effect of MC on the respiration rate of 'Bengal' and 'Cypress' rice harvested in the fall of 1998 from University of Arkansas Rice Research and Extension Center located at Stuttgart and the Northeast Research and Extension Center in Keiser, was tested. For respiration rate measurement, rice samples over a range of MCs from 12 to 23% wet basis (w.b.) were sealed in quart jars and equilibrated to 86°F. The respiration rate was quantified by measuring the carbon dioxide (CO_2) content of the head space. The respiration rate increased exponentially with MC with rapid increases appearing when the MC was above 15% w.b. A model will be developed from these data to predict the respiration rate of rice at a known MC.

INTRODUCTION

Post-harvest yellowing of rice or "stackburn" can be a significant problem to the rice industry. Delayed or improper drying can cause "heat burns or heat discoloration" yielding yellow rice kernels (Sahay and Gangopadhyay, 1985). Yellowing is a form of deterioration that affects quality, appearance, flavor, and yield (Phillips, *et al.*, 1988; Singaravadivel and Raj, 1983). Other problems include weakened kernels, resulting in breakage and economic loss (Misra and Vir, 1991).

There are many theories as to what causes yellowing. Some of these include the effects of fungi or mold, high respiration rates, and elevated water activity, temperature, and carbon dioxide content. It has also been proposed that several of these factors interactively produce yellowing (Bason, *et al.*, 1990). A multi-faceted project has been initiated to study the overall phenomena of rice yellowing, including respiration effects. This article reports the effect of MC on the respiration rate of rice.

PROCEDURES

Respiration rates of rough rice at different MCs were tested. In 1998, two cultivars, Cypress and Bengal, were harvested at approximately 23, 20, and 18% MC w.b. from

University of Arkansas Rice Research and Extension Center at Stuttgart and the Northeast Research and Extension Center at Keiser. Rice from each harvest MC was dried to approximately 12.5% MC w.b. in 3 to 4 % increments. Respiration rate was measured at the initial (harvest) MC, then at each MC increment as the rice dried. Three 300-g samples were tested from each MC for each cultivar from each harvest location. Head space sampling and CO_2 measurement was conducted by sealing rough rice samples in quart jars with a septum in the lid for taking head space samples. After sealing in the jar, and before any head space samples were taken, the rice was equilibrated to 86°F by incubating for 1.5 hours in an oven. Immediately after this equilibration period, 1-ml samples of head space gas were taken with a 1-ml disposable syringe, then injected into a Fisher-Hamilton gas partitioner with helium as the carrier gas. The rice was maintained in the 86°F oven for four hours for the high MC rice, six hours for the medium MC rice, and 24 hours for the low MC rice. After these durations, another headspace sample was taken and analyzed. The difference in the CO_2 content of the two head space samples was used to quantify the respiration rate.

RESULTS AND CONCLUSIONS

Statistical analyses were performed using JMP software (The SAS Institute). Since Bengal and Cypress from Stuttgart and Keiser showed similar trends, the data from both locations were pooled for each cultivar (Fig. 1). By fitting a curve to the data points, we can see that the respiration rate increased exponentially with MC. Respiration rates increased dramatically as MC increased over 15%. Rice with MC lower than 15% showed respiration rates approaching 0 mg CO_2 / kg-hr. Similar respiration curves were reported by Brooker *et al.* (1974). These data will now be used to develop equations that can be used to predict respiration rate for a given MC.

SIGNIFICANCE OF FINDINGS

These data provide information on the respiration rate of rough rice. Work is in progress to determine possible relationships between rice kernel yellowing and the respiration rate. By knowing the respiration rate, how it is affected by MC, and its relationship to yellowing, this problem may be easier to control.

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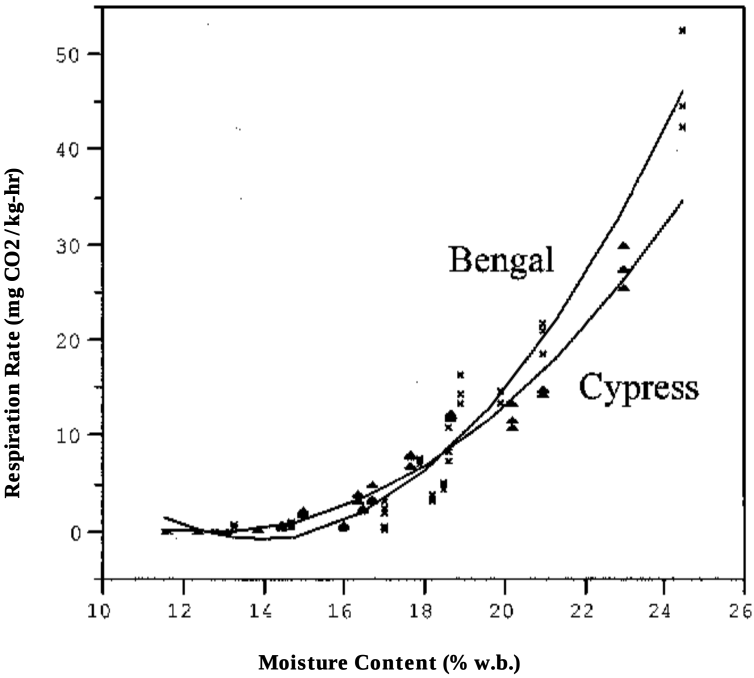

Fig. 1. Respiration rates of Bengal and Cypress rough rice at different moisture contents.

NEAR-INFRARED PREDICTION OF FUNCTIONAL CHARACTERISTICS OF MILLED RICE

T.B. Horner, B.P. Marks, and J.-F. Meullenet

ABSTRACT

Three cultivars of rice harvested in 1996 and 1997 were subjected to different drying and storage conditions. Subsamples were periodically removed, hulled, milled, scanned, and analyzed for functional characteristics (cooking and pasting properties). All samples were scanned for near-infrared (NIR) reflectance (400-2500nm), and multivariate calibrations were developed. For volume expansion, water absorption, peak viscosity, and final viscosity, the standard errors of prediction for the NIR calibrations were 0.20, 0.16, 61 Brabender Units (BU), and 83 BU, respectively, with R^2 ranging from 0.28 to 0.61 in the calibration models. The results indicate that it might be feasible to use NIR technology for rapid screening of functional properties influenced by postharvest handling. Further analysis is necessary to evaluate cultivar-specific calibrations.

INTRODUCTION

As rice continues to grow in popularity in value-added products, the need for information about postharvest effects on end-use functionality will also increase. Functional characteristics are important because they affect the performance of rice both as a consumer product and food ingredient. Because of the time and cost involved in laboratory testing for functional properties, there is a need in industry for rapid methods to test for these attributes. The development of rapid methods would also help to tailor postharvest management and marketing strategies to a particular end-user.

One method that could be used to assess functionality is near-infrared spectroscopy; however, little is currently known about the effectiveness of NIR in predicting rice attributes, especially as they are influenced by postharvest parameters. Delwiche *et al.* (1996) found NIR to be acceptably accurate ($R^2 > 0.89$) at predicting apparent amylose, protein, whiteness, transparency, and milling degree. Chen *et al.* (1997) successfully used NIR to predict residual surface lipids on milled rice ($R^2 = 0.99$).

Delwiche *et al.* (1996) also looked at using NIR to predict functional attributes, such as alkali spreading value and viscosity, with less success ($R^2 \leq 0.82$) than for other quality attributes. Their data consisted of samples taken from a wide range of breeding lines, with no variation in postharvest treatment. Because practical applications in the processing industry typically involve less genetic variability, but greater variability in postharvest treatments, there is a need to test NIR for predicting functional attributes that are influenced by postharvest handling. Industry sources have also mentioned the potential value of cultivar-specific calibrations instead of a “one size fits all” approach that is often used in this type of work.

As a result, the specific objectives of this on-going study are:

1. To evaluate the feasibility of using NIR to predict the functional properties of milled white rice, including cooking and amylographic properties, as affected by drying conditions and rough rice storage history.
2. To generate and validate NIR calibrations to predict these properties over a wide range of drying and storage treatments.

PROCEDURES

Rice Samples

Rice was harvested at the University of Arkansas Rice Research and Extension Center at Stuttgart (1996 and 1997) or at the Meins’ farm, Stuttgart (1997). The rice was either dried on-farm or transported to the U of A Rice Processing Laboratory and dried in laboratory drying facilities. After drying, the rice was slowly equilibrated to a target storage moisture content (MC) of 10, 12, or 14% wet basis. Rice at each MC was then divided into three lots and placed into sealed plastic buckets, which were stored in temperature-controlled chambers at 4, 21, or 38°C. Subsamples were removed at specified intervals (up to 52 weeks) and subjected to the various physiochemical analyses.

Table 1 presents the different experimental treatments used to generate the two years’ data. The storage moisture contents and storage temperatures were the same for both years.

NIR Analysis

After the samples were removed from storage, they were milled in a McGill #2 laboratory mill to a degree of milling of ~90 on a Satake MM-1B milling degree meter (Satake, Hiroshima, Japan). For NIR analysis, samples (~100 g) of head rice were then scanned in a scanning monochrometer (NIR Systems 6500, Perstorp Analytical, Silver Springs, Maryland). Each sample was poured into a rectangular transport cell and scanned in reflectance mode from 400 to 2500 nm at 2-nm increments. The average of 25 scans for each sample was stored for calibration.

Functional Attribute Analysis

Cooking Tests

Cooking ratios were determined in duplicate. Head rice (20 g) was cooked in excess boiling water for 20 minutes. After draining, volume expansion (VE) was calculated as the ratio of cooked rice height to raw rice height. Water absorption (WA) was calculated as the ratio of water absorbed to initial rice weight.

Amylography

Rice flour was ground from head rice and mixed with water to make an 8% (dry weight) slurry. The slurry was exposed to a predefined temperature treatment, according to a modified version of the AACC Method 61-01 (AACC, 1996) for milled rice, in a Brabender Viscographi-E. Peak viscosity (PV) and final viscosity(FV) values were extracted from the amylograph.

Calibration Development

Calibrations were developed using a partial least squares (PLS1) multivariate technique, via Unscrambler 6.11 (CAMO, Trodnheim, Norway). The entire spectrum (400 to 2500 nm) was used for analysis. After combining the data from 1996 and 1997, there were 405 samples in the data set, 202 from 1996 and 203 from 1997.

In order to better assess the predictive abilities of each calibration, the data were divided into two independent data sets, one for calibration and one for validation. The calibration set consisted of 303 samples, while the remaining 102 samples were reserved for validation. Prior to calibration, the data were arranged from minimum to maximum values for the attribute being modeled, and every fourth sample was chosen for validation, with remaining samples used in the calibration set.

Various methods of spectral pre-treatment were assessed, including no pretreatment, multiplicative scatter correction (MSC), mean normalization of the spectra, and weighting the spectra and/or functional data. In addition, first and second derivative treatments were evaluated for their usefulness in interpreting the data. To further explore possible improvements, various spectral ranges were reviewed for their value in improving each calibration.

Random cross-validation was performed during calibration development, using 10 segments of randomly chosen samples. Because the data were also being validated with an independent data set, the cross-validation step provided an estimate of the model's predictive ability prior to prediction on the validation set.

RESULTS AND DISCUSSION

Spectral Changes

Observable spectral changes occurred during storage of 'Bengal' (medium-grain) (Fig. 1). Similar changes are seen for rice stored at different moisture contents or at different temperatures. These qualitative results show that age-induced changes are occurring that eventually impact the functional characteristics and therefore spectral properties of the rice.

Pre-treatments

Scatter correction and derivative pretreatments were assessed with regard to their usefulness in improving calibration results (data not shown) with the best outcome from weighting all of the data by 1/(standard deviation). Weighting produced lower values for standard error of calibration (SEC) and standard error of prediction (SEP), and higher R^2's for all of the models. In addition, spectral ranges of 400-2500 nm (entire spectra), 1100-2500 nm (near-infrared region), and 1120-1800 (lower near-infrared region) were compared. Of these, using the entire spectra resulted in the best calibration models.

Calibration Results

Independent calibrations were developed for each of the four functional attributes of interest (Table 2).

Cooking Tests

For the two cooking parameters, VE and WA, the correlation coefficients (R^2) were low, 0.275 and 0.337, respectively, indicating that the proportion of the variance in the predicted values attributable to the variance in the measured values was also low. However, when the calibrations were applied to the validation set, the SEP / SEC ratios were 1.113 and 0.902 for VE and WA, respectively. This ratio would ideally be one, but these values indicate that the calibration did a good job of explaining the prediction data set.

Amylography

For the two starch properties PV and FV, the correlation coefficients were slightly better than those seen for the cooking ratios, 0.607 for PV and 0.495 for FV. These values show that 61% of the variability in predicted peak viscosity was explained by the calibration, as was 50% of the variability in predicted final viscosity. Figure 2 shows the plot of predicted vs. measured values for peak viscosity for the calibration data set, and Fig. 3 shows the plot of predicted vs. measured values for the validation data set. After the calibration was applied to the validation set, the SEP / SEC ratios were close to one–1.109 for final viscosity and 1.051 for peak viscosity–which indicated that the model did a good job of forecasting the prediction data set.

SIGNIFICANCE OF FINDINGS

We know from previous and on-going research that there are additional factors that have an affect on how rice changes during postharvest handling. As these data become more concrete, we will be able to include them in these models and further improve the predictive abilities of the calibrations. The models presented here are adequate for predicting the functional behavior of rice from two different harvest years and a range of postharvest treatments. As this work continues, the results should lead to a method for rapid screening of functional characteristics.

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Table 1. Variation in treatment structure for 1996 and 1997 harvested rice.

	Cultivar			Drying condition				Storage duration (week)								
Year	Bengal[z]	Cypress[y]	Kaybonnet[y]	high temp	low temp	farm high	farm low	0	3	6	9	12	18	24	36	52
1996	X	X	X	X	X			X	X	X	X	X	X	X	X	X
1997	X	X		X	X	X	X	X	X	X		X		X	X	X

[z] Medium-grain rice.
[y] Long-grain rice.

Table 2. Summary of calibration results for four functional attributes.

Calibration	R^{2z}	SEC[y]	SEP[x]	SEP/SEC
Final viscosity, Brabender units	0.5	74.83	83.02	1.11
Peak viscosity, Brabender units	0.61	57.96	60.91	1.05
Volume Expansion, 2 - 4 units	0.28	0.18	0.20	1.11
Water absorption, 1 - 3 units	0.34	0.17	0.16	0.90

[z] R2 = Correlation coefficient of the calibration set.
[y] SEC = Standard error of calibration.
[x] SEP = Standard error of prediction for independent validation set.

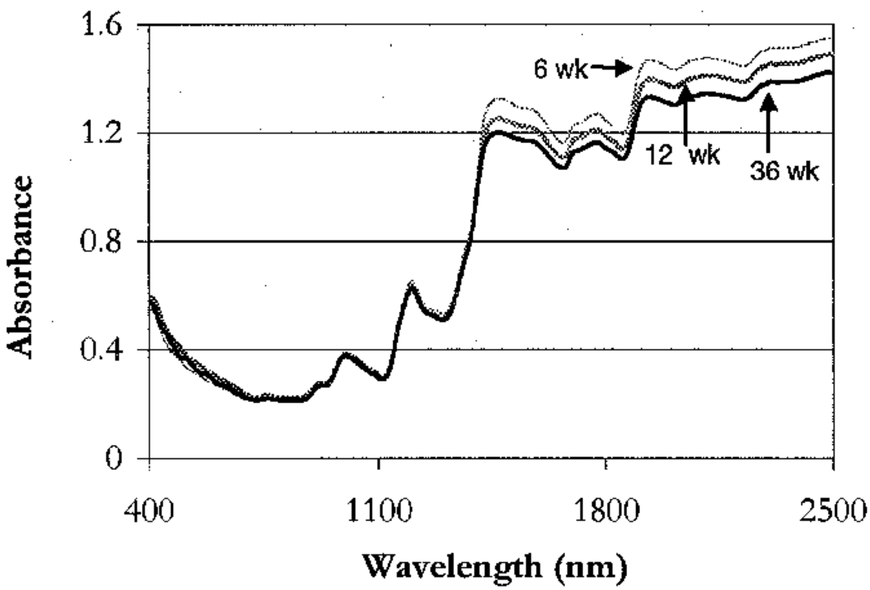

Fig. 1. Time-induced spectral changes in 12% moisture Bengal rice stored at 21°C.

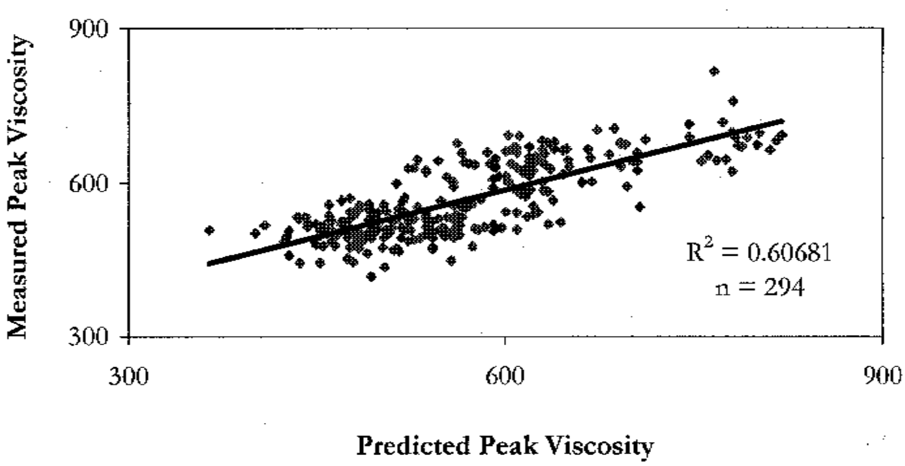

Fig. 2. Predicted vs. measured peak viscosity from calibration set.

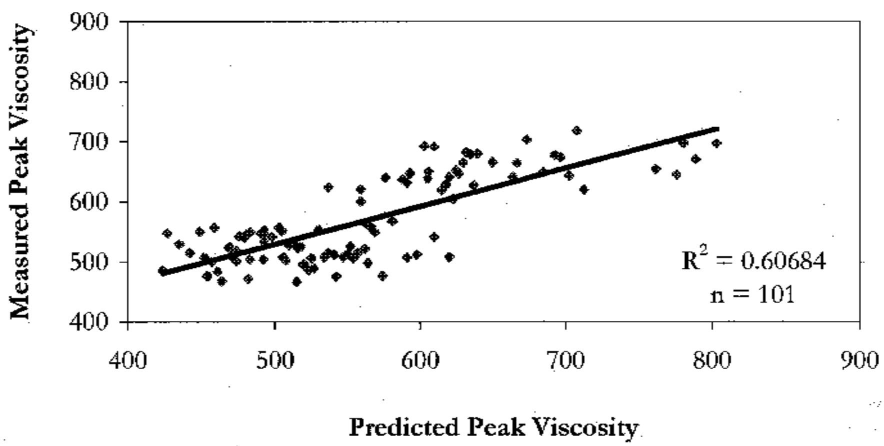

Fig. 3. Predicted vs. measured peak viscosity from validation set.

RICE PREFERENCE MAPPING FOR U.S. ASIAN CONSUMERS

J.-F. Meullenet, K. Carson, G. Davis, S. Davis, J. Gross, J.A. Hankins, E. Sailer, C. Sitakalin, S. Suwansri, and A.L. Vasquez Caicedo

ABSTRACT

A total of 21 rice products (instant, parboiled, aromatics, long-, medium-grain) were evaluated by a group 120 Asian consumers and by a professional sensory panel. Imported jasmine type rice was preferred over any of the other rices tested including domestically grown Jasmine rice. Sensory characteristics most important to acceptance of rice by Asian consumers were identified.

INTRODUCTION

Per capita rice consumption in the United States has risen from 10.25 lb in 1980 to 21.33 lb in 1997 (U.S. Rice Council,1998). Convenience and nutritional value continue to be contributing factors to the increasing rice consumption throughout the United States and consumers are now beginning to appreciate the versatility of this American grown grain. An emerging trend in U.S. rice consumption is the growing market share attributed to imported specialty rice varieties such as Thai, Jasmine, and Basmati. The Asian population is the primary consumer of these specialty rices.

The U.S. Asian population is the fourth largest ethnic group in the United States and the fastest-growing group in all regions (Campbell, 1996). It is projected that the Asian population will increase by more than 11 million by 2015. Additionally, rice consumption by Asian ethnic groups is usually about 10 times more than the average for the U.S. population (i.e. 150-200 lb per capita consumption; Goodwin, 1992).

Specialty rice varieties are defined as rice varieties not typically grown in the United States. Examples of aromatic rice varieties are Thai Jasmine grown in Thailand, Basmati grown in India, and 'Koshihikari' grown in Japan. These rice varieties are generally not adapted to growing conditions found in the United States and as a result need to be adapted by crossing with other varieties in order to be successfully commercially grown in the United States.

Rice imports to the United States have grown by 85% since 1990 while the overall rice consumption has increased by 20%. The rice imports to the United States come primarily from Thailand (73%), India (13%), Vietnam (7%), and Pakistan (3%) demonstrating that Thai Jasmine and Basmati varieties represent most of the import market (United States Rice Council, 1998). The total retail value of aromatic rice imported for 1998 is projected to be $240 million for a total of 285,000 metric tons.

Rice growers in Arkansas have not been able to capitalize on the growing markets for aromatic rice varieties. Goodwin (1992) reported that the source of the obvious shortcomings of domestically grown aromatic rice cultivars was unclear. This project will help rice farmers in Arkansas understand the shortcomings of existing cultivars and will determine the socioeconomic issues and the sensory characteristics of rice driving the Asian market for specialty rice. Ultimately, the results of this research will assist rice breeders in developing specialty rice varieties that will be competitive in this growing market.

The objectives of this preliminary study were (1) to determine the drivers of rice acceptance among Asian American consumers and (2) to predict consumer acceptance from descriptive sensory data.

PROCEDURES

Samples

A total of 21 rice samples including major classes of rice products (i.e. imported and domestic Thai Jasmine, imported and domestic Basmati, domestic long- and medium-grain, parboiled, and instant) were collected and prepared for testing. Each sample was pre-measured (to yield six 4-ounce servings), placed into a coded plastic bag (Glad Sandwich Baggies), and sealed. The coded and sealed samples were then placed in plastic, airtight storage buckets. Buckets were then stored in a commercial walk-in refrigerator (4°C) until ready for testing. A list of samples and their respective cooking procedures is presented in Table 1.

Sample Preparation

Rice samples were retrieved from cold storage and allowed to temper for approximately 12 hours before cooking. Long-grain, medium-grain, and aromatic varieties of rice were prepared in rice cookers (Rice-O-Mat, National Brand: model #SR-w10F-5 quart capacity). Samples were prepared using a 2:1 water to rice ratio (200g of rice in 400 ml of water). Rice sample and water were emptied into the cooker holding chamber, covered with a vented lid, and rice cooker switched to "on" 21 minutes prior to the scheduled presentation time to either the consumer panel or the professional descriptive panel. The samples remained covered throughout the cooking cycle. When the cooking cycle was completed, the removable holding chamber was immediately lifted out of the heating chamber to prevent overcooking or scorching. The instant and parboiled samples were prepared according to the manufacturer specifications. An electric portable buffet range (Munsey Brand, model # 702-1650 watt) was used to cook these products. Preparation duration ranged from 15 to 30 minutes depending on the sample (Table 1). Instant and parboiled samples were prepared in six-quart, stainless steel saucepans with lids.

When the specific cooking cycle was complete, each sample was stirred three to four times and spooned into a coded styrofoam food cup, (WinCup Brand 8FC). The sample was then covered with an air-tight lid, (WinCup Brand-FL13108) to contain volatiles and maintain temperature, and presented for evaluation (approximately 160°F).

Descriptive Analysis

Eleven panelists, trained in descriptive analysis (Spectrum Method, Sensory Spectrum Inc., Chatham, New Jersey) evaluated 18 flavor and 11 texture attributes of cooked rice. The attributes evaluated, their definitions, and the references used are described for flavor and texture in Tables 2 and 3, respectively. Panelists developed flavor and texture ballots for cooked rice in three orientation sessions. Panelists intensified aroma, flavor and texture attributes on a 0 to 15 continuous scale. Panelists were instructed to complete their evaluation before the sample reached 140°F. Water and crackers were provided for panelists to rinse their palate between samples. Serving orders were randomized across treatments and two replications for each sample were evaluated on separate testing days.

Consumer Testing

The consumer test was conducted in the food court of a national retail store and in the consumer testing facilities of the Center for Poultry Excellence at the University of Arkansas. Asian consumers were recruited via e-mail lists provided by the University of Arkansas. To encourage participation, a $10 gift certificate was offered upon completion of the test. Each consumer was assigned a log number, given a brief explanation of the test objectives, and seated at a test booth with foam board partitions. Once seated and briefed, each panelist received an eight-page questionnaire about rice consumption habits to complete before testing began. For sample presentation and evaluation, each panelist was provided with a Styrofoam tray (Formpac), a ballot, individually wrapped spoons, (Clear Shield National Inc., Shreveport, Louisiana), napkins and a water cup (Wincup 8FC). Samples were presented in styrofoam food cups with lids and identified by a three digit code. Each panelist evaluated a subset of seven samples as a unit. Consumers were asked to answer six questions for each sample. Panelists were first asked to record the three-digit code for the rice sample they were about to taste. The panelists were then asked to express their overall acceptance of the sample and their acceptance of the appearance, aroma, flavor and texture using a 9-point hedonic scale. In addition to the hedonic responses, consumers were also asked to rate the intensity of the aroma, flavor, firmness, and stickiness of the sample using a 9-point category scale.

RESULTS AND DISCUSSION

Results reported for Asian consumers (Fig. 1) show that imported jasmine rice (iJ) was most preferred by this consumer group. This is not surprising since a majority of Asians participating in the test originated from Thailand, Vietnam, Taiwan, and China. Domestically grown jasmine rices (dJ) were less accepted than the imported products but were overall liked by Asian consumers. Asian consumers were fairly indifferent to long-grain (L), domestic and imported Basmati (dB, iB) rices.

Heated oil, cooked grain, cardboard, floral, burlap and woody aroma, and flavor attributes were found to bear a positive impact on the acceptance of flavor and aroma among Asian consumers (Fig. 2). Test results also indicate that Asian consumers prefer rice with a softer, more cohesive (i.e. sticky) texture (Fig. 2).

Consumers indicated that the most important factor in determining their overall acceptance of a rice product was first its appearance and second its aroma (Fig. 3). Flavor and texture seemed to play a small role in determining overall acceptance by American Asians. Consumers clearly preferred rice with a high degree of whiteness over more yellow samples.

SIGNIFICANCE OF FINDINGS

Imported jasmine type rice was preferred over any of the other rices tested including domestically grown Jasmine rice. Acceptance of rice by Asian consumers needs to be further investigated so that "gold standards" that will be accepted by consumers can be identified. Current breeding efforts toward the development of specialty rice are emphasizing yield, pest resistance, and production characteristics without accurately quantifying the sensory quality of the crosses. The U.S. Asian population is very discriminative of the quality of the rice they eat. In order to take full advantage of this and other potential markets, we need to ensure that cultivars to be released in the future will fulfill consumer needs.

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Table 1. Rice samples and cooking procedures.

Product name	Water to rice ratio	Cooking instructions
Aromatic Rice		
Della (dB)	400ml : 200gr	Cook for 21 minutes
Rice Tec Basmati (dB)	400ml : 200gr	Cook for 21 minutes
Rice Tec Jasmati (dJ)	400ml : 200gr	Cook for 21 minutes
Rice Tec Kasmati (dA)	400ml : 200gr	Cook for 21 minutes
Thai Kitchen Jasmine (iJ)	400ml : 200gr	Cook for 21 minutes
Dragon 88 Jasmine (iJ)	400ml : 200gr	Cook for 21 minutes
Double Horse Jasmine (iJ)	400ml : 200gr	Cook for 21 minutes
Basmati Sharda (iB)	400ml : 200gr	Cook for 21 minutes
Basmati Royal (iB)	400ml : 200gr	Cook for 21 minutes
Instant Rice		
Boil in Bag (Kraft Minute Rice) (I)	1 2/3 cups : 2 cups	Boil water. Submerge bag & cook for 5 minutes
Riceland Quickcook (I)	275ml : 200gr	Bring water & rice to boil. Let simmer for 20 minutes Let stand for 5 minutes
Minute Rice (Kraft) (I)	3 1/3 cups : 1 1/3 cups	Boil water. Stir in rice and let stand for 5 minutes
Minute Rice Premium (Kraft) (I)	1 2/3 cups : 2 cups	Boil water. Stir in rice. Let stand for 5 minutes
Long-Grain Rice		
Riceland (L)	400ml : 200gr	Cook for 21 minutes
Producers Rice Mill (L)	400ml : 200gr	Cook for 21 minutes
Mahatma (Riviana) (L)	400ml : 200gr	Cook for 21 minutes
Medium-Grain Rice		
Gulf Coast (M)	400ml : 200gr	Cook for 21 minutes
Riceland (M)	400ml : 200gr	Cook for 21 minutes
Parboiled Rice		
Riceland Instant Parboiled (P)	2cups : 2cups	Cook for 20 minutes Let stand for 5 minutes
Riceland Parboiled (P)	2 1/4cups : 1 cup	Cook for 20 minutes Let stand for 5 minutes
Uncle Bens (P)	3 1/3 cups : 1 1/3 cups	Cook for 20 minutes Let stand for 5 minutes

Table 2. Descriptive flavor lexicon.

Term	Definition	Reference
STARCHY	The aromatic associated with the starch of a particular grain source.	Rice flour paste; Rice flour in water.
GRAINY	A general term used to describe the aromatics of raw or cooked grains, which cannot be tied to a specific grain.	Cereal Grains: 2methyl pyrazene
FEEDY	The aromatic associated with a mixture of grains reminiscent of animal feed.	Chicken Feed, Bran Buds
SCORCHED	The aromatic associated with scorching.	
WET CARDBOARD / PAPERY	The aromatic associated with early stages of oxidation.	Place wet cardboard in a reference jar, sniff.
NUTTY	The aromatic associated with nuts or nut meats which cannot be tied to a specific origin.	Toasted Wheat Germ
SWEET AROMATIC	The aromatic associated with materials that also have a sweet taste, such as molasses, caramelized sugars, cotton candy, maple syrup, maltol.	1-Vanilla 2-Maltol
SULFURY	The aromatic associated with Hydrogen sulfide, boiled or rotten eggs.	Boiled Eggs, Struck Match, Sewer Gas, Cooked Cabbage
HEATED OIL	The aromatic associated with fresh oil that has been heated: not indicative of any oxidized or “off” notes.	Heated Vegetable Oil Heated Cottonseed Oil
METALLIC	1) The aromatic associated with metals, tinny or irony. 2) A flat chemical feeling factor stimulated on the tongue and teeth by metal (coins, tin foil).	Pineapple Can, Tin Foil
DAIRY “OFF” NOTE	The aromatic associated with an off or negative note reminiscent of soured or old dairy products.	Texmati Rice
BURLAP	The aromatic associated with burlap.	Burlap Rice Bags
FLORAL / MINTY	The aromatic associated with a non-specific floral note and sometimes described as minty.	Jasmine Scent
WOODY		Heptanol
SALT	The basic taste on the tongue stimulated by sodium chloride.	Solutions of sodium chloride and spring water.
SOUR	The basic on the tongue stimulated by acids.	Solutions of citric acid in spring water.
SWEET	The basic taste on the tongue stimulated by sugars and high potency sweeteners.	Solutions of sucrose and spring water.
BITTER	The basic taste on the tongue stimulated by solutions by substances such as quinine and certain other alkaloids.	Solutions of caffeine and spring water.

Table 3. Descriptive texture lexicon.

Term	Definition	Technique
INITIAL		
COHESION OF SAMPLE (STICKINESS)	The degree to which the unchewed sample holds or sticks together	Place 1/4 teaspoon of sample in mouth and immediately evaluate how tightly the mass is sticking or holding together.
PARTICLE SIZE	The amount of space the particle takes up in the mouth.	Place sample in center of mouth and evaluate.
PARTIAL COMPRESSION		
ADHESION TO LIPS	The degree to which the sample adheres to the lips. the degree to which the product remains on the lips.	Compress sample between lips, release and evaluate.
FIRST BITE / CHEW		
HARDNESS	The force required to compress the sample.	Compress or bite through sample one time 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		
COHESIVENESS OF MASS	The amount that the chewed sample holds together.	Chew sample with molar teeth up to 15 times and evaluate.
MACRO ROUGHNESS OF MASS	The amount of roughness perceived on the surface of the chewed sample.	Chew the 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 - 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 sample 10-15 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.

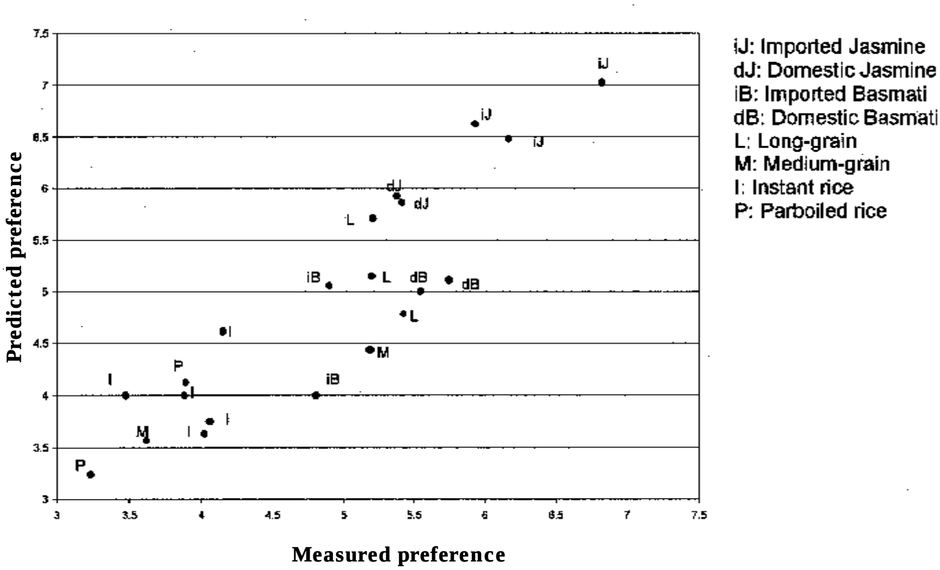

Fig. 1. Predicted vs. observed acceptance of rice by Asian consumers.

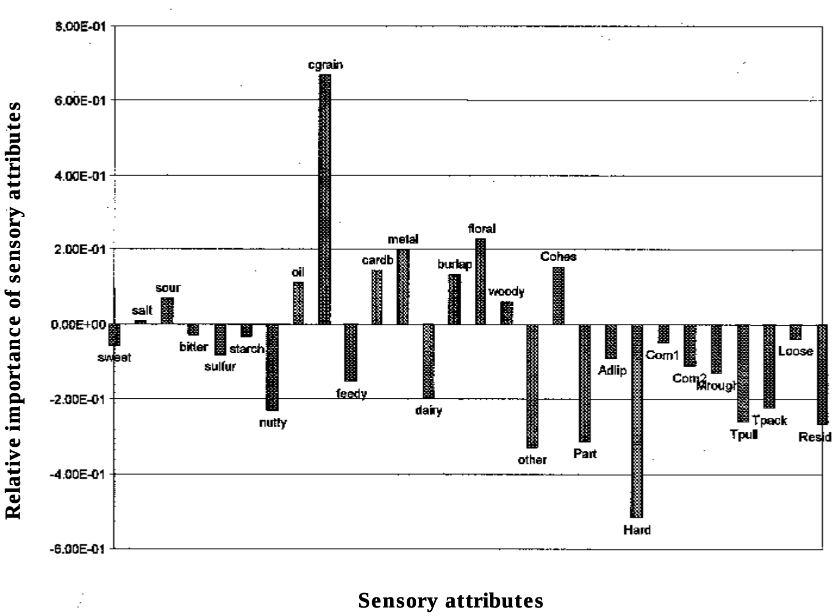

Fig. 2. Sensory descriptors most important to Asian consumers acceptance of rice.

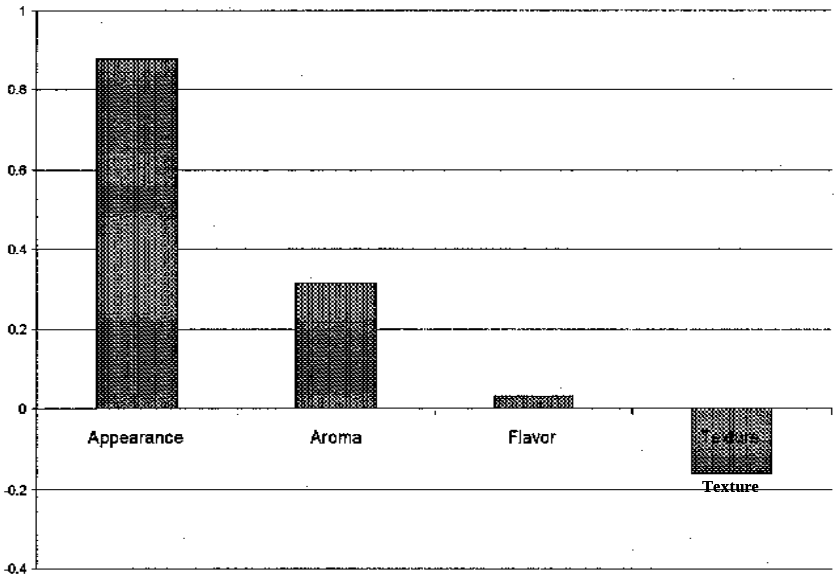

Fig. 3. Relative importance of sensory characteristics for rice acceptance by Asian consumers.

RAPID ASSESSMENT OF COOKED RICE TEXTURE CHARACTERISTICS: A METHOD FOR BREEDERS

J.-F. Meullenet, D. Kauffmann, and E. Champagne

ABSTRACT

Sensory texture characteristics of cooked rice (64 samples) were predicted using a miniature extrusion cell and a novel data analysis method (i.e. Spectral Stress Strain Analysis). Ten sensory texture characteristics were evaluated and stress values from instrumental tests 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, four (i.e. stickiness, toothpacking, cohesiveness of mass and hardness relative ability of prediction [RAP>0.6]) can be satisfactorily predicted using an instrumental test and subsequent Spectral Stress Strain Analysis.

INTRODUCTION

Texture is an important attribute of food acceptance by consumers (Moskowitz and Drake, 1972), and as such, an important part of cooked rice quality. Sensory analysis techniques, as well as instrumental tests, are useful in the characterization of cooked rice texture properties. The two approaches are usually explored simultaneously, the aim being to evaluate correlations between the two methods (Szczesniak, 1968).

Historically, rice breeding programs have devoted most of their efforts toward the development of high-yielding varieties, adapted to cultivation under specific climatic conditions. Furthermore, rice quality has been defined as milling quality and rough compositional characteristics, such as amylose and amylopectin, or their ratio. However, it has been demonstrated that the prediction of cooked rice texture characteristics from compositional characteristics has become obsolete (Meullenet *et al.*, 1998; Juliano *et al.*, 1984). In many instances, rice breeders cultivate small experimental plots and the small amounts of rice yielded do not allow for instrumental testing. As a result, there is a need for developing an instrumental method less demanding on sample quantities and more adapted to rice breeding program needs.

The objective of this study was to develop an instrumental method suitable for predicting cooked rice textural characteristics from small rice quantities.

PROCEDURES

Rice Samples

The samples used in this study were provided by the USDA-ARS Laboratories in New Orleans, Louisiana. The samples were chosen to represent a wide range of rice cultivars. A total of 64 samples, cultivated in four locations in the United States (California, Arkansas, Louisiana, Texas) and three other countries (Taiwan, Korea, Australia), were submitted to both sensory texture profiling and instrumental mechanical testing (Table 1).

Sample Preparation for Sensory Evaluation

Water added was adjusted for a specific rice cultivar according to three different ratios according to amylose content (1:1, 1:1.4, 1:1.7). Rice was presoaked in the cooker insert bowl for 20 minutes at room temperature and subsequently cooked in the rice cooker (Panasonic SR-W10G HP).

Sensory Evaluation Protocol

Sensory evaluation of rice samples was performed at the USDA-ARS Laboratories in New Orleans, Louisiana. Twelve panelists, previously trained in the principles and concepts of descriptive analysis (Civille and Szczesniak, 1973; Civille and Liska, 1975; Munoz, 1986) were selected to participate in the study. The sensory texture profile included 10 sensory attributes (Table 2). Each sample was presented to the panelists twice following a randomized design in which each session consisted of three samples, a “standard”, and a blind control (‘Calrose’, commercial product).

Extrusion Cell Design

The extrusion cell was created in response to breeding program needs. Thus, it considers several constraints related to its size, its price, and the rice quantities necessary for instrumental mechanical testing. The cell was developed (90mm in length and 20mm in diameter) and fitted with an extrusion plate consisting of a metallic mesh and a Teflon extrusion cylinder (19.5 mm in diameter) (Fig. 1).

Sample Preparation for Instrumental Analysis

Since rice texture is greatly influenced by temperature (Okabe, 1979), it must be very closely monitored so that mechanical testing is accurate and reproducible. A cooking protocol similar to that used for sensory testing was developed. Thirty g milled rice were rinsed three times in cold water covering rice, strained to remove excess water, and then transferred to a 150-ml breaker. Water was added according to rice cultivar amylose content (Table 1). Rice was steamed for 30 minutes. Cooked rice was then thoroughly mixed using a plastic fork before transferring 8.5 g of cooked rice to each of six identical extrusion cells. The six filled cells were then quickly replaced into the rice cooker and held an additional 10 minutes at “warm” setting.

Instrumental Measurements

Instrumental evaluation was carried out using a texture analyzer model TA-TX2 (Texture Technologies, Scarsdale, New York). The cross-head speed was set at 2.0 mm / sec for a total travel of 85-mm. Force-distance curves were recorded.

Statistics Analysis

The six replications of the force-distance curves from each sample were compared and an average force-distance curve was determined. Each point of the curve (i.e., force in g) corresponded to a given extrusion cylinder travel. Unscrambler (version 6.11, CAMO, Throndheim, Norway, 1996), a multivariate analysis software, was used to determine predictive models of sensory texture attributes. Partial Least Squares (option PLS1) was used for predicting sensory attributes from force-distance curve. To compare the predictive ability of the calibration models Relative Ability of Prediction values (RAP), as described by Martens and Martens (1986), were calculated for each sensory.

RESULTS AND DISCUSSION

Among the texture attributes evaluated by the panel, four (i.e. stickiness, toothpacking, cohesiveness of mass, and hardness [RAP>0.6]) can be satisfactorily predicted using an instrumental test and subsequent Spectral Stress Strain Analysis (Table 3). Predictive models were evaluated for specific grain types (i.e. medium and long) as well as for medium- and long-grain cultivars combined. The behavior of medium- and long-grain samples was found to be different for some of the sensory attributes evaluated.

Rice stickiness was well predicted (RAP=0.73). This result was expected for two reasons. First, the extrusion test was performed using warm cooked rice with cooking methods similar to those used for sensory evaluation. In previous studies by Meullenet *et al.* (1998), rice was rinsed and kept at cold temperature before measuring texture. Meullenet *et al.* (1998) reported that the prediction of rice stickiness was an unreliable task using an instrumental extrusion test. A possible reason for the reliable prediction of rice stickiness in the present study is that the starch leaching from individual rice kernels was not rinsed after cooking. Hardness is the most commonly evaluated sensory attribute using instrumental tests. The instrumental test performed in this study using a miniature extrusion cell showed promising results with an RAP=0.65. It approaches the RAP reported by Meullenet *et al.* (1998), using a standard back extrusion cell. This value is high enough to allow discrimination between samples exhibiting minute differences for this sensory characteristic. Cohesiveness of mass is defined as the amount the chewed sample holds together. The sensory definition implies that the perception of this attribute is related to the global mass cohesion after the sample has been compressed and sheared. Thus, the sensory definition is in accordance with the instrumental test principle (i.e. extrusion is a combination of compression and shearing). Cooked rice cohesiveness of mass was relatively well predicted by the multivariate model (RAP=0.60).

Rice samples used in this study were mostly of two different grain types, medium and long. The results obtained with each of the two grain types individually are comparable with results obtained for all samples combined for almost all attributes. However, cohesiveness was the exception to the rule. Whereas the predictive model established for medium-grain rice cultivars was of acceptable quality (RAP=0.6), the model established for predicting cohesiveness of long-grain cultivars was poor. The standard deviations for both grain types were found to be similar (S_{tot}»0.5). Thus, this unexpected result cannot be explained by an insufficient variability in long-grain rice samples.

Residual, roughness and slickness intensities were not well predicted by the extrusion test used in this study. Sensory estimation of residual particles present in the mouth after swallowing did not exhibit large differences. All samples sensory intensities were evaluated between 3.5 and 4.6 (i.e. on a 15-point scale). The same was observed to a lesser extent for roughness and slickness. In general, the sensory attributes exhibiting large intensity differences were those best predicted by instrumental Spectral Stress Strain Analysis. This instrumental test and analysis technique may allow one to distinguish between rice samples presenting primary rice textural characteristics. It was found that it is not possible to establish a predictive model from samples not exhibiting differences as evaluated by a descriptive panel.

SIGNIFICANCE OF FINDINGS

The use of a miniature extrusion in combination with multivariate analysis techniques showed that it was possible to satisfactorily predict the four main attributes of cooked rice texture (stickiness, hardness, cohesiveness of mass, and toothpacking). In the instrumental spectrum used for modeling sensory perception, important portions of the prediction of the textural attributes were identified. This method should allow rice breeders to make a quick assessment of rice texture quality on a routine basis.

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Table 1. List of rice samples evaluated.

Cultivar	Location[z]	Grain type[y]	Cooktype[x]
CM101	TX	M	1
CM101	AR	M	1
PELDE	TX	L	2
ZENA	TX	L	2
M201	TX	M	2
M401	CA	M	2
M202	TX	M	2
M202	CA	M	2
NATO	LA	M	2
BALDO	LA	M	2
BALDO	TX	M	2
CP231	TX	L	3
KOSHIHKARI	CA	M	2
MERCURY	LA	M	2
MARS	LA	M	2
NIPPONBARE	LA	S	2
AB869	LA	M	2
PECOS	LA	M	2
V4716	LA	M	2
CALROSE76	TX	M	2
BENGAL	LA	M	2
BENGAL	TX	M	2
NANKING SEL	LA	M	2
BRAZOS	TX	M	2
S102	CA	S	2
A301	LA	L	3
BLUEBONNET	LA	L	3
M204	CA	M	2
DELLA	LA	L	3
GOOLARA	LA	L	3
IR64	TX	L	3
LEAH	LA	L	3
CYPRESS	LA	L	3
CYPRESS	TX	L	3
LEMONT	TX	L	3
AS 3510	LA	L	3
KAYEENA	LA	L	3
L110	LA	L	3

continued

Table 1. Continued.

Cultivar	Location[z]	Grain type[y]	Cooktype[x]
LABELLE	LA	L	3
LACASSINE	LA	L	3
STARBONNET	LA	L	3
DREW	AR	L	3
LEBONNET	LA	L	3
KAYBONNET	TX	L	3
BELLEMONT	LA	L	3
TAIM	LA	L	3
NEWREX	LA	L	3
REXMONT	AR	L	3
REXMONT	LA	L	3
GUICHOW	LA	M	3
L202	AR	L	3
AB647	LA	M	2
IRGA409	TX	L	3
L144	TX	L	3
IR72	TX	L	3
KOSANBARE	LA	M	2
NORTAI	LA	S	2
DIXIEBELLE	TX	L	3
L203	CA	L	3
BRAZOS	LA	M	2
TAIGUNG 8	TAIWAN	M	2
TAICHUNG SEN WAXY	TAIWAN	S	1
CHOOCHUNG	KOREA	M	2
DINGJIN	KOREA	M	2
ILLABONG	AUST	M	3

[z] Location: California (CA), Arkansas (AR), Louisiana (LA), Texas (TX), Taiwan, Korea, and Australia (AUST).
[y] Grain type: L = long-grain, M = medium-grain; S = short-grain.
[x] Cook type: 1 = 1:1 rice to water ratio; 2 = 1:1.4 rice to water ratio; 3 = 1:1.7 rice to water ratio.

Table 2. Definitions of sensory attributes.

Attributes	Definition
Slickness	The degree to which the surface of individual kernels is slick
Roughness	The amount of large peaked and sloped angle irregularities detected on the surface of the sample
Stickiness between grains	The degree to which the individual grains stick together
Springiness	The amount the product spontaneously regains its former size, shape, or bulk after being compressed
Hardness	The force required to compress the sample
Cohesiveness	The amount of deformation undergone by a material before rupture when biting completely through the sample using molars
Uniformity of bite	The evenness of force throughout the bite
Cohesiveness of mass	The amount the chewed sample holds together
Residuals	The amount of particles remaining in and on the surface of the mouth after swallowing
Toothpacking	The amount of product packed into the crowns of your teeth after mastication

Table 3. Summary of sensory attributes and relative ability of prediction (RAP).

Sensory attributes		MSE[z]	S_{tot}[y]	S_{ref}[x]	RMSEP[w]	RAP[v]
Combined rice types						
COH	Cohesiveness	1.29	0.55	0.28	0.44	0.50
HAR	Hardness	0.79	0.49	0.22	0.34	0.65
MAS	Cohesiveness of mass	1.50	0.76	0.31	0.54	0.60
RES	Residuals	0.39	0.21	0.16	0.21	-
ROU	Roughness	1.38	0.61	0.29	0.54	0.29
SLI	Slickness	1.85	0.77	0.34	0.74	-
STI	Stickiness between grains	1.60	0.85	0.32	0.52	0.73
TOO	Toothpacking	0.94	0.36	0.24	0.28	0.68
UNI	Uniformity of bite	1.64	0.41	0.32	0.37	0.49
Medium-grain rice						
COH	Cohesiveness	1.28	0.53	0.28	0.40	0.60
HAR	Hardness	0.70	0.45	0.21	0.33	0.58
MAS	Cohesiveness of mass	1.34	0.78	0.29	0.47	0.73
RES	Residuals	0.39	0.21	0.16	0.24	-
ROU	Roughness	1.36	0.67	0.29	0.66	-
SLI	Slickness	1.80	0.72	0.34	0.67	-
STI	Stickiness between grains	1.41	0.99	0.30	0.70	0.56
TOO	Toothpacking	0.89	0.41	0.24	0.37	0.23
UNI	Uniformity of bite	1.47	0.45	0.30	0.40	0.40
Long-grain rice						
COH	Cohesiveness	1.16	0.56	0.27	0.56	-
HAR	Hardness	0.90	0.42	0.24	0.31	0.67
MAS	Cohesiveness of mass	1.47	0.63	0.30	0.40	0.77
RES	Residuals	0.38	0.21	0.15	0.22	-
ROU	Roughness	1.41	0.56	0.30	0.58	-
SLI	Slickiness	1.72	0.55	0.33	0.68	-
STI	Stickiness between grains	1.67	0.63	0.32	0.50	0.49
TOO	Toothpacking	0.96	0.28	0.24	0.30	-
UNI	Uniformity of bite	1.75	0.37	0.33	0.34	0.76

[z] MSE = mean square error.
[y] S_{tot} = standard deviation total.
[x] S_{ref} = standard deviation ref.
[w] RMSEP = root mean square error of prediction.
[v] RAP = relative ability of prediction.

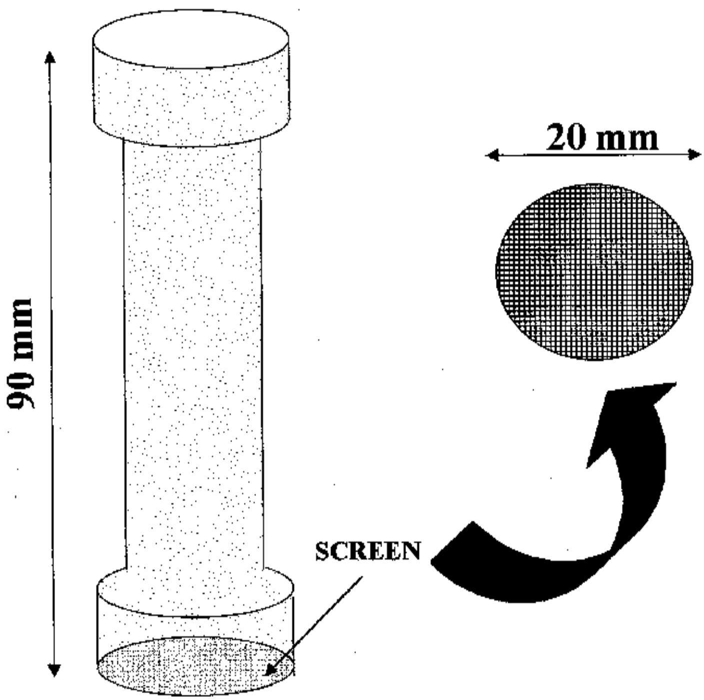

Fig. 1. Plastic extrusion cell.

PREDICTION OF RICE TEXTURE BY SPECTRAL STRESS STRAIN ANALYSIS: A METHOD FOR THE 21ST CENTURY

J.-F.C. Meullenet, C. Sitakalin, B.P. Marks, and T.J. Siebenmorgen

ABSTRACT

Sensory texture characteristics of cooked rice for three cultivars (74 samples) were predicted using an extrusion cell and a novel data analysis method (i.e. Spectral Stress Strain Analysis). Eight sensory texture characteristics were evaluated and stress values from instrumental tests were used in combination with Partial Least Squares regression to evaluate predictive models for each of the sensory attributes studied. Relative Ability of Prediction (RAP) values ranged from 0.06 to 0.85. Satisfactory models are proposed for the two major texture characteristics of cooked rice, namely hardness (RAP=0.85) and stickiness as evaluated by adhesion to lips (RAP=0.76). Other sensory attributes such as roughness of mass (RAP=0.73) and toothpack (RAP=0.81) were also satisfactorily predicted.

INTRODUCTION

Cooked rice texture has been shown to govern its acceptance by consumers when consumed as whole kernels (Okabe, 1979). As value-added uses for rice continue to expand, there is an increasing need for quantitative methods for evaluating rice functionality and rice texture in particular. A number of instruments have been employed to measure the texture of cooked rice, including the Instron food tester (Juliano *et al*., 1981; Juliano *et al*., 1984), the Tensipresser (Tsuji, 1982), the Haake Consistometer (Manohar Kumar *et al*., 1976), and the Texture Analyzer TAXT2 (Champagne *et al*., 1998; Meullenet *et al*., 1998a, 1998b). These studies aimed to devise a reliable texture test, so that a set of simple indicators of the eating quality could be evolved. A great deal of valuable information has been gathered, but the overall objective (i.e., devising a reliable instrumental test to predict rice texture) still remains to be achieved. As a result, an instrumental method that could accurately describe textural characteristics of cooked rice is needed. The objective of this study is to investigate an alternative method of analysis (i.e., Spectral Stress Strain Analysis) for data generated using mechanical tests assessing rice texture.

PROCEDURES

Samples used in this study and their respective processing conditions (i.e. drying, moisture content, storage temperature and duration) were described by Meullenet *et al.* (1998a).

Sensory Methodology

Nine panelists trained in descriptive analysis techniques (Sensory Spectrum, Chatham, New Jersey) with three years of experience in descriptive analysis developed a texture lexicon for cooked long- and medium-grain rice. Eight texture attributes were identified as adequately describing the texture profile of cooked rice for the cultivars studied (Table 1). Intensities were assessed by comparison with carefully chosen references anchored on specific attribute scales (Table 1). Samples were cooked for 20 minutes in household steam rice cookers (National, model SR-W10FN) with a 1:2 (vol:vol) rice to water ratio. Samples were presented at 71°C ±1 in preheated glass bowls insulated with Styrofoam cups and covered with watch glasses. Samples were evaluated twice by each of the panelists on two separate days.

Instrumental Texture Analysis

Sample Preparation

A 100-g rice sample was added to 946 ml of boiling water and cooked for 20 minutes. Rice samples were sifted immediately after cooking and rinsed.

Extrusion Test

A cylindrical extrusion cell (40mm in diameter and 70mm deep) was used in conjunction with a Texture Analyzer (model TAXT2, Texture Technologies, Scarsdale, New York). A 35-g sample of rice was placed in the extrusion cell for each test repetition. Force (kg) required to extrude the sample was recorded as a function of test duration and six test replications were performed.

Force-Deformation Curves Analysis by Spectral Stress-Strain analysis

With empirical instrumental methods for assessing textural properties of foods, instrumental tests have been used to extract parameters such as maximum load and correlations evaluated between instrumental parameters and sensory attributes. This approach is not always successful and definitely not appropriate for samples exhibiting minute texture differences. We hypothesized that the instrumental force deformation curve of any food product could be considered as a spectrum. The stress-distance curves from each sample evaluated were treated as spectral data to create an instrumental thumbprint of each rice sample evaluated. The concept for this analysis is then based on the prediction of textural characteristics from the shape of the force-deformation curves rather than on arbitrarily chosen instrumental parameters. Unscrambler (version 6.11, CAMO, Throndheim, Norway) was used to determine predictive models of sensory textural attributes. The 220 instrumental variables extracted from the force deformation curve were used in a Partial Least Squares Regression model (PLS1 option) to predict each of the eight texture attributes evaluated. Relative Ability of Prediction (RAP) values, indicators of the quality of predictive models, which take into account the unexplained variation in the sensory data, were calculated as described by Martens and Martens (1986).

RESULTS AND DISCUSSION

In an attempt to justify the use of alternative methods for predicting sensory intensities of texture attributes from instrumental tests, Pearson's correlation between the eight sensory attributes evaluated in this study and the maximum load from the instrumental test were evaluated (Table 2). Table 2 clearly shows that the maximum load from an instrumental test does not adequately predict cooked rice hardness (R=0.36) or any of the other sensory attributes discussed here (R<0.46). We feel that these results largely justify the development of alternative instrumental methods for assessing cooked rice texture.

Adhesion to lips was relatively accurately predicted using Spectral Stress Strain Analysis (SSSA) methods (Table 3). The Relative Ability of Prediction (RAP=0.76) value is high enough to feel confident with predicting rice stickiness of samples exhibiting relatively small differences. Furthermore, the Root Mean Square Error of Prediction (RMSEP=0.46), an indicator of the average error of prediction expressed in sensory units, was less than half a point on the 15-cm scale used in sensory testing. In addition, the RAP reported here (RAP=0.76) is much greater than that reported by Meullenet *et al.* (1998b) (RAP=0.21). In our previous studies, a set of five instrumental parameters were used to predict individual texture attributes. This more conventional method of analysis, even if novel, showed that predicting texture of rice samples exhibiting small overall differences was a difficult task. The results obtained in the present study demonstrate the potential of Spectral Stress Strain Analysis (SSSA) for predicting rice stickiness. Hardness was well predicted (RAP=0.85) using SSSA (Table 3). The RAP value reported here is much improved over values reported earlier (RAP=0.52) by Meullenet *et al.* (1998b). Furthermore, the average error of prediction (RMSEP=0.20) was extremely small, demonstrating the ability of SSSA to provide reliable prediction of cooked kernel hardness. Cohesiveness of mass evaluated after three chews (COM_1) was not well predicted by SSSA (RAP=0.16, RMSEP=1.19). This result is in agreement with results previously reported by Meullenet *et al.* (1998b), demonstrating that this sensory texture attribute is difficult to predict using instrumental mechanical testing. Results reported for cohesiveness of mass evaluated after eight chews (RAP=0.57, RMSEP=0.44) showed that the prediction of this sensory attribute is not entirely satisfactory (Table 3). The RAP reported by Meullenet *et al.* (1998b) for the same attribute was similar (RAP=0.60) to that reported here, illustrating that SSSA did not improve upon predictive models determined by using more conventional methods of data analysis. Roughness of mass was well predicted by SSSA (RAP=0.73, RMSEP=0.19, Table 3). This is a surprising result since no significant predictive model was reported in previous studies by Meullenet *et al.* (1998b). The RMSEP is small enough for accurately predicting roughness of mass in cooked rice. Toothpack was satisfactorily predicted using SSSA (RAP=0.81, RMSEP=0.15, Table 3) and SSSA improved upon the prediction models determined by Meullenet *et al.* (1998b). Meullenet *et al.* (1998b) reported satisfactory predictive models for the texture attribute toothpull (RAP=0.73). Surprisingly, SSSA was found to poorly predict toothpull (RAP=0.12, Table 3). This result shows that SSSA may not always be the method of choice for predicting individual sensory attributes. The predictive model for particle size (RAP=0.52, Table 3) was improved over the model proposed by Meullenet *et al.* (1998b). However, the RAP is not large enough to accurately predict particle size. This may be a result of the small variation observed for this attribute among the samples evaluated. The attribute loose particles was poorly predicted using SSSA (RAP=0.06) as previously reported by Meullenet *et al.* (1998b). It should not be surprising that predicting the amount of residual particles after swallowing would be an impossible task since the sensory evaluation of this attribute occurs after extensive mastication and expectoration of the rice sample.

SIGNIFICANCE OF FINDINGS

Overall, SSSA offered significant improvements for predicting sensory texture characteristics of cooked rice over more conventional modeling techniques as reported by Meullenet *et al.* (1998b). Furthermore, SSSA provided dramatic improvements for main characteristics of cooked rice (i.e. stickiness as measured by adhesion to lips and hardness). Spectral Stress Strain Analysis, even in its infancy, is providing a truly new approach to relating instrumental measurements of texture to sensory intensities. SSSA could provide, if further investigated, an accurate tool to rice breeders and the rice industry as a whole for predicting sensory texture characteristics of rice. However, before models of this sort can reliably be used in the rice industry, there will need to be more extensive studies to include samples with a more diverse genetic makeup.

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Table 1. Vocabulary for sensory texture attributes of cooked rice.

Term	Definition	Technique	Reference	
SURFACE:				
ADHESIVENESS TO LIPS	The degree to which the sample adheres to the lips.	Compress sample between lips, release, and evaluate.	Tomato	0.0
			Nougat	4.0
			Bread stick	7.5
			Pretzel rod	10.0
			Rice Krispies	15.0
FIRST BITE:				
HARDNESS	The force required to compress the sample.	Solids - Compress or bite through sample 1 with molars or incisors.	Cream cheese	1.0
			Egg white	2.5
			Am cheese	4.5
			Hot dog (K)	5.5
			Olive	7.0
			Peanut	9.5
			Almond	11.0
			Carrot	11.0
			Life savers	14.5
CHEWDOWN:				
COHESIVENESS OF MASS after 3 or 8 chews	The amount the chewed sample holds together.	Chew sample with molar teeth 3 times or 8 times and evaluate.	Licorice	0.0
			Carrots	2.0
			Mushrooms	4.0
			Hot dog	7.5
			Am cheese	9.0
			Brownie	13.0
			Dough	15.0
ROUGHNESS OF MASS	The amount of roughness perceived in the chewed sample.	Chew sample with molar teeth 8 times and evaluate.	Unchewed Jello	0.0
			Orange peel	3.0
			Cooked oatmeal	6.5
TOOTHPULL	The force required to separate the jaws during mastication.	Chew sample up to 3 times and evaluate.	Clam	3.5
			Caramel	5.0
			Jujubes	15.0

continued

Table 1. Continued.

Term	Definition	Technique	Reference	
PARTICLE SIZE	The amount of space the particle fills in your mouth.	Place sample in center of mouth and evaluate.	Rice grain	5.0
			Tic Tac	2.5
			M & M (plain)	4.0
			Mikes & Ikes	6.0
			Cherry bite	11.0
			Sprmnt leaf	13.0
			Peprmint patti	20.0
TOOTHPACK	The amount of product packed into the crowns your teeth after mastication.	Chew sample up 8 times, expectorate, and feel the surface of the crowns of the teeth with tongue.	Cpt. Crunch	5.0
			Heath bars	10.0
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.	Carrot	10.0

Table 2. Pearson's correlation coefficients between sensory texture attributes of cooked rice and instrumental maximum load.

adlip	*hard*	*cm1*	*cm2*	*rough*	*tpull*	*parz*	*tpack*	*loose*	*max load*	
adlip	1									
hard	-0.441367	1								
cm1	0.367890	-0.233699	1							
cm2	0.409060	-0.371385	-0.236808	1						
rough	-0.446850	0.802219	-0.315153	-0.329501	1					
tpull	0.306066	-0.159145	-0.462025	0.794281	-0.174898	1				
parz	0.016311	0.326059	-0.074111	-0.277239	0.310880	-0.159620	1			
tpack	0.479090	-0.580363	-0.281612	0.588529	-0.539044	0.602503	-0.016034	1		
loose	-0.439798	0.278540	-0.784824	0.075447	0.391240	0.210077	0.049871	0.095154	1	
max load	0.011595	0.359705	0.163048	-0.192503	0.380649	-0.132080	0.451090	-0.253279	-0.152714	1

n=74.

Table 3. Modeling results from Spectral Stress-Strain Analysis (SSSA).

Attribute	R[z]	# of PCs[y]	RMSEP[x]	RAP[w]
Adhesion to lips	0.77	5	0.46	0.76
Hardness	0.81	3	0.19	0.85
Cohesiveness of mass after 8 chews	0.61	4	0.44	0.57
Particle size	0.59	4	0.07	0.52
Toothpack	0.67	4	0.15	0.81
Toothpull	0.44	2	0.27	0.12
Loose particles	0.31	1	0.22	0.06

[z] R is the correlation coefficient between observed and predicted validation scores.
[y] Number of principal components chosen according to the residual variance plot to avoid overfitting.
[x] Root Mean Square Error of Prediction expressed in sensory units.
[w] Relative Ability of Prediction.

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. In this kind of market environment, both current year and long-term base line projections by country are useful not only for supply/demand analysis but for policy analysis as well. Base line results show that world rice output increases by over 1% per year mainly due to improvements in grain yield. United States rice is expected to maintain a strong competitive position in world markets and continue to supply a growing domestic market.

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 in the United States is growing steadily at over 2% 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 GATT which requires opening markets to imports, reduction in aggregate support levels, and reduction in export subsidies. MERCOSUR (a regional initiative which 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 United States Federal Agricultural Improvement and Reform (FAIR) Act of 1996 is another relevant policy initiative which radically changed the nature of government intervention in the U.S. rice sector.

Starting in 1996, 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 seven years (Wailes *et al.*, 1998).

OBJECTIVES

Given the changes going on 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 as to 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 base line projections for the world rice economy is useful as it provides the basis for conducting a wide variety of market and policy analyses on the rice economy, including evaluating and comparing alternative macroeconomic policies, and different weather and technology scenarios.

The Arkansas Global Rice Modeling Project aims to address these needs. The Arkansas Global Rice Model is a dynamic partial equilibrium econometric model which provides supply and demand projections for 21 selected countries/regions (Wailes *et al.*, 1998). In order to provide timely and relevant market information, the model needs to be constantly 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 Arkansas Global Rice Model, a multi-country econometric model framework that provides projections for a set of 20 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, United States Department of Agriculture (USDA/ERS, 1999 a,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 base line 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 constant 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 21 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 (Tables 1 and 2)

World rice area is estimated to decline slightly to 149 million hectares in 1999, 0.3% lower than last year, due to slight declines in Thailand, Vietnam, Pakistan, and Australia. Global rice area is projected to increase by over 400 thousand hectares in 2000, and gain about 100 thousand hectares per year through 2010. Average global rice yield is estimated to improve by 3% in 1999 and is expected to recover and grow annually by nearly 1% through 2010. With the combined effects of area decline and yield gain, production in 1999 would increase by 3% to 389 million metric tons (mmt). Production is projected to continue growing by 1% per year through 2010. Consumption is projected to grow nearly 1% in 1999 and maintain that rate of growth through 2010, due mainly to growing Asian populations. Global trade is expected to slow down substantially in the near-term, declining by 3% in 1999 following a drop of 16% in 1998. World ending stocks are projected to increase slightly to 45 mmt in 1999, after a substantial decline of 15% in 1998 mainly due to weather-related production shortfall in China. The global rice stocks-to-use ratio is projected to be unchanged in 1999 at 11.5%, compared to 13.6% in 1997.

Over the long-term, world rice output will grow by 1%--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 due to implementation of the United States General Agreement on Tariffs and Trade, Federal Agriculture and Improvement Act of 1996 and other regional free trade initiatives. Ending stocks are projected to increase slowly over the long-term, reaching 54 mmt in 2010 from 45 mmt in 1999. The base line international rice price (Thai 5% freight on board [f.o.b]) is expected to remain around $300 per metric ton.

United States Rice (Tables 3 and 4)

United States rice acreage expanded by nearly 7% in 1998 to 3.32 million acres compared to 1997. Harvested acreage is projected to increase by 3.5% in 1999 to 3.43 million, and decline and stabilize around 3.2 million thereafter. Average yield per acre is projected to recover to 59 hundredweight (cwt) in 1999, following a decline of 3% in 1998. As a result, estimated production would increase by 7% in 1999 to 202 million cwt---resulting in higher volume of stocks (+21%). Domestic use in 1999 is expected to increase 3% to 112 million cwt due mainly to growth in food use. Exports in 1999 are projected to grow 4% to 93 million cwt. Season average farm price is projected to increase slightly to $8.91 per cwt in 1999 from the 1998 estimate of $8.78.

Over the long-term, total U.S. rice area and production would decline and remain around 3.2 million acres and 200 million cwt, respectively. Domestic consumption is expected to continue growing steadily due to the expanding 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 due to the strength of rough rice exports to a number of Latin American countries. These countries prefer to import rough rice to improve use of their milling capacities. United States rough rice is well-positioned to maintain its competitive edge in this market segment 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 of $9-10 per cwt over the projection period.

SIGNIFICANCE OF FINDINGS

The foregoing set of baseline rice projections generated by the Arkansas Global Rice Model is useful as a benchmark against which changes in rice supply and demand and policies can be evaluated.

1. Base line 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.

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Table 1. World rice supply and use, 1997-2003.

Variable	Unit/Year	1997	1998	1999	2000	2001	2002	2003
Area harvested	1000 ha	149646	149521	149505	149537	149881	150079	150117
Yield	mt/ha	2.57	2.53	2.60	2.63	2.65	2.68	2.71
Production	1000 mt	384335	378134	389393	393190	397481	401728	406232
Total consumption	1000 mt	383860	386103	389859	393392	397189	401236	405362
Net exports	1000 mt	23921	20056	18763	19256	19918	20464	20875
Net imports	1000 mt	23921	20056	18763	19256	19918	20464	20875
Ending stocks	1000 mt	51467	43499	43033	42831	43123	43614	44485

Table 2. World rice supply and use, 2004-2010.

Variable	Unit/Year	2004	2005	2006	2007	2008	2009	2010
Area harvested	1000 ha	150147	150091	150122	150185	150242	150297	150371
Yield	mt/ha	2.74	2.77	2.79	2.82	2.84	2.87	2.89
Production	1000 mt	411512	415345	419143	423182	426806	430878	434912
Total consumption	1000 mt	409558	413580	417625	421735	425879	430137	434466
Net exports	1000 mt	21232	21623	22134	22634	23090	23578	24079
Net imports	1000 mt	21232	21623	22134	22634	23090	23578	24079
Ending stocks	1000 mt	46439	48203	49721	51168	52095	52836	53282

Table 3. U.S. rice supply and use (in English units) 1997-2003.

Variable	Unit/Year	1997	1998	1999	2000	2001	2002	2003
Yield (rough basis)								
Actual	lb/acre	5897	5669	5887	6055	6097	6157	6214
Program	lb/acre	4827	4827	4827	4827	4827	4827	4827
Harvested acreage								
Program area/contract area	1000 acre	4157.0	4161.4	4157.0	4157.0	4157.0	4157.0	4157.0
Total harvested area	1000 acre	3103.0	3317.0	3396.9	3123.8	3239.9	3219.1	3197.1
Supply (rough basis)	mil. cwt	219.4	224.8	239.4	234.5	239.6	241.9	243.4
Production	mil. cwt	183.0	188.1	200.0	189.1	197.5	2.891	198.7
Beginning stocks	mil. cwt	27.2	27.7	29.5	35.1	31.4	32.5	33.0
Imports	mil. cwt	9.2	9.1	9.9	10.2	10.7	11.2	11.7
Domestic use (rough basis)	mil. cwt	106.5	109.3	112.8	114.5	116.5	118.7	120.8
Food	mil. cwt	82.0	84.0	86.8	88.6	90.5	92.7	94.7
Seed	mil. cwt	4.3	4.4	4.3	4.3	4.3	4.2	4.2
Brewing	mil. cwt	15.4	15.4	15.7	15.6	15.7	15.8	15.9
Residual	mil. cwt	4.8	5.5	6.0	6.0	6.0	6.0	6.0
Exports	mil. cwt	85.2	86.0	91.4	88.5	90.6	90.2	89.7
Total use	mil. cwt	191.7	195.3	204.2	203.1	207.1	208.9	210.5
Ending stocks	mil. cwt	27.7	29.5	35.1	31.4	32.5	33.0	32.9
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	9.70	8.52	8.07	8.69	8.67	8.66	8.72
Long-grain farm price	US$/cwt	10.04	8.01	7.68	8.48	8.40	8.36	8.40
Medium-grain farm price	US$/cwt	8.96	10.03	8.98	9.15	9.32	9.34	9.43
LG-MG margin	US$/cwt	1.08	-2.03	-1.31	-0.67	-0.92	-0.98	-1.03
Export price, FOB Houston (U.S. No. 2)	US$/cwt	18.82	17.37	17.46	18.01	18.16	18.06	18.12

continued

Table 3. Continued.

Variable	Unit/Year	1997	1998	1999	2000	2001	2002	2003
Medium-grain price, FOB CA (U.S. No. 2)	US$/cwt	17.96	20.82	18.54	18.75	18.99	19.07	19.29
Deficiency/CLD/contract pay rate	US$/cwt	2.71	4.35	2.75	2.53	2.04	1.98	1.98
World price	US$/cwt	7.83	6.30	6.30	6.39	6.46	6.40	6.46
EXPP-SAFP margin	US$/cwt	5.35	5.54	6.26	5.94	6.12	6.03	6.02
Income factors								
Production market value	mil. US$	1775	1602	1614	1643	1713	1717	1732
Deficiency/contract payments	mil. US$	465	745	480	443	358	348	348
Marketing loan/certificates	mil. US$	0	0	0	0	0	0	0
Total income	mil. US$	2240	2347	2094	2086	2071	2065	2080
Returns above variable cost	US$/acre	175.84	100.44	82.16	128.80	125.52	124.60	126.94

Table 4. U.S. rice supply and use (in English units) 2004-2010.

Variable	Unit/Year	2004	2005	2006	2007	2008	2009	2010
Yield (rough basis)								
Actual	lb/acre	6276	6338	6392	6446	6499	6552	6607
Program	lb/acre	4827	4827	4827	4827	4827	4827	4827
Harvested acreage								
Program area/contract area	1000 acre	4157.0	4157.0	4157.0	4157.0	4157.0	4157.0	4157.0
Total harvested area	1000 acre	3171.1	3147.5	3154.6	3145.1	3142.2	3137.6	3155.8
Supply (rough basis)	mil. cwt	244.0	244.4	246.0	246.8	247.5	248.1	250.1
Production	mil. cwt	199.0	199.5	201.6	202.7	204.2	205.6	208.5
Beginning stocks	mil. cwt	32.9	32.3	31.3	30.6	29.4	28.1	26.8
Imports	mil. cwt	12.1	12.6	13.0	13.5	14.0	14.4	14.9
Domestic use (rough basis)	mil. cwt	122.8	124.8	126.8	128.7	130.6	132.5	134.4
Food	mil. cwt	96.8	98.7	100.6	102.5	104.3	106.2	108.0
Seed	mil. cwt	4.1	4.1	4.1	4.1	4.0	4.0	4.0
Brewing	mil. cwt	15.9	16.0	16.0	16.1	16.2	16.3	16.4
Residual	mil. cwt	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Exports	mil. cwt	88.9	88.2	88.7	88.7	88.8	88.9	89.7
Total use	mil. cwt	211.7	213.1	215.5	217.4	219.4	221.4	224.1
Ending stocks	mil. cwt	32.3	31.3	30.6	29.4	28.1	26.8	26.0
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	8.78	8.97	9.11	9.29	9.46	9.65	9.81
Long-grain farm price	US$/cwt	8.45	8.65	8.80	9.02	9.24	9.48	9.67
Medium-grain farm price	US$/cwt	9.51	9.68	9.78	9.87	9.96	10.04	10.12
LG-MG margin	US$/cwt	-1.06	-1.04	-0.98	-0.85	-0.72	-0.57	-0.45
Export price, FOB Houston (U.S. No. 2)	US$/cwt	18.14	18.50	18.63	18.69	18.74	18.78	18.86

continued

Table 4. Continued.

Variable	Unit/Year	2004	2005	2006	2007	2008	2009	2010
Medium-grain price, FOB CA								
(U.S. No. 2)	US$/cwt	19.52	19.94	20.20	20.44	20.68	20.92	21.15
Deficiency/CLD/contract								
pay rate	US$/cwt	1.98	1.98	1.98	1.98	1.98	1.98	1.98
World price	US$/cwt	6.48	6.77	6.87	6.93	6.96	6.98	7.03
EXPP-SAFP margin	US$/cwt	5.95	6.05	5.98	5.80	5.60	5.37	5.24
Income factors								
Production market value	mil. US$	1747	1789	1837	1883	1932	1985	2046
Deficiency/contract payments	mil. US$	348	348	348	348	348	348	348
Marketing loan/certificates	mil. US$	0	0	0	0	0	0	0
Total income	mil. US$	2095	2137	2185	2231	2280	2333	2394
Returns above variable cost	US$/acre	130.35	142.38	150.15	160.41	170.36	187.60	202.90

MARKET EFFICIENT TESTS OF U.S. ROUGH RICE FUTURES MARKET

G.L. Cramer, E.J. Wailes, B. Jiang, and L. Hoffman

ABSTRACT

An efficient futures market could be used as a risk management tool for the rice market. This study examines the market efficiency of the U.S. rough rice futures market using the Dickey-Fuller test for data stationarity, standard regression models, Johansen's cointegration test, and an additive ARIMA model. Stationarity tests indicate that the price series for both cash and futures tend to be non-stationary during the growing season, April to August, but are stationary during the remaining part of the year or the storage season. Initial results indicate that the long-grain rough rice futures market is efficient in Arkansas. Hence, market participants can use this market, in conjunction with other management tools, to manage price risk. These results can be used to evaluate the potential role of futures market in other states.

INTRODUCTION

The rough rice futures market is relatively new compared to the well-established futures markets for corn, wheat, and soybeans. The rice futures market has been referred to as a thinly-traded futures market. It is generally believed that a thinly-traded market is more likely to be unbalanced and biased than a more heavily-traded market. Inefficiency in the rough rice futures market is one argument given by some members of rice industry for low participation in the market.

An efficient futures market could be used as a risk management tool for all market participants including producers, elevator operators, and processors. This role for the futures market becomes more important as U.S. agricultural policy changes. The passage of The Federal Agricultural Improvement and Reform Act of 1996 (FAIR Act) continues the sector's trend toward market orientation and transfers risk from the government to the private sector.

OBJECTIVES

With the implementation of the FAIR Act, it is important for rice market participants to have a better understanding of the rough rice futures and to know whether they can reduce their price risk by using this futures market as a risk management tool. This study examines the market efficiency of the U.S. rough rice futures market using both descriptive and quantitative techniques (Fama, 1970, 1991; Tomek and Gray, 1970; Kofi, 1973; Kahl and Tomek, 1986; Chowdhury, 1991; Elam and Dixon, 1988; Garcia *et al*., 1988; Hakkio and Rush, 1989; Lai and Lai, 1991; Antoniou and Holmes, 1996).

PROCEDURES

Long-grain rough rice futures prices, contract volume, open interest, and deliveries per contract are obtained from the Chicago Board of Trade. Weekly (every Tuesday) cash prices for the Arkansas market[1] are obtained from an industry source. Cash prices reflect traded values for No. 2 long grain rice. The time period for this study is August 1986 to August 1998.

In addition to the methods of analysis used in previous studies, a relatively new Johansen cointegration procedure is also used in this study (Johansen, 1988; Johansen and Juselius, 1990). The approaches employed to assess efficiency of the rough rice futures market include descriptive measures such as, contract volume, open interest and deliveries per contract, econometric models, and time series techniques. The analysis provides a historical perspective and a cross commodity comparison. Hedging efficiency is also examined using an ordinary least squares (OLS) time trend model.

The efficient market hypothesis is examined using weak-form and semi-strong form tests (Fama, 1970, 1991). The test for stationarity[2] of the price series is completed before analyzing market efficiency, because the weak-form efficiency test depends on the stationarity property of the price series, an issue that previous efficiency studies for rice did not consider. A standard weak form test is conducted if both cash and futures price series are stationary and Johansen's cointegration approach is used when they are non-stationary[3]. An additive ARIMA model is chosen to perform the semi-strong form market efficiency test. The model is estimated and is used to forecast out-of-sample one to six months ahead. The mean root squared errors and Theil's U cofficient are used as criteria to compare the performance of the model's forecasts with futures price forecasts

RESULTS AND DISCUSSION

Volume of rice traded has risen over time, especially since the FAIR Act of 1996. Volume traded as a percent of production rose from 4% in 1986 to 192% in 1997. It is expected that the deliveries per contract will decline over time as many believe it to be less efficient to deliver on a contract than to offset the position in the futures market and deliver to a local cash market. Preliminary results suggest the presence of hedging efficiency as the basis tends to narrow over time for selected contracts.

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[1] Weekly cash prices for other rice producing states were not available.

[2] A stationary time series has a mean, variance, and autocorrelation function that are essentially constant through time.

[3] No appropriate test is available to test weak-form market efficiency for cases when one of the prices (cash or futures) is stationary and the other is non-stationary. These situations usually arise across both a growing season and harvest season.

Stationarity test results indicate that the price series for both cash and futures tend to be non-stationary during the growing season April to August, and stationary during the remaining part of the year or the storage season. This phenomenon may relate to the level of rice stocks and expectations for future supply. The period after harvest has a known supply level compared to the growing season. Stocks levels play a role in reducing price volatility.

Preliminary results of the weak form test using OLS support the hypothesis of an efficient futures market. The Johansen cointegration procedure for the non-stationary price series also provides evidence in favor of market efficiency. The semi-strong form market efficiency test shows ARIMA model forecasts of cash prices one to six months ahead are less accurate than futures price forecasts. This suggests that the semi-strong form test does not provide evidence of an inefficient rice futures market.

SIGNIFICANCE OF FINDINGS

Initial/expected results of this study could provide rice market participants a better understanding of the rough rice futures; and determine whether they can use this futures market as a management tool to reduce their risk.

1. Preliminary results suggest that the long-grain rough rice futures market is efficient for Arkansas; and rice market participants can use this market as a price risk management tool.

2. Rice market participants in other states could assess the potential of the long-grain rough rice futures market by examining the results of this study and the rice price relationship between Arkansas and corresponding states.

3. Stationarity properties of price series should be taken into account in analyzing grain market efficiency. The price series in this study do not exhibit uniform properties of stationarity. Questions remain for hedging positions across both growing and harvest seasons because the nature of one of the two price series is stationary and another is non-stationary.

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U.S. RICE MARKET PRICE RELATIONSHIP AND CROSS HEDGING OF MEDIUM-GRAIN RICE

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ABSTRACT

The two major types of rice grown in the United States are long-grain and medium-grain. This study examines the potential of using the long-grain rice futures market as a price discovery and risk management tool for medium-grain rice. Initial results of a separate study by the same authors found that the futures market for long-grain rice in Arkansas is efficient. Initial results indicate that cross hedging of medium-grain rice with long-grain rice futures should be effective, at least in Arkansas.

INTRODUCTION

This paper focuses on whether the futures market for long-grain rice can be used as a risk management tool for medium-grain rice. Initial results of a separate study by the same authors found that the futures market for long-grain rice in Arkansas is efficient. A better understanding of whether and how the futures market of long-grain rice can be used for price discovery and risk management for medium-grain rice could promote more participation in the rice futures market. Previously published studies on this issue have not been found. Lord and Turner (1998) analyzed cross hedging of milled rice.

Long- and medium-grain rice are the two major types of rice produced in the United States, while short-grain rice accounts for less than 1% of total U.S. rice production. Medium-grain rice is an important part of the rice industry as it accounts for one-third of the total rice production. Arkansas' production is 83% long-grain and 17% medium-grain. Louisiana produces 92% long-grain and 8% medium-grain. In California, medium-grain accounts for 95% of total production; while long-grain and short-grain account for about 2% and 3%, respectively. Texas produces 98% long grain and 2% medium-grain. There is some competition between long- and medium-grain rice in using production resources and also in consumption. The differences between long- and medium-grain rice, such as cooking quality, appearance or taste, result in a non-homogenous market for rice.

The U.S. long-grain rough rice futures market is relatively new compared to the well-established futures markets for corn, wheat, and soybeans. The rice futures market has been referred to as thinly-traded. The futures market for long-grain rough rice was first established in the early 1980s and has been affiliated with the Chicago Board of Trade (CBOT) since mid-1986. The trade volume has increased over the years and exceeds the volume of a low volume contract as specified by the Commodity Futures Trading Commission.

OBJECTIVES

This research aims to examine how the medium- and long-grain rice rough rice markets are integrated among major rice-producing states; analyze the cross hedging effectiveness between medium-grain rough rice and long-grain rough rice futures; and discuss the interaction between price relationships and cross hedging effectiveness.

PROCEDURES

Cross hedging is believed to be more complicated than direct hedging. The difficulty lies in the selection of the appropriate futures market to be used as cross hedging vehicles. Typically, the ratio of a futures price of a related commodity (such as complement or substitute) to cash price of a commodity in both the input and output markets, could serve as a potential cross-hedging vehicle (Hayenga *et al.*, 1996). The classical cross hedging study by Anderson and Danthine (1981) showed that cross hedging is feasible if there is significant covariance between the cash and futures price. Therefore, correlation analysis between those two prices of related commodities could be used ex ante to analyze the potential usefulness of a particular futures commodity as cross hedging media.

This study examines the four top medium-grain producing states in the United States: California, Arkansas, Louisiana, and Texas. Rice futures prices and producer cash prices are used in this study. Daily futures prices for long-grain rice were obtained from the CBOT. Monthly cash prices for long- and medium-grain rice from five major rice-producing states including Arkansas, California, Louisiana, Mississippi, and Texas, were acquired from the United States Department of Agriculture's National Agriculture Statistics Service.

For Arkansas, the state possessing all the delivery points of rice futures market, cross hedging effectiveness of medium-grain rice will depend upon the degree of price relationship between medium- and long-grain rice. For the other three states, cross hedging effectiveness will depend upon two price relationships: a cross price relationship in Arkansas and a spatial price relationship between medium-grain rice prices in Arkansas and in the other states.[1] Two methods will be used to examine the cross and spatial price relationships: Johansen's cointegration test (Johansen, 1988; Johansen and Juselius, 1990) and Ravallion's market integration test (Ravallion, 1986).

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[1] As an alternative, these two price relationships could be: a strong spatial price relationship of long-grain rice between Arkansas and other states, and a strong cross price relationship between long- and medium-grain rice in other states.

Cross hedging effectiveness will be examined by the traditional hedging model[2] and generalized conditional hedging model which takes into account current market information. The monthly average of the nearby futures price is used in the estimation. The optimal hedge ratios will be obtained for hedging of 1 to 11 months ahead. Both fixed and time-variant optimal hedge ratios will be examined.

RESULTS AND DISCUSSION

Both Johansen cointegration test and Ravillion's market integration test show evidence of an integrated U.S. rice market to some extent. Some exceptions include California, where the Johansen procedure with different lag structure indicates that rice prices of both long- and medium-grain may not be cointegrated with corresponding prices in Arkansas; and Texas, where Ravellion's test shows that medium-grain rice market is not integrated with Arkansas medium-grain rice market.

All three cross hedging models demonstrate the potential of long-grain rough rice futures as a cross hedging media for the medium-grain rice, especially in Arkansas and Louisiana. California models also indicate some potentials of cross hedging its medium-grain rice with the long-grain rice futures. Caution should be taken for cross hedging Texas medium-grain rice for most of the year. Comparison of various hedging models indicates that the effectiveness of cross hedging also depends on model specification. For example, cross hedging using generalized conditional hedging models is most effective, and the traditional hedging model with an intercept term is more effective than the model without an intercept term. Results also show that optimal hedging ratios are time variant, which depends on both the time placing the hedge and the length of hedging position. This study also indicates that price relationship tests provide good information about cross hedging potentials of a particular futures for other related commodities.

SIGNIFICANCE OF FINDINGS

Expected results of this study indicate that the futures market for long-grain rice can be used as a risk management tool for medium-grain rice, especially in Arkansas and Louisiana. A better understanding of whether and how the futures market of long-grain rice can be used for price discovery and risk management for medium-grain rice could promote more participation in the rice futures market.

1. Cross hedging of medium-grain rice with long-grain rough rice futures should be effective at least for Arkansas and Louisiana. More effective cross hedging for Arkansas' medium-grain rice than California's may be due to factors other than location. Caution should be taken for cross hedging Texas medium-grain rice. One plausible reason is the low share of long-grain in California's total rice production, and the low share of medium-grain in Texas' total rice output.

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[2] Two traditional (unconditional) hedging models are estimated which regress cash prices on futures prices, with and without intercept terms. The cash to futures price ratios commonly used by industry are equal to the hedge ratio obtained from the regression without an intercept term.

2. The characteristics of medium-grain in California are different from medium-grain rice in the Southern states which is believed to be similar to long-grain rice. The degree of cross and spatial price relationships may or may not be a good indicator of cross hedging effectiveness.

3. An interesting observation is that cross hedging ratios are close to one or larger for hedges that are lifted in July, August, and September, while hedge ratios for hedges lifted in other months are usually less than one. These observations deserve further study.

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YIELD RISK FOR ARKANSAS RICE PRODUCTION

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ABSTRACT

Yield risk for 32 rice-producing counties in Arkansas was estimated using 15 years of time-series data collected over the period 1981-95. Over this period, Arkansas experienced 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. Using 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 the first step in providing risk management information which 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 which 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 (AASS) 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 which has been continuously engaged in rice production over the 15-year period 1981-95. These 32 counties–26 counties in eastern Arkansas' crop reporting districts 3, 6, and 9, and six additional counties in southwestern and west-central Arkansas–account for 99% of all rice production in Arkansas.

Summary statistics computed for each county included the 15-year mean yield, standard deviation (SD), and coefficient of variation (CV). The latter two measures provide a preliminary indication of yield variability (risk) encountered in each county. Subsequently, the estimate of probability distribution parameters for rice yield in each county were taken from a linear trend regression line fitted through the 15-year (1981-1995) time series of yield data for each county. Variance (risk) of yield was measured as the root mean square error (RMSE) of the residuals about each yield trend line. Mean yield over the 15-year series was measured as the trend line projected rice yield for 1995. RMSE was used as the absolute measure of rice yield risk in order to isolate the random variability in yield after the systematic trend had been removed. Residuals from all trendline regressions were tested using the Jarque-Bera statistic (Jarque and Bera, 1987). Cumulative distribution functions of yield were plotted as normally distributed random variables based on the parameters (trendline projected yield, RMSE) estimated from the 15-year county data series.

RESULTS AND DISCUSSION

Summary Statistics

Over the period 1981-95, the county with the largest rice production was Arkansas County which produced over 9% of the state's rice annually (Table 1). 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 5,558 lb / acre (Arkansas County) and 3,950 lb / acre (Little River County). By contrast, SD of yield (i.e., yield variability) ranged from a high of 717 lb / acre (Pulaski County) to a low of 271 lb / acre (Lafayette County) resulting in CVs of 14.7% and 6.3%, respectively.

Trendline Analysis

Trendline analysis of these same 32 rice-producing counties showed that 28 of them experienced statistically significant yield increases over the 1981-95 period amounting to an average annual statewide increase of 80 lb / acre (Table 2). However, the annual yield increase was as low as 19 lb / acre for some counties (Lafayette County) but as high as 119 lb / acre for others (White County). These yield increases result in trendline projected average annual yields ranging between 6,169 lb / acre (Arkansas County) and 4,429 lb / acre (Lafayette County). Over the same period, yield risk–measured as the root mean square error (RMSE) of residuals around each yield regression trendline–also varied dramatically from one county to another. Counties with the highest and lowest *absolute* yield risk over the 15-year period had RMSEs of 577 lb / acre and 268 lb / acre, respectively, which indicates that some counties experienced nearly twice the yield risk encountered in other counties. The CVs in Table 2 convert the RMSEs to *relative* measures of yield risk by reporting them as percentages relative to the county projected trendline yield.

Levels of yield risk among counties were separated into three arbitrary categories (low, medium, high) by grouping the range of RMSEs reported in Table 2 into thirds. In general, low yield risk counties are located in the northeast and east central districts of the state, whereas high risk counties are scattered throughout the central, southwestern, and southeastern districts of the state (Fig. 1).

Cumulative Distribution Functions

Cumulative distribution functions (CDF) of rice yield in graphical form for a selected sampling of six counties are presented in Fig. 2. These six counties demonstrate the diversity of yield level and yield risk in Arkansas. Counties portrayed reflect high (Arkansas) and low (Lafayette) trendline yield levels, high (Miller) and low (White) risk levels as measured by RMSE, as well as other relatively important rice producing counties (Jefferson and Woodruff). In general, counties whose CDFs lie farther to the right exhibit higher yields than those to the left. Likewise, steep CDFs (Arkansas, Woodruff, Lafayette) reflect lower risk than CDFs with flatter slope (Miller, Jefferson). CDFs in Fig. 2 provide a visual estimate of the probability of attaining specified yield levels in each county. For example, producers in both Lafayette and Miller counties can expect yields below 4,200 lb / acre in 2 out of 10 years (i.e., 20% probability). However, in 8 out of 10 years (80% probability), yields in Lafayette County are less than 4,500 lb / acre whereas in Miller County, yields are at this same probability level are below 5,000 lb / acre. Conversely stated, Lafayette, and Miller County producers can expect yields in excess of 4,500 lb / acre and 5,000 lb / acre, respectively, in 2 years out of 10. Correspondingly, producers in Arkansas County experience yields below 6,500 lb / acre 80% of the time. Conversely stated, Arkansas County producers can expect yields in excess of 6,500 lb / acre 2 years out of 10.

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 which can be used by rice producers in their cropping and marketing decisions.

ACKNOWLEDGMENTS

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

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Table 1. Rice production and summary yield statistics for rice-producing counties in Arkansas, 1981-1995.

County name	County code	15-year average share of state production	15-year summary yield statistics					
			Mean	SD	CV	Maximum	Minimum	Range
		(%)	----- (lb/acre) -----		(%)	------------ (lb/acre) --------------		
District 3 Northeast								
Clay	CLY	5.04	5012	468	9.34	5662	4150	1512
Craighead	CRG	5.59	5138	432	8.40	5750	4420	1330
Greene	GRE	3.64	4864	410	8.43	5608	4020	1587
Independence	IND	0.61	4899	464	9.48	5999	4070	1928
Jackson	JAC	5.86	4953	581	11.73	5707	3940	1767
Lawrence	LAW	5.08	5220	547	10.48	5781	4310	1470
Mississippi	MIS	1.32	5021	496	9.88	5632	4060	1571
Poinsett	POI	8.26	5270	407	7.73	5945	4510	1435
Randolph	RAN	1.62	5158	498	9.66	5700	4140	1560
White	WHI	1.91	4685	633	13.51	5480	3351	2129
District 6 East Central								
Arkansas	ARK	9.03	5558	507	9.12	6200	4650	1550
Crittenden	CRI	1.38	5058	516	10.21	5654	4080	1573
Cross	CRO	6.74	5199	456	8.78	5881	4410	1471
Lee	LEE	2.57	4852	599	12.36	5611	3720	1891
Lonoke	LON	6.15	5364	533	9.94	6030	4410	1620
Monroe	MNR	3.30	4964	603	12.15	5686	3830	1855
Phillips	PHI	1.55	4722	467	9.89	5283	3930	1352
Prairie	PRA	5.32	5368	461	8.58	6200	4580	1619
Saint Francis	STF	3.23	4895	435	8.90	5417	4050	1366
Woodruff	WDR	3.97	4837	396	8.19	5300	4070	1229

continued

Table 1. Continued.

County name	County code	15-year average share of state production	15-year summary yield statistics					
			Mean	SD	CV	Maximum	Minimum	Range
		(%)	----- (lb/acre) -----		(%)	--------------- (lb/acre) ---------------		
District 9 Southeast								
Ashley	ASH	1.55	4791	558	11.64	5500	3990	1510
Chicot	CHI	3.12	4979	487	9.79	5670	4230	1440
Desha	DES	3.24	5092	542	10.64	5700	4060	1640
Drew	DRW	1.29	5120	641	12.53	5889	3980	1908
Jefferson	JEF	3.70	4993	689	13.81	6100	3850	2249
Lincoln	LIN	2.32	5003	545	10.90	5850	4080	1770
Miscellaneous Counties and Districts								
Yell (4)	YEL	0.16	4536	565	12.46	5500	3400	2100
Faulkner (5)	FAU	0.21	5010	528	10.54	5750	4040	1710
Pulaski (5)	PUL	0.45	4871	717	14.71	5583	3720	1863
Lafayette (7)	LAF	0.44	4298	271	6.32	4667	3576	1091
Little River (7)	LIT	0.09	3950	587	14.87	5158	3179	1978
Miller (7)	MIL	0.58	4400	587	13.33	5276	3100	2176
Aggregated Districts								
Dist 3 Northeast	NE	38.92	5022	494	9.86	5726	4097	1629
Dist 6 East Central	EC	43.24	5082	497	9.81	5726	4173	1553
Dist 9 Southeast	SE	15.23	5044	573	11.37	5858	4036	1822
State Total**	AR	100.00	5092	463	9.09	5700	4280	1420

**100.00% 15-yr average production for Arkansas State = 61,847,400 cwt.

Table 2. Trendline yield regression equations for rice-producing counties in Arkansas, 1981-1995.

County name	County code	Intercept* (1981=0)	Predicted trendline yield '95	slope coeff.	Sig. level of slope coefficient	RMSE	Trendline CV	R^2	Sig. level of F
		--- (lb / acre) ----		(lb / acre / yr)		(lb / acre)	(%)		
District 3 Northeast									
Clay	CLY	4479	5544	76.1	0.0019	334	6.02	0.528	0.0021
Craighead	CRG	4637	5639	71.6	0.0014	301	5.33	0.550	0.0016
Greene	GRE	4488	5239	53.7	0.0208	345	6.58	0.343	0.0218
Independence	IND	4611	5186	41.0	0.1432	443	8.54	0.156	0.1449
Jackson	JAC	4323	5583	90.0	0.0038	435	7.78	0.480	0.0042
Lawrence	LAW	4666	5774	79.2	0.0085	433	7.50	0.419	0.0091
Mississippi	MIS	4545	5497	67.9	0.0144	407	7.41	0.375	0.0152
Poinsett	POI	4904	5636	52.3	0.0240	346	6.14	0.330	0.0251
Randolph	RAN	4621	5695	76.7	0.0041	375	6.58	0.474	0.0045
White	WHI	3850	5519	119.2	0.0001	354	6.41	0.710	0.0001
District 6 East Central									
Arkansas	ARK	4946	6169	87.4	0.0006	335	5.43	0.594	0.0008
Crittenden	CRI	4526	5590	76.0	0.0070	403	7.21	0.434	0.0076
Cross	CRO	4633	5764	80.8	0.0004	289	5.02	0.627	0.0004
Lee	LEE	4065	5638	112.3	0.0001	339	6.02	0.702	0.0001
Lonoke	LON	4731	5998	90.5	0.0009	360	6.01	0.576	0.0010
Monroe	MNR	4255	5672	101.2	0.0011	414	7.29	0.563	0.0013
Phillips	PHI	4233	5211	69.9	0.0058	360	6.90	0.449	0.0063
Prairie	PRA	4819	5917	78.5	0.0008	310	5.24	0.580	0.0010
Saint Francis	STF	4411	5378	69.1	0.0027	318	5.92	0.504	0.0030
Woodruff	WDR	4382	5293	65.1	0.0016	279	5.26	0.540	0.0018

continued

Table 2. Continued.

County name	County code	Intercept* (1981=0)	Predicted trendline yield '95	Slope coeff.	Sig. level of slope coefficient	RMSE	Trendline CV	R^2	Sig. level of F
		--- (lb/acre) ----		(lb/acre/yr)		(lb/acre)	(%)		
District 9 Southeast									
Ashley	ASH	4225	5357	80.9	0.0083	440	8.22	0.421	0.0089
Chicot	CHI	4460	5499	74.2	0.0047	370	6.73	0.464	0.0052
Desha	DES	4475	5710	88.2	0.0018	385	6.75	0.530	0.0021
Drew	DRW	4294	5946	118.0	0.0001	378	6.35	0.678	0.0002
Jefferson	JEF	4288	5699	100.8	0.0076	541	9.50	0.427	0.0082
Lincoln	LIN	4414	5592	84.2	0.0040	410	7.32	0.476	0.0044
Miscellaneous Counties and Districts									
Yell (4)	YEL	4170	4901	52.3	0.1236	534	10.89	0.171	0.1253
Faulkner (5)	FAU	4299	5721	101.6	0.0000	279	4.87	0.741	0.0000
Pulaski (5)	PUL	4100	5641	110.1	0.0042	540	9.58	0.472	0.0047
Lafayette (7)	LAF	4166	4429	18.8	0.2587	268	6.05	0.096	0.2602
Little River (7)	LIT	3284	4616	95.1	0.0020	420	9.10	0.525	0.0023
Miller (7)	MIL	4107	4693	41.9	0.2448	577	12.29	0.102	0.2463
Aggregated Districts									
Dist 3 Northeast	**NE**	**4560**	**5584**	**73.2**	**0.0015**	**311**	**5.57**	**0.544**	**0.0017**
Dist 6 East Central	**EC**	**4598**	**5774**	**84.0**	**0.0003**	**293**	**5.07**	**0.639**	**0.0003**
Dist 9 Southeast	**SE**	**4374**	**5628**	**89.5**	**0.0021**	**399**	**7.09**	**0.520**	**0.0024**
State Total	**AR**	**4531**	**5654**	**80.3**	**0.0006**	**303**	**5.36**	**0.602**	**0.0007**

*All intercepts are significantly different from zero at the 1% level of significance.

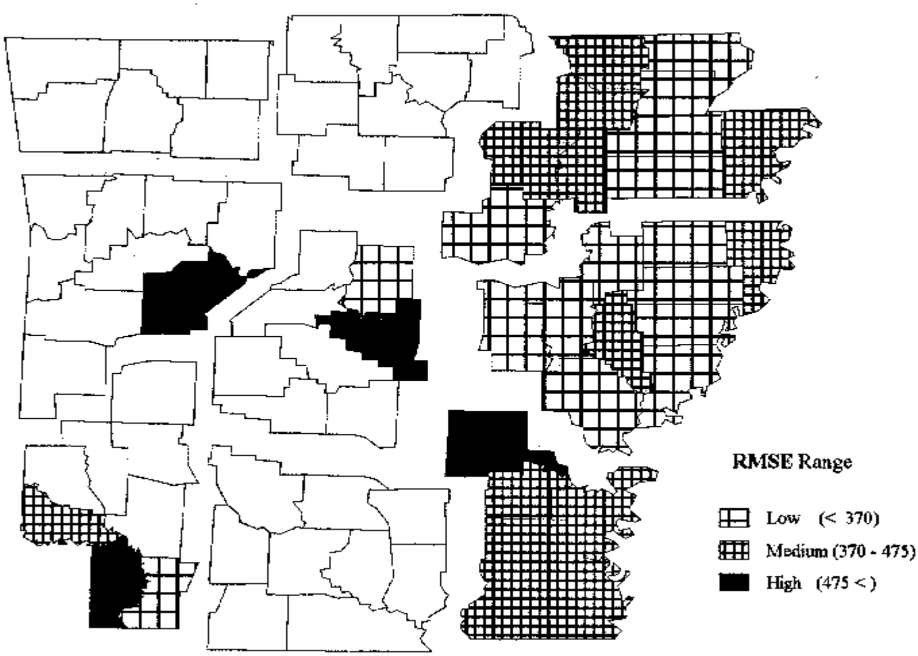

Fig. 1. Yield risk for rice-producing counties, Arkansas.

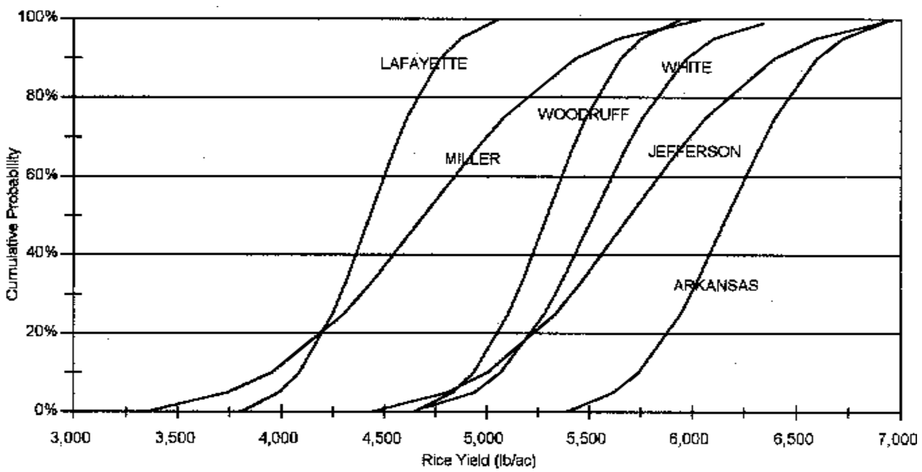

Fig. 2. Cumulative distribution functions (CDFs) of rice yield, six selected counties, Arkansas.

EL NIÑO'S EFFECTS ON GLOBAL RICE PRODUCTION, CONSUMPTION, AND TRADE

E.J. Wailes, G.L. Cramer, and J.M. Hansen

ABSTRACT

In this study, the Arkansas Global Rice Model (AGRM) is used to analyze the impact of El Niño on world rice yields, harvested area, production, consumption, and trade for 22 major rice-producing, consuming, and trading countries, and the impacts on Arkansas rice prices and returns. In the model, the countries directly affected by El Niño are India, Indonesia, Australia, and Brazil. El Niño effects on the Philippines are indirectly incorporated. The major rice trading countries are simulated from 1997 to 2005, assuming that no El Niño event occurs. This projection is referred to as the El Niño base line. The El Niño base line is compared to two alternative scenarios, which reflect two different degrees of El Niño, moderate and severe scenario.

India and Indonesia had the largest effect on the international rice market. Indonesia is one of the world's largest rice importers, and India, in recent years, has become one of the largest rice exporters trailing only Thailand, Vietnam, and the United States. The effect on India's rice exports was exceptionally large due to policy instruments incorporated in the Indian model which protect domestic consumers from higher international prices. Most countries are responsive to higher international prices and decrease consumption.

The results indicated that El Niño weather events, in important exporting and importing rice countries, have major effects on all countries participating in the international rice market. The results also indicate that the effects are relatively strong, but of short duration. By the third year, rice production, consumption, and trade were almost the same as the base line without El Niño. Exporting countries not directly affected by El Niño, such as Thailand, Vietnam, and the United States, greatly benefit from increased exports.

INTRODUCTION

Weather accounts for the largest variability in production, consumption, and trade in the world rice economy. In 1997, reports of El Niño conditions within the Pacific region contributed to increased uncertainty of the world rice market. Consistent weather anomalies associated with El Niño are well-known and this affected some major Asian rice-producing countries. The climates of these Asian countries are typically influenced by oceanic conditions. In the Pacific region, the Philippines, Indonesia, eastern Malaysia, and Australia are most greatly affected; and in the Indian Ocean region, all of India and Sri Lanka are affected. El Niño usually results in abnormally dry conditions and warmer climates for these countries. The drought of 1982-1983 in these regions was the result of El Niño climatic conditions, which were among the strongest El Niño effects of this century (Glantz, 1996).

El Niño was first defined in the late 18th century. Until the early 1960s, El Niño was only used to describe the local warming of ocean currents that moved southward along the Peruvian coast and usually occurred around Christmastime. The term "El Niño" today describes the warming of the tropical Pacific surface waters, which occurs every two to seven years. Associated with El Niño is an inverse correlation of surface pressure over the Pacific and Indian Oceans. This inverse correlation of surface pressure is measured by the Southern Oscillation Index (SOI) (Kiladis and Van Loon, 1988). Recent El Niños occurred in 1972-73, 1976-78, 1982-83, 1987, 1991-93 and 1997-98. The two most severe being 1982-83 and 1997-98.

Rice production, consumption, and trade in regions affected by El Niño have a significant impact on the world rice market. For the past five years, the combined countries of India, Malaysia, the Philippines, Indonesia, and Australia accounted for one-third of the world rice production, consumption, and rice stock inventory. During this time period, Indonesia, the Philippines, and Malaysia have imported 14% of the world rice trade, and India and Australia have shipped 15% of the world rice exports. Because these countries do account for one-third of the world's rice stock inventory, there could also be a significant effect on world rice stock levels.

OBJECTIVE

The objective of this research was to assess the potential impact of El Niño weather patterns on the international rice market. The effect of previous El Niño's on rice yield and area harvested were analyzed for these countries and it was determined that El Niño has had a significant effect on rice production in Indonesia, India, Philippines, and Sri Lanka. Information on the significance of El Niño effects was then applied to an econometric simulation model of the world rice economy, the Arkansas Global Rice Model (AGRM), to assess the impact of El Niño on major rice-producing and consuming countries. Specific effects on production, consumption, trade, and prices for different countries and types of rice were analyzed.

PROCEDURES

The AGRM is used to assess the impact of El Niño on world rice production, consumption, and trade. The countries under study are India, Indonesia, Philippines, Australia, and Malaysia. The AGRM is a representation of the world rice economy used to simulate world rice production, consumption, and trade. The model consists of 22 submodels (one for each country or region) which include the United States, Thailand, Pakistan, China, India, Burma, Vietnam, Australia, Japan, South Korea, Taiwan, Indonesia, the EU, Spain, Italy, Egypt, Iran, Iraq, Saudi Arabia, Brazil, Argentina, Uruguay, and the rest-of-the-world (ROW). The AGRM implicitly attempts to capture the imperfect nature of the international rice market by incorporating government policies in the model's supply, demand, export (or import), stocks, and price equations (Wailes *et al.*, 1996).

In this study, harvested area, production, consumption, and trade for India, Indonesia, Australia, Brazil, the United States (a major exporter), and the major rice-trading countries were simulated from 1997 to 2005 assuming that no El Niño event occurs. The base line incorporates current trading policies such as GATT and MERCOSUR, as well as domestic policies.The base line does not incorporate exogenous weather conditions. Area harvested and yield expectations were based on normal weather conditions.

Scenario 1 assumes a moderate El Niño effect on rice production. Area harvested is most affected by El Niño in these countries with only slight effects on yields. Moderate El Niño is evaluated by reducing the rice harvested area for only the year 1998 by 3% for Indonesia and 2.5% for India, Australia, and Brazil. The effect on Indonesia is 0.5% higher to incorporate the effects of the Philippines and Sri Lanka on the international market; all three countries are net importers. No price response is allowed to affect harvested area and yield equations in the El Niño countries for 1998. The area harvested equations in El Niño countries in 1999 are assumed to be directly unaffected by El Niño, but market forces such as higher prices, stock levels, international trade, do alter the 1999 scenario results from the baseline.

Scenario 2 assumes a severe El Niño with strong effects on production by reducing the harvested area for the same countries as evaluated in Scenario 1. Harvested area in 1998 is assumed to be reduced by 6% for Indonesia and 5% for India, Australia, and Brazil. The same price response conditions for 1999 are assumed to hold for this scenario as in Scenario 1.

Data used are from the United States Department of Agriculture, Production Supply and Distribution for production, consumption, trade, and ending stocks (USDA, 1997). Countries modeled in greater detail used country government statistics and USDA data. Price data were obtained from country government statistics. Policy instruments are incorporated for different countries such as GATT agreements, government support prices, and tariffs. Macroeconomic variables are exogenous.

RESULTS AND DISCUSSION

A moderate El Niño effect results in lower Indonesian harvested area in the year for the El Niño shock, 1998. In Table 1, results for Indonesia are presented. In 1998, production decreased 2.5% resulting in increased imports of 635. Production increased the following year and then leveled off with a slight increase. Imports were slightly lower for 1999-2005 because of increased production and slightly lower per capita consumption.

Results for Australia are presented in Table 2. The moderate El Niño has little effect on Australia. In 1998, area harvested decreased 2.4%. Production decreased 1.1% in 1998 which resulted in reduced exports of 1.1%. The Australian model returned to equilibrium in 1999.

In Table 3, results for India are presented. India's harvested area decreased 1.52% in 1998, which resulted in decreased production of 1.55%. Consumption was not affected because of assumptions and policy instruments, such as food subsidies, which are incorporated for this protected economy. By insulating the domestic consumption market from the international market, the decrease in exports is quite large. In 1998, exports decreased 75%. Harvested area and production, responding to higher international prices in 1999-2005, increase slightly, which results in increased exports of 0.25% in 1999.

Results for Brazil are presented in Table 4. In 1998, area harvested and production decreased by 2.5% resulting in increased imports of 7.0%. In 1999, Brazil responded to higher international prices and production increased 1.4%. This resulted in lower imports of 1.6%.

The severe scenario assumed a decrease in harvested area twice as large as the moderate scenario. Harvested area decreased by 5% for India, Australia, and Brazil. Indonesia harvested area decreased 6%. The effect is similar to the moderate scenario, but the response is larger. Indonesia imports increased in 1998 by 63%. Under the severe El Niño scenario, India decreased exports 150% (becoming a net importer) and then leveled off near the base line. Brazil increased imports 14% and leveled off with imports 1.5 to 3% lower.

In Table 1, results for prices are presented. The Thai 5% fob price increased 23% in 1998, and the average U.S. farm price increased 12%. The Thai 5% fob price was lower in 1999 by 7.6%. Under the severe El Niño scenario the Thai 5% fob price increased 57% in 1998 and decreased by 14% in 1999 because of increased global rice production and exports. Under this same scenario, the average U.S. farm price increased 30% in 1998 and decreased 24% in 1999 because of increased global rice production.

In 1998, the United States was affected by increased Thai 5% broken fob rice price in the international market. In Table 5, results for the United States are presented. In the United States, production did not respond in 1998 because of naïve price expectations incorporated in the supply equations. U.S. exports increased 6% in 1998, which came from decreased consumption and lowered ending stocks. From 2000-2005, production and exports oscillate toward an equilibrium with almost no effect in the rice market by 2005.

Under the severe El Niño scenario, U.S. rice exports increased 15% in 1998 and 18% in 1999, because producers responded to the higher price in 1998. From 2000-2005, production and exports oscillate toward equilibrium similar to moderate El Niño scenario, but with larger oscillations.

In Table 6, results for the world are presented. In the econometric simulation model, AGRM, world harvested area and production decreased 0.64% in 1998 under the moderate El Niño scenario. In 1998, world consumption declined 0.74% and world trade decreased 5.4%. Higher 1998 prices affected 1999 world production, which increased 0.5%. World consumption increased in 1999 by 0.22% because of lower world prices that year. Total trade increased 3.45% in 1999 because of increased supply caused by higher prices in 1998 and increased demand due to lower prices in 1999. In the Arkansas Global Rice Model, the world quickly established equilibrium for 2000-2005 with little difference in production, consumption, and world trade.

SIGNIFICANCE OF FINDINGS

This study was conducted in the summer of 1997 before the effects of El Niño in 1997-1998 were realized. Effects on India and Indonesia lead to large influences on the international rice market. Indonesia is one of the world's largest rice importers, and India, in recent years, has become one of the largest rice exporters behind Thailand, Vietnam, and the United States.

The results indicate that El Niño weather events, in major exporting and importing rice countries, have major effects on all countries participating in the international rice market. The results also indicate that the effects are relatively strong, but of short duration. By the third year, rice production, consumption, and trade are almost the same as the base line without El Niño. Exporting countries such as Thailand, Vietnam, and United States, which were not directly affected by El Niño, greatly benefit from increased exports.

RESEARCH IMPACT

1. This study should be of interest to private traders, governments, food agencies, and policy-makers because it indicates that the worldwide weather phenomenon caused by El Niño can have significant impacts on agricultural commodity markets in a relatively short time period, and those effects can be widespread.

2. The study may be a point of departure for studying and understanding other commodity markets in which El Niño or other global weather patterns may play a significant role in world markets, i.e., wheat, corn, and soybeans.

3. The study points out the importance of agriculture and meteorological research directed toward specific weather events which may occur sporadically but cause widespread damage and change the prices and returns to Arkansas rice farmers.

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Table 1. Impacts of El Niño on prices and on Indonesia's rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
Prices: Base line								
Average US farm price (US$/cwt.)	9.71	9.29	9.16	9.34	9.39	9.36	9.57	9.55
Thai 5% broken FOB price (US$/mt)	300.00	292.00	293.00	302.00	299.00	293.00	298.00	296.00
Scenario 1: Moderate El Niño, (change from base line)								
Average US farm price (US$/cwt.)	1.19	-0.97	0.35	-0.17	0.05	-0.03	0.00	-0.01
Thai 5% broken FOB price (US$/mt)	69.00	-22.00	2.00	-3.00	-1.00	-1.00	-1.00	-1.00
Scenario 2: Severe El Niño, (change from base line)								
Average US farm price (US$/cwt.)	2.96	-2.20	0.67	-0.34	0.09	-0.05	0.00	-0.01
Thai 5% broken FOB price (US$/mt)	170.00	-42.00	3.00	-6.00	-1.00	-2.00	-1.00	-1.00
Indonesia: Base line								
Area harvested base (1000 ha)	11700	11777	11836	11890	11942	11993	12043	12091
Production base (1000 mt)	34389	35026	35603	36155	36697	37230	37753	38262
Consumption base (1000 mt)	35719	36247	36779	37364	37875	38393	38948	39501
Imports base (1000 mt)	1342	1424	1405	1423	1205	1191	1226	1269
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	-293	3	3	2	2	1	1	1
Production (1000 mt)	-860	9	9	8	6	5	3	3
Consumption (1000 mt)	-12	-6	-3	-1	0	0	0	0
Imports (1000 mt)	847	-15	-12	-9	-6	-5	-3	-2
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	-702	8	8	7	5	4	3	2
Production (1000 mt)	-2063	23	23	20	16	13	10	7
Consumption (1000 mt)	-29	-16	-9	-4	-1	0	0	0
Imports (1000 mt)	2033	-39	-32	-24	-18	-13	-10	-7

Table 2. Impacts of El Niño on Australia's rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
Australia: Base line								
Area harvested base (1000 ha)	166	166	166	167	168	168	169	170
Production base (1000 mt)	1033	1041	1049	1058	1069	1082	1095	1109
Consumption base (1000 mt)	290	295	300	305	310	315	320	325
Exports base (1000 mt)	728	726	733	746	755	763	774	783
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	-4	0	0	0	0	0	0	0
Production (1000 mt)	-11	-1	0	0	0	0	0	0
Consumption (1000 mt)	0	0	0	0	0	0	0	0
Exports (1000 mt)	-8	-1	0	-1	0	0	0	0
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	-8.3	0.8	0.4	0.4	0.3	0.2	0.2	0.2
Production (1000 mt)	-22.4	1.9	1.0	0.9	0.7	0.6	0.6	0.5
Consumption (1000 mt)	0	0	0	0	0	0	0	0
Exports (1000 mt)	-16	-2	-1	1	1	2	1	1

Table 3. Impacts of El Niño on India's rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
India: Base line								
Area harvested base (1000 ha)	42874	42998	43076	43136	43255	43324	43386	43430
Production base (1000 mt)	84098	85753	87390	88952	90827	92519	94907	96490
Consumption base (1000 mt)	81998	83526	85078	86660	88283	89950	91665	93415
Net exports base (1000 mt)	1727	1798	1910	2015	2129	2241	2375	2499
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	-652	2	0	0	0	0	0	0
Production (1000 mt)	-1302	4	1	1	0	0	0	0
Consumption (1000 mt)	0	0	0	0	0	0	0	0
Exports (1000 mt)	-1302	4	1	1	0	0	0	0
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	-1304	4.4	0.9	0.6	0.1	0.0	0.0	0.0
Production (1000 mt)	-2306	11.1	2.5	1.5	0.3	0.1	0.0	-0.1
Consumption (1000 mt)	0	0	0	0	0	0	0	0
Exports (1000 mt)	-2603	11.1	2.5	1.5	0.3	0.1	0.0	-0.1

Table 4. Impacts of El Niño on Brazil's rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
Brazil: Base line								
Area harvested base (1000 ha)	3499	3511	3479	3470	3447	3439	3412	3402
Production base (1000 mt)	6558	6738	6836	6981	7102	7255	7371	7527
Consumption base (1000 mt)	8084	8151	8211	8267	8321	8415	8526	8653
Imports base (1000 mt)	1562	1422	1399	1320	1252	1204	1186	1165
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	-87	53	7	9	2	1	0	-1
Production (1000 mt)	-164	101	14	19	5	2	0	-1
Consumption (1000 mt)	-2	0	0	0	0	0	0	0
Exports (1000 mt)	110	-23	-32	-15	-12	-4	-2	0
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	-175	117	25.4	24.3	7.6	4.0	0.9	-0.3
Production (1000 mt)	-327	225	49.8	48.8	15.6	8.3	1.9	-0.6
Consumption (1000 mt)	-4.6	-0.9	-1.4	-0.9	-0.6	-0.3	-0.1	0.0
Exports (1000 mt)	218	-63	-83.9	-42.7	-31.1	-12.2	-8.2	-2.4

Table 5. Impacts of El Niño on United States' rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
United States: Base line								
Area harvested base (1000 ha)	1200	1215	1174	1152	1159	1153	1138	1147
Production base (1000 mt)	5866	6006	5842	5774	5843	5847	5808	5885
Consumption base (1000 mt)	3661	3721	3771	3827	3884	3934	4000	4068
Exports base (1000 mt)	2661	2565	2519	2461	2428	2399	2368	2356
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	0	12	-97	35	-16	4	-2	0
Production (1000 mt)	0	595	-463	165	-77	21	-12	-1
Consumption (1000 mt)	-15	-4	1	0	1	0	0	0
Exports (1000 mt)	161	173	-99	32	-20	2	-5	-3
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	0	306	-217	71	-32	9	-5	0
Production (1000 mt)	0	1473	-1034	332	-155	41	-23	1
Consumption (1000 mt)	-38	-12	3	1	2	1	1	0
Exports (1000 mt)	398	457	-211	66	-39	4	-9	-3

Table 6. Impacts of El Niño on the World's rice production, consumption, and trade.

Countries and scenarios	1998	1999	2000	2001	2002	2003	2004	2005
World: Base line								
Area harvested base (1000 ha)	149666	149992	150124	150276	150539	150672	150723	150831
Production base (1000 mt)	387513	392025	396090	400163	404979	408982	413297	417333
Consumption base (1000 mt)	385763	390653	395034	399797	404972	409482	413670	417837
Trade base (1000 mt)	16771	17105	17238	17532	17895	18120	18484	18765
Scenario 1: Moderate El Niño, (change from base line)								
Area harvested (1000 ha)	-1037	712	-64	145	34	47	32	31
Production (1000 mt)	-2337	1859	-1622	-31	-391	-255	-29	-6
Consumption (1000 mt)	-2844	854	37	245	117	109	95	79
Trade (1000 mt)	-899	591	-21	164	63	67	58	49
Scenario 2: Severe El Niño, (change from base line)								
Area harvested (1000 ha)	-2191	1674	-55	329	83	86	37	25
Production (1000 mt)	-5019	4361	-3079	-728	-1517	-1351	-1138	-976
Consumption (1000 mt)	-6070	1906	231	543	258	215	158	130
Trade (1000 mt)	-1636	1436	60	361	139	129	89	75

FROM MINIMUM ACCESS TO TARIFFICATION OF RICE IMPORTS IN JAPAN AND SOUTH KOREA

E.J. Wailes, G.L. Cramer, D.S. Lee, and J.M. Hansen

ABSTRACT

In this study the Arkansas Global Rice Model (AGRM) is used to examine the potential benefits and losses to Arkansas rice producers from tariffication of rice imports in Japan and South Korea, an issue that is becoming important in the next World Trade Organization (WTO) negotiations. Already positions are being established as Japan has announced a rice trade policy of rice tariffication in addition to a modified minimum access. However, the results of this study suggest that the benefits of pursuing tariffication are positive at the country, region, and global level of aggregation. Losses to rice producers in Japan and South Korea are found to be less than the gains to consumers and revenue for both countries, implying that both countries could be better off, even with full compensation for producer surplus losses. For both Japan and South Korea, net benefits are substantially higher than for the rest of the world.

INTRODUCTION

One of the significant achievements of the Uruguay round agreement for agricultural trade liberalization was the minimum access requirement for rice imports into Japan and South Korea (Wailes, Young, and Cramer, 1993, 1994). Rice imports were previously banned due to the high levels of domestic rice price support in both countries. Initial minimum access requirements were 4% for Japan increasing to 8% by 2000, and 2% for South Korea increasing to 4% by 2004. Analysis shows the volume of additional imports, initially 500 thousand mt in 1995, increasing to 850 thousand mt by 2000 have had large country effects on world prices, especially for the high quality, short-grain japonica varieties preferred by Japan and South Korea (Cramer, Wailes, and Shui, 1993; Kako, Gemma, and Ito, 1995; and Park, 1997). Higher prices have stimulated additional production, especially in Australia and the United States (Wailes *et al.*, 1997b). The next multilateral trade negotiations are approaching and there will be strong pressure by the export countries to push for tariffication of the minimum access import requirements and subsequent tariff reductions in line with other grains and oilseeds (USDA, Foreign Agriculture Service, 1995-1998).

OBJECTIVES

This research presents an analysis of the effects of tariffication compared to a continuation of the minimum access requirement for rice imports of Japan and South Korea. The objective of the research is to evaluate the effect of tariffication on world trade, prices, production, and consumption with respect to the 1) aggregate, 2) the United States, and 3) other major rice importing and exporting countries. This study should be of interest to policy-makers, governments, food agencies, and private traders because it indicates that domestic and trade policies can have significant impacts on agricultural commodity markets in a relatively short time period, and that the effects of specific policies vary.

PROCEDURES

The Arkansas Global Rice Model (AGRM), is an econometric model, which is disaggregated for 22 of the major rice importing and exporting countries, by long- and medium/short-grain rice markets. This representation of the world rice economy is used to simulate rice trade which includes the countries of Thailand, United States, Pakistan, China, India, Burma, Vietnam, Australia, Japan, South Korea, Taiwan, Indonesia, the EU, Spain, Italy, Egypt, Iran, Iraq, Saudi Arabia, Brazil, Argentina, Uruguay, and the rest-of-the-world (ROW) (Wailes *et al.*, 1997a). The AGRM implicitly attempts to capture the imperfect nature of the international rice market by incorporating government policies in the model's supply, demand, export (or import), stocks, and price equations.

AGRM is used to simulate a base line projection to 2010 assuming a continuation of the minimum access requirements (Wailes *et al.*, 1997a). Sensitivity analysis is conducted with respect to an initial tariffication rate and a rate of tariff reduction. The research highlights the importance of these parameters that likely will be critical issues in the negotiation phase of the next WTO agreement.

The tariffication scenario requires that an import demand elasticity, with respect to price, be estimated for Japan and South Korea. This estimate is derived from the econometric estimates of the domestic demand and supply elasticities weighted by import share to consumption and production, respectively. The import demand elasticities are estimated to be -5.12 for South Korea and -2.98 for Japan (Lee, 1997). Trade and price effects of tariffication are then possible to estimate for both countries.

The base line scenario assumes that the minimum access requirements increase at the same rate as under the current agreement. Japan is assumed to increase imports as a percent of domestic consumption from 8% in 2001 to 14% by 2010. South Korea is assumed to increase import tariffs from 5% in 2005 to 8% by 2010. The tariffication scenario begins with an estimate of the tariff rate equivalent in the year that the current agreement expires, 2000 for Japan and 2004 for South Korea. The tariff rate equivalent is based on a border price off the United States California medium-grain No. 2 fob price. For Japan, the initial tariff rate equivalent using this method is 910% and for

South Korea, 290%. Under the tariffication scenario, Japan is assumed to reduce import tariffs by 6% annually over the period 2001 to 2010. The same tariff reduction rate is assumed for South Korea, except it is applied only to the period 2005 to 2010.

The models for Japan and South Korea are simulated based on the policy objective of maintaining desirable levels of ending stocks. Desired ending stocks are assumed to be 15% of domestic consumption for both countries.

RESULTS AND DISCUSSION

With the import-quota base line and tariffication scenario, Japanese domestic prices decrease, but more rapidly under tariffication. The domestic rice price decreases with tariffication from $4170 / mt in 2001 to $2425 / mt in 2010, at an average annual decrease of 5%. In the base line, price decreases from $4308 / mt in 2001 to $3451 / mt in 2010, only a 2% average annual decrease. Imports increase at a faster rate with tariffication from 875,000 mt in 2001 to 3,506,000 mt by 2010. With the import-quota, imports increase from 805,000 mt in 2001 to 1,421,000 mt by 2010. With tariffication, Japanese domestic price is less by $1026 / mt by 2010 and imports are greater by 2.09 mmt compared to the baseline import-quota.

The impact on South Korea's domestic prices and imports under tariffication and import-quotas also show that prices are lower and imports are higher under tariffication compared to the base line import-quotas. With tariffication in 2005, domestic price is $1674 / mt and decreases to $1373 / mt by 2010. With continuation of the minimum access, price only decreases to $1490 / mt by 2010, which is $117 mt higher than under tariffication. Imports increase from 226,000 mt in 2005 to 623,000 mt by 2010 under tariffication. In the base line, imports increase from 231,000 in 2005 to 410,000 mt by 2010, which is 213,000 mt less than tariffication. Because the initial level of protection is much lower in South Korea than Japan, the impacts of tariff reduction are also smaller for South Korea, given the same percentage reduction in tariffs.

Tariffication results in higher world short-grain rice trade and export prices than under the import-quota base line.With tariffication, world japonica trade increases from 3.7 mmt in 2001 to 4.5 mmt by 2010. Under import-quotas, japonica trade decreases to 3.5 mmt by 2010 which is 1 mmt (equal to approximately 5% of total world rice trade) less than under tariffication. The world japonica price increases from $401 / mt in 2000 to $455 / mt by 2010, $28 / mt higher than the import-quota base line.

To achieve the desired rice stock levels, rice land diversion is necessarily higher with tariffication in Japan. By 2010, only 1,107 thousand ha are needed with tariffication compared to 1,403 thousand ha under the base line. Japanese rice production with tariffication is only 6 mmt compared to 7.61 mmt in the base line.This means that the rice self-sufficiency ratio for Japan would decrease from 86% to only 64% as a result of tariffication. Lower prices with tariffication result in higher consumption by 2010– 3.32 more kg per capita or 471 thousand mt of total rice consumption.

The adjustments on South Korea's rice economy are less severe than for Japan. By 2010, area harvested is lower with tariffication, 866 thousand ha compared to 905 thousand ha in the base line analysis. Production is lower by 204 thousand mt and the self-sufficiency ratio falls from 92% to only 88% with tariffication. Differences in per capita consumption are slight due to the low demand elasticity with respect to price. Total consumption is higher with tariffication by only 9000 mt by 2010.

The economic welfare effects of tariffication of rice imports in Japan and South Korea are given. The results reveal that while losses to Japan's rice farmers are large, the consumer and revenue effect of moving to tariffication are substantially larger and the stream of net benefits to Japan as a whole are US $233 million in 2001, increasing to $4.94 billion by 2010. South Korea has negative net benefits of $8 million in the first year 2005, but becomes positive in 2006 of $26 million, and increases to $197 million by 2010. In 2005, net benefits are negative because consumer surplus and revenue effects are negative, and producer surplus is positive because the domestic price under the tariffication scenario is greater than the import quota base domestic price. However, in the following years, the negative producer surplus and positive consumer surplus and revenue effects result in positive net benefits. The welfare gains to net exporters in the rest of the world increase from $7 million in 2001 to $111 million by 2010. The global net gain from tariffication is substantial, with most of the benefits accruing to Japan. Net benefits increase from $241 million in 2001 to $5.25 billion by 2010.

SIGNIFICANCE OF FINDINGS

The results of this study suggest that the benefits of pursuing tariffication are positive at the country, region, and global level of aggregation. Losses to rice producers in Japan and South Korea are estimated, and are found to be, less than the gains to consumers and revenue for both countries implying that both countries could be better off, even with full compensation for the producer surplus losses. Net benefits are substantially higher for both Japan and South Korea than for the rest of the world.

RESEARCH IMPACT

This research demonstrates the importance of rice trade policy for U.S. rice producers. The results provide information necessary to develop varieties and resource commitment in the United States that can satisfy the Japanese and Korean markets subject to tariff or minimum access rules.

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ECONOMIC IMPACTS ON ARKANSAS RICE FROM GROUND WATER DEPLETION

E.J. Wailes, G.L. Cramer, K.B. Young, and P. Tacker

ABSTRACT

A computer model has been developed that simulates the collection and use of surface water in on-farm reservoirs for rice and soybean irrigation. The model estimates the costs and returns of reservoir use in different farm resource situations.

INTRODUCTION

Ground water depletion is a significant problem facing Arkansas rice producers. By 1997, six eastern counties had already become critical ground water areas as a result of over pumping. Additional counties have been added since then. 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 wasted rainfall runoff and tail water losses; however, many farmers have been reluctant to invest in high-cost, on-farm reservoirs until their ground water supply becomes critical to maintain irrigation.

The purpose of this research was to provide benefit and cost information to the rice producer, industry, and public policy decision-makers on the use of surface water for irrigation of Arkansas rice. A farm irrigation simulation model has been developed to evaluate the use of on-farm reservoirs as a means of increasing surface water use and extending the use of available ground water. The simulation model is designed to model a rice-soybean farm over a 30-year period with daily computation of reservoir and ground water use, crop water requirements, aquifer response to pumping, and crop yield response to water use during the growing season.

PROCEDURES

The Arkansas Offstream Reservoir Analysis (ARORA) model was developed by Edwards and Ferguson (1990) for soybean irrigation analysis. It was modified in our study to add rice production, provide adjustability to shift between rice and soybean production, include the capture of surface water runoff, and better evaluate the costs and returns of adding an on-farm reservoir to a farm irrigation system (Young, Wailes, and Smartt, 1998).

The modified model referred to as MARORA has been used to evaluate investment in on-farm reservoirs. Alternative farm resource conditions were simulated to measure the effect of on-farm reservoirs on annual net income over a 30-year period. The MARORA is currently being further refined to evaluate representative farms, located in different subregions of the delta, under research funding by the Rice Research and Promotion Board (RRPB).

Results were evaluated for varying ground water supply situations: (1) initial saturated thickness of 50 or 25 ft, and (2) annual water table decline rates of one ft, 0.75 ft and 0.5 ft. Crop prices evaluated were $5.40, $6.75, and $8.10 per bu for soybeans and $4.00, $5.00, and $6.00 per bu for rice. Alternative discount rates used to calculate the present worth of net farm income over a 30-year period were 4 and 8%. Crop production costs were based on Cooperative Extension Service budget data. The analysis was done for 160 cultivated acres with a crop rotation of one-third rice and two-thirds soybeans with the choice available to discontinue rice if it was not profitable, or to continue rice irrigation over the 30-year period. Soybeans could be either fully or partially irrigated or shifted to dry land soybeans, with a corresponding yield adjustment, if it was not profitable to continue irrigation.

RESULTS AND DISCUSSION

Reservoir construction on farms, with 50 ft initial saturated thickness, was estimated to not be economically justified for an individual farmer without other financial assistance. At the 25 ft initial saturated thickness level, typical of the critical water areas in Arkansas, the MARORA model selected an optimal reservoir size of 250 acre-feet capacity at both discount rates with the medium and high crop price levels, and 170 acre-feet capacity with the low crop prices at all three rates of annual water table decline. The reservoir with 250 acre-feet capacity displaced 34 acres of crop land allowing production of 84 acres of soybeans and 42 acres of rice on 160 acres. Estimated reservoir cost for 250 acre-feet capacity included $41,604 for excavation, $7,467 for seeding levees, and $16,000 for fill and discharge pumps with a 2200 GPM discharge rate. This reservoir cost compared with about $10,400 for installing a new well, plus pump and gear head, capable of pumping about 1100 GPM.

To estimate the public funding needed to induce producers to invest in on-farm reservoirs before the ground water supply becomes critical, we have used MARORA to address this question using alternative approaches.

1) Lump sum approach. Since a 250 acre-foot reservoir eventually would be selected as optimal according to our model assumptions when the water table declined to 25 ft, a comparison was made of the effect on present worth of 30 years net annual income from 160 acres if the farmer was assumed to build the reservoir when the water table was still at 50 ft saturated thickness (Table 1). The estimated difference in present

value or worth of the projected net annual income is $178,700 to $137,100, i.e., about $41,600. Thus the farmer would need this lump sum incentive to be persuaded to build a 250 acre-feet reservoir at the outset of the 30-year period. This incentive required from public funding is equivalent to about a 62% cost share of the total estimated reservoir cost (excluding the value of the land used for the reservoir and diverted from crop production). A 250 acre-feet reservoir could supply all irrigation requirements, without depending on ground water pumping, and would be sustainable beyond 30 years if sufficient surface water were available to fill this size of reservoir.

2) Cost share approach. Another approach used to estimate the public funding needed to induce private reservoir investment was done by determining the cost share in reservoir excavation. Assuming an annual 1 ft water table decline, a cost share of 2:1, public to private, resulted in a 200 acre-feet reservoir. The 200 acre-feet reservoir provides adequate irrigation up to 30 years. With this cost share, income compared favorably with farm income without a reservoir.

SIGNIFICANCE OF FINDINGS

Many farm operations in the delta are experiencing problems in maintaining ground water irrigation and are looking for solutions. The MARORA model is being developed as a tool that can be applied with a personal computer to evaluate the irrigation system of individual farms over a projected 30-year period.

Benefits of an on-farm reservoir will vary for different farm situations depending on the local and regional ground water supply conditions and other factors. In many cases, public assistance is likely to be needed to make it economically feasible for farmers to construct on-farm reservoirs before the water table declines to a critical level. MARORA has therefore also been designed to answer the public assistance issues.

ACKNOWLEDGMENTS

The model was initially improved with a grant from the USGS and is currently being further refined to evaluate a wider range of farm situations for representative delta farms with support of the Rice Research and Promotion Board.

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Table 1. Present worth of 30-years projected annual net income with and without a 250 acre-feet reservoir.[z]

Factor	Without reservoir	With reservoir
Years of irrigation[y]	24	30
Reservoir size	0	250
PW of income ($1,000)[x]	178.7	137.1
Rice area[w]	53.3	42
Soybean area	106.7	84

[z] Assumes initial 50 ft saturated thickness and 1 ft/year decline rate. Calculated for a 160 acre area with price of $6.75 per bu for soybeans and $5.00 per bu for rice.

[y] Defined as at least 75% of average application rate.

[x] Present worth of projected annual net income from the 160 acre area discounted at 8% per year.

[w] Shifted 100% to soybeans when irrigation terminated.

QUALITY CHARACTERISTICS OF MEDIUM-GRAIN RICE MILLED IN A THREE-BREAK COMMERCIAL MILL

H. Chen, T.J. Siebenmorgen, and L. Du

ABSTRACT

A medium-grain rice cultivar, 'Bengal', was milled to three degree of milling (DOM) levels in a three-break commercial milling system and separated into four thickness fractions. Thin kernels were milled at a greater bran removal rate, as indicated by surface lipid content (SLC), than thick kernels. For rice milled to a low DOM level, thin kernels had significantly higher SLC and protein content than thick kernels. For well-milled rice, SLC tended to be uniform across thickness fractions, while protein content varied across thickness fractions in a way similar to kernels milled to a low DOM level.

INTRODUCTION

Within all rice varieties, individual kernels vary in size. The effect of kernel size on milling performance and quality has been studied (Matthews and Spadaro, 1976; Wadsworth *et al.*, 1982; Sun and Siebenmorgen, 1993; Chen and Siebenmorgen, 1997). These studies focused on long-grain rice milled in single-break, laboratory or commercial-scale friction mills. It was reported that as rice was milled from a low to high degree of milling (DOM) level, more surface bran was removed from thin kernels than from thick kernels. Concurrently, thin kernels were broken at a greater rate than thick kernels.

There is an increasing trend to use multi-break milling systems in the rice industry. Chen *et al.* (1998) conducted research on the milling performance of long-grain rice in both single-break and triple-break commercial milling systems. It was found for both milling systems that the surface lipids content (SLC) and protein content of the milled rice varied significantly across kernel thickness fractions. SLC was influenced by DOM level more than by kernel thickness, while the protein content was influenced by thickness more than by DOM level. As milling progressed from a low to high DOM level, thin kernels were milled at a greater bran removal rate than thick kernels, as indicated by SLC. However, the protein content decreased much more uniformly across thickness fractions than did SLC during milling.

All the above work was limited to long-grain rice. The objective of this work was to investigate the bran removal characteristics of medium-grain rice milled in a multi-break commercial milling system.

PROCEDURES

The three-break commercial milling system used for this study comprised a Satake VTA vertical rice whitener (first break), a Satake VBF vertical rice whitener (second break), and a Satake KB-40 rice polishing machine (third break) located at Jonesboro. Brown rice was fed into the top of the VTA machine, which applied an abrasive milling action as the rice flowed downward through the mill. The rice from the VTA machine was then fed into the top of the VBF machine, which applied a friction milling action to the kernels. Additionally, water mist was injected into the milling chamber of the VBF machine. The rice from the VBF machine then flowed horizontally through the KB-40 machine, which applied a friction milling action to polish the rice.

In the production of milled rice for cereal manufacturers, which entails milling to a much lower DOM level than for most milled rice customers, the system was adjusted to remove only part of the bran from kernels. For this application, brown rice was passed sequentially through only the first two breaks (VTA and VBF). In order to produce well-milled rice (medium or high DOM levels), brown rice was passed sequentially through all three breaks. This commercial milling system was slightly different from the commercial milling system used previously for investigating long-grain rice milling performance (Chen *et al.*, 1998) in that the second break for the system reported herein was a VBF machine, while that used by Chen *et al.* was a KB-40. Both of these milling machines, however, are friction-type mills.

A medium-grain rice cultivar, Bengal, at approximately 14%[1] moisture content (MC), was milled in the three-break system in May 1997. The system was adjusted by professional milling personnel to yield three DOM levels (low, medium, and high). A single set of milled rice samples was collected from the outlet of the first two breaks at the low DOM level and from all three breaks at medium and high DOM levels. All milled rice samples were separated into head rice and broken rice in a Satake test rice grader. Head rice was then separated into four thickness fractions (<1.79, 1.79-1.84, 1.84-1.89, >1.89 mm) using a Carter-Day laboratory precision sizer. Each thickness fraction was measured for surface lipids content (SLC) and protein content.

Surface lipids of the milled head rice samples from each thickness fraction were extracted in a Soxtec System HT extractor, which consisted of an extraction unit (model 1043) and a service unit (model 1044), as used previously (Chen and Siebenmorgen, 1997; Chen *et al.*, 1998). Prior to extraction, 5 g of head rice was placed in a cellulose extraction thimble (diameter 26 mm, length 60 mm) and dried in a convection oven at 100°C for one hour. The thimble and dried sample were then presented to the extractor for surface lipids extraction. The surface lipids content (SLC) was calculated as the amount of extracted surface lipids expressed as a percentage of the original head rice mass (5 g). For each sample, duplicate measurements were performed.

Protein content of milled rice samples was measured in a Fisons NA-2000 Nitrogen / Protein Analyzer by means of the Dumas technique (Schmitter and Rihs, 1989).

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[1]Unless otherwise specified, all moisture contents are presented on a wet basis.

Prior to measurement, head rice samples from each thickness fraction were ground in a UDY cyclone sample mill with a 0.5-mm screen. A ground sample of 50 mg was placed into a tin capsule and loaded into the analyzer. The sample was melted and converted to combustion gases at 900°C in a combustion reactor. Nitrogen was then separated from the combustion gases and detected by a thermal conductivity detector. Protein content (expressed on a dry basis) of each sample was calculated as the detected nitrogen content multiplied by a calibration constant of 5.95. Duplicate measurements were performed.

The experimental data were statistically analyzed. Using Duncan's multiple range test (SAS Institute 1996), thickness fractions at each DOM level for all three breaks were grouped according to SLC and protein content (Table 1).

RESULTS AND DISCUSSION

Compared with several long-grain rice cultivars ('Alan', 'Katy', 'Newbonnet', and 'Kaybonnet') investigated earlier (Chen and Siebenmorgen, 1997; Chen *et al.*, 1998), Bengal had greater overall kernel thickness, and was more uniform in thickness as indicated by a narrower thickness range. For milled rice at each of the three DOM levels, Bengal had similar SLC and lower protein content in comparison with the long-grain rice cultivars tested earlier.

For rice leaving the first break (VTA), the thinnest kernel fraction had higher SLC than other thickness fractions at all three DOM levels (Table 1). The ranges of SLC across thickness fractions were 0.21, 0.12, and 0.09 percentage points (pp) respectively at low, medium, and high DOM levels. For rice leaving the second break (VBF), the thinnest kernel fraction had higher SLC than the other thickness fractions only at low and medium DOM levels, and corresponding ranges were reduced to 0.12 and 0.05 pp. For rice leaving the second break (VBF) at the high DOM level and leaving the third break (KB-40) at medium and high DOM levels, the SLC was not significantly different across thickness fractions. As milling progressed from a low to high DOM level, or from one break to another, SLC was reduced at a greater rate on thin kernels than on thick kernels. In all the milling settings, thin kernels had higher protein content than thick kernels (Fig.1 and Table 1). Increasing the DOM level from low to high did not significantly influence the distribution of protein content across thickness fractions.

For rice milled to the low DOM level (Fig.1), the thinnest kernel fraction (<1.79) had higher SLC than the other kernel fractions, and thin kernels had higher protein content than thick kernels across the entire thickness range. For more well-milled rice (medium and high DOM levels in Fig.1), SLC was not significantly different across thickness fractions, while protein content decreased almost linearly with increases in kernel thickness. The trends of SLC distribution across thickness fractions were similar to those of long-grain rice. However, the near linear trends of protein content distribution were different from those of long-grain rice, which approximated the general trends followed by the SLC distributions.

The head rice milled to a high DOM level had fewer thick kernels (>1.89 mm) and more thin kernels (<1.79 mm) than the rice milled to low and medium DOM levels (Fig.1). One possibility causing the shift of mass distribution towards thinner kernel fractions was that the thickest kernels (>1.89 mm) were broken at a higher rate than thinner kernels in the three-break commercial milling system. Another possibility was that bran removal during milling caused an effective reduction in kernel thickness. As a result of increased milling and reduced kernel thickness, kernels would "move" to the adjacent, thinner thickness fractions. At this stage, no conclusion could be made as to which possibility was the predominate factor causing mass distribution change.

SIGNIFICANCE OF FINDINGS

For the medium-grain rice Bengal, milled at a low DOM level in a three-break system, the thinnest kernel fraction (<1.79 mm) had considerably higher SLC and protein content than other kernel fractions. Since SLC of kernels affects end-use processing, this could have ramifications to cereal producers using this rice. The high protein levels of thin kernels could have ramifications in producing new value-added products in which high protein content is desired.

ACKNOWLEDGMENTS

We thank Riceland Foods for their cooperation in this research. We also wish to acknowledge the financial support of the Arkansas Rice Research and Promotion Board, the University of Arkansas Institute of Food Science and Engineering, and the corporate sponsors of the University of Arkansas Rice Processing Program.

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Table 1. Surface lipids content (SLC) and protein content[z] across thickness fractions for three degree of milling (DOM) levels at the exit stream of each of the three breaks of a commercial milling system.

Kernel	Low DOM		Medium DOM			High DOM		
thickness	VTA	VBF	VTA	VBF	KB40	VTA	VBF	KB40
(mm)	(%)							
Surface lipids content								
<1.79	1.04 a[y]	0.72 a	0.85 a	0.53 a	0.46 a	0.77 a	0.46 a	0.38 a
1.79-1.84	0.90 b	0.63 b	0.77 ab	0.48 b	0.42 a	0.69 b	0.42 a	0.33 a
1.84-1.89	0.83 c	0.60 b	0.74 b	0.49 b	0.42 a	0.68 b	0.42 a	0.35 a
>1.89	0.85 c	0.63 b	0.73 b	0.50 b	0.44 a	0.69 b	0.43 a	0.35 a
Protein content								
<1.79	7.80 a	7.78 a	7.68 a	7.50 a	7.38 a	7.80 a	7.43 a	7.38 a
1.79-1.84	7.63 a	7.20 b	7.30 b	7.25 b	7.08 b	7.33 b	7.13 ab	7.08 ab
1.84-1.89	7.35 b	7.20 b	7.23 b	7.10 bc	6.80 c	7.20 b	6.83 bc	6.75 b
>1.89	7.18 b	6.90 c	7.05 b	6.98 c	6.63 d	6.98 c	6.63 c	6.70 b

[z] Values are the mean of duplicate measurements.
[y] Values in each column followed by the same letter are not significantly different at P=0.05 using Duncan's multiple range test.

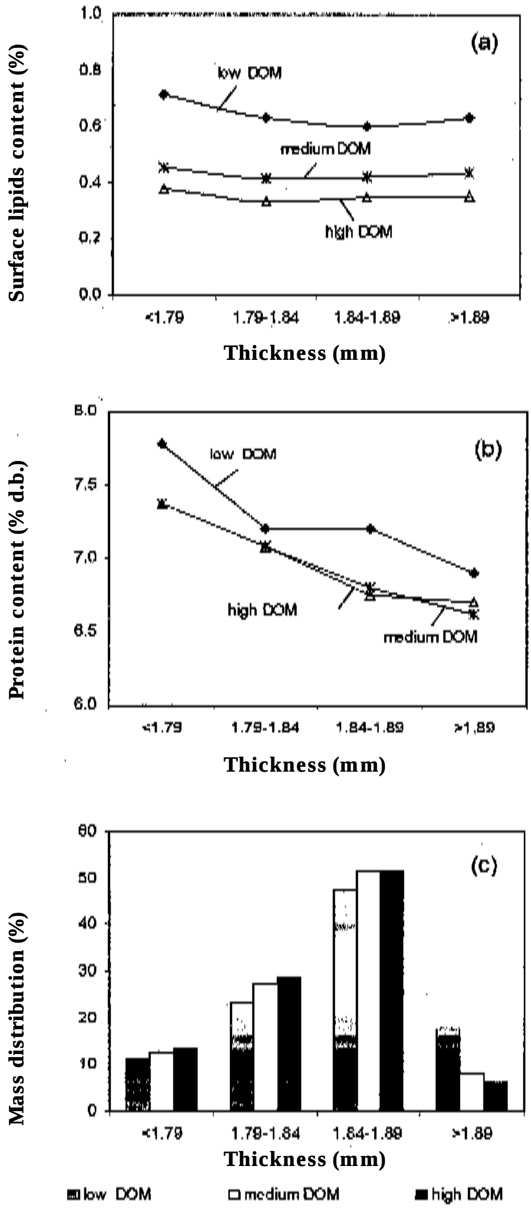

Fig. 1. Surface lipids content (a), protein content (b), and mass distribution (c) of head rice thickness fractions at the indicated degree of milling (DOM) levels for Bengal medium-grain rice milled in a multi-break commercial milling system. Data at the medium and high DOM levels represents rice milled by sequentially passing through Satake VTA, VBF, and KB-40 milling machines, while that at the low DOM level was passed through only the VTA and VBF machines.

EFFECTS OF DRYING CONDITIONS ON HEAD RICE YIELD REDUCTION OF LONG- AND MEDIUM-GRAIN RICE CULTIVARS

J.Fan and T.J. Siebenmorgen

ABSTRACT

This research investigates the effects of drying air conditions and drying duration on head rice yield reduction (HRYR). The rice cultivars used were 'Bengal', 'Kaybonnet', and 'Cypress', harvested at moisture contents (MCs) of ~16-26% from Stuttgart and Keiser. The rough rice was dried under three conditions: A (110°F, 38.2% RH, 9.5% equilibrium moisture content [EMC]), B (125°F, 24.9% RH, 7.3% EMC); and C (140°F, 16.9% RH, 5.8% EMC). The results indicate that HRYR depends on grain type, harvest MC (HMC), and drying air condition. Medium-grain Bengal rice exhibited more HRYR than did long-grain Cypress or Kaybonnet rices under a given drying condition. Rice harvested at higher MCs had less HRYR for given drying durations. The results further indicate that a decrease in MC of rice at the early drying stages did not significantly affect the head rice yield (HRY) until a certain MC level was reached. The allowable amount of MC removed before HRYR occurred increased as rice HMC increased.

INTRODUCTION

Rough rice should be dried to a certain MC, typically 12 to 13%, prior to storage. Drying creates moisture and temperature gradients within a kernel, which induces the development of tensile stress at the surface and compressive stress at the interior of the kernel (Sharma and Kunze, 1982; Sarker *et al.*, 1996).

Improper drying operations result in extensive kernel fissuring with a significant HRYR during subsequent milling (Henderson, 1957; Arora *et al.*, 1973). Sharma and Kunze (1982) observed that only a small number of kernels fissured during drying, but most kernel fissuring occurred within 48 hours after drying. Sarker *et al.* (1996) reported that a high initial MC and/or high drying air temperature produced a great number of fissured kernels. A recent, related investigation (Chen *et al.*, 1997) indicated that HRYR can be related to drying rate constant and drying duration.

The objectives of this ongoing research are to determine the drying behavior of long- and medium-grain rice cultivars harvested at various MCs and locations. The data are presented in a manner so as to provide information on the number of points of MC that can be removed per pass at various MCs with HRYR.

PROCEDURES

Three rice cultivars were studied: Bengal (medium-grain), Cypress, and Kaybonnet (long-grains). They were harvested at various MCs ranging from 16 to 26% from the Rice Research and Extension Center at Stuttgart, and the Northeast Research and Extension Center at Keiser, in the fall of 1996.

After harvest, the rice was immediately transported to the University of Arkansas Rice Processing Lab at Fayetteville and cleaned using a dockage tester (Carter Dockage Co., Minneapolis, Minnesota). Top and middle screen sizes used for both long- and medium-grain cultivars were no. 28 and no. 25, respectively, while the bottom screen size for the long- and medium-grain types was a no. 22 and no. 4, respectively.

Drying was conducted using three relative humidity and temperature control units (Climate-Lab-AA, Parameter Generation and Control, Inc., Black Mountain, North Carolina). Each control unit supplied air to a drying chamber. The control units were separately set to drying condition A (110°F, 38.2% RH), condition B (125°F, 24.9% RH); or condition C (140°F, 16.9%RH); with corresponding EMCs of 9.5%, 7.3%, and 5.8%, respectively. Each drying chamber consisted of 16, 6- x10-inch screen trays. For each drying run, about 300 g of rough rice was spread uniformly onto each screen tray to give a rice layer thickness of ~2 cm. Samples were removed at set durations to produce various levels of MC removed. The drying duration for each drying air condition was allocated as follows: 0, 10, 20, 30, 60, 90, 120, and 180 minutes for condition A; and 0, 10, 20, 30, 45, 60, 90, and 120 minutes for conditions B and C. The MC of samples removed from the drier was measured using an oven drying method (ASAE, 1995).

Upon removal from the dryer, after a given duration, the samples were immediately transferred to a conditioning chamber held at 21°C, 50%RH, which corresponds to a rice EMC of ~12.5%. After the samples reached equilibration, the samples were placed in sealed plastic bags and were held in cold storage at 4°C for three or four months prior to milling.

To determine milling quality resulting from the drying treatments, two 150 g subsamples of each rough rice sample were hulled using a McGill sample huller (Rapsco, Brookshire, Texas) and the resultant brown rice was milled for 30 seconds using a McGill no. 2 laboratory mill (Rapsco, Brookshire, Texas) with a 1.5 kg weight positioned on the mill lever arm 15 cm from the centerline of the milling chamber. The head rice was collected by using a double tray shaker table, with both trays having 4.76 mm indentions. The milling quality of the dried rice was evaluated in terms of HRY, which was defined as the percentage of head rice mass remaining from the original 150 g rough rice sample.

RESULTS AND DISCUSSION

Figure 1 shows the HRY of medium-grain Bengal (22.5% HMC) dried under the three drying conditions. The rice dried under condition A showed no reduction in HRY, regardless of drying duration. HRY for condition B did not change with drying duration until being dried for 50 minutes; after that, a significant HRYR was observed. When the rice was dried under condition C, a severe drying condition with high air temperature and low relative humidity, the HRY decreased rapidly in the early stages of drying. For example, the rice dried at condition C for 30 minutes resulted in approximately 10% of HRYR. At a given drying duration, Bengal exhibited more HRYR than did Cypress or Kaybonnet, particularly under drying condition C.

HRYR is also affected by harvest MC. Figure 2 shows the effect of HMC on HRY of three Bengal rice lots dried under condition C. For rice lots with HMCs of 17.4% and 22.5%, HRY significantly decreased after drying for 10 minutes. The rice with high HMC (25.9%) could be dried for a longer duration (up to 20 minutes) without affecting the HRY. For a given drying duration and drying air condition, a lower HMC resulted in more HRYR. For example, for Bengal with HMCs of 25.9%, 22.5%, and 17.4%, the resulting HRY after 30 minutes of drying was 55.6%, 52.3%, and 38.5%, respectively (Fig. 2). The effect of HMC on HRY was less at drying conditions A and B than that at condition C.

Figure 3 shows a correlation between HRY and the MC of Cypress rough rice achieved by drying the indicated HMC lots for various drying durations under drying air condition C. Drying of Cypress rice from its harvest MC of 24.6% to a MC around 19% did not significantly influence the resulting HRY. However, further drying rough rice to a lower MC caused marked reduction in HRY. A similar trend was observed for Cypress rice lots harvested at MCs of 19.8% and 16.5%. It was shown that the MC of the rough rice greatly decreased at the early drying stages but the HRY was not significantly affected. The results in Fig. 3 also indicate that the amount of moisture which can be removed before a certain HRYR occurred, depended on HMC of the rice (i.e. the higher the HMC, the more moisture that could be allowed to be removed without decreasing HRY).

Following on the general finding depicted in Fig. 3, Fig. 4 shows percentage points of MC removed before HRYR occurred as a function of HMC. The amount of allowable MC that could be removed prior to HRY reduction increased as the HMC of the rice increased. When drying air condition was severe (e.g. condition C), the amount of moisture allowed to be removed decreased. For a given drying air condition, Cypress, a longer, more slender kernel cultivar, was allowed to have more percentage points of MC removed per pass than could Bengal, a shorter, more bold kernel type.

SIGNIFICANCE OF FINDINGS

Increases in HRY, even by 1%, would bring significant increased value to the Arkansas rice industry. These results demonstrated the effect of drying air conditions and drying duration on HRY. The relationship between HMC and percentage points of MC removed before a certain HRYR occurred could be valuable for the design and operation of dryers. Additionally, these data will be used as base information for a working hypothesis explaining fissure formation in rice kernels during the drying process.

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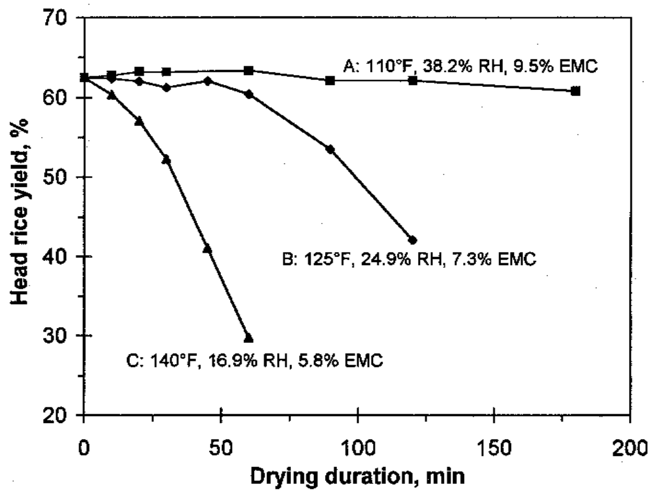

Fig. 1. Changes in head rice yield of Bengal (harvested at 22.5% MC) with drying duration under the three indicated drying air conditions.

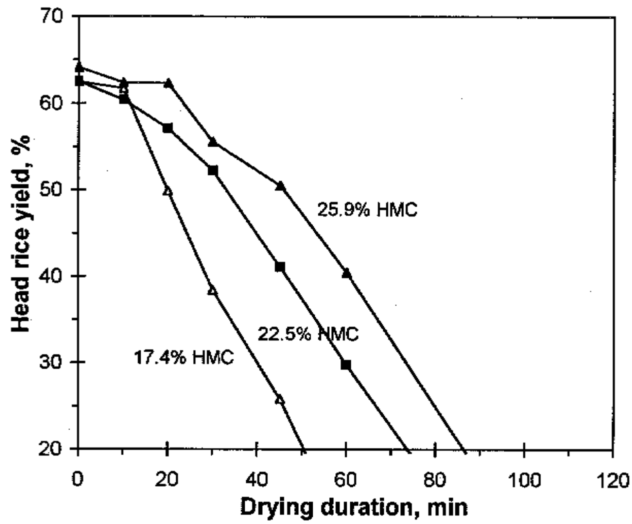

Fig. 2. Effect of harvest moisture content (HMC) on head rice yield of Bengal at drying condition C.

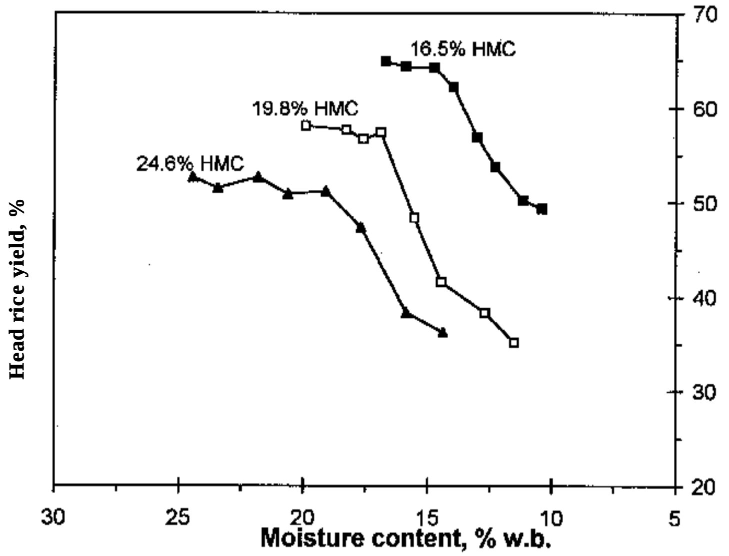

Fig. 3. Head rice yield of Cypress vs. moisture content achieved by drying the indicated harvest moisture content (HMC) lots for various durations under drying air condition C.

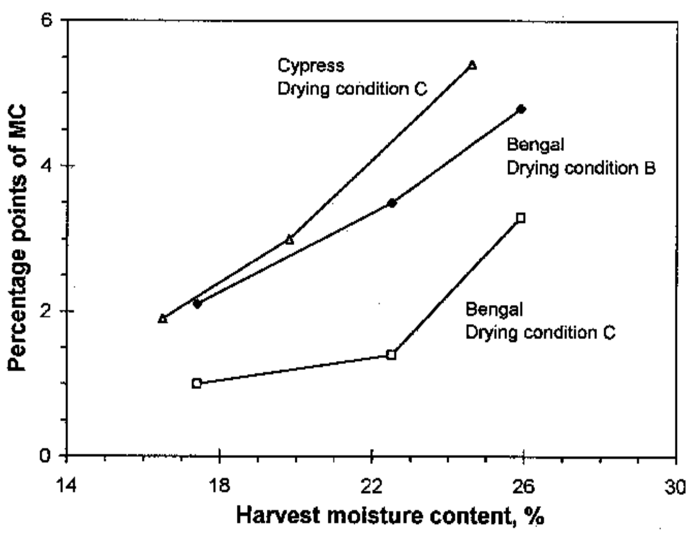

Fig. 4. The percentage points of moisture content (MC) removed before head rice yield reduction (HRYR) occurred in relation to harvest moisture content.

EFFECT OF PLANT AGE ON THE DEVELOPMENT AND SPREAD OF RICE BLAST FROM FOCI

D.H. Long and D.O. TeBeest

ABSTRACT

Field experiments were conducted in 1997 and 1998 with a sulfate non-utilizing strain of *Pyricularia grisea*, that could be readily distinguished from wild-type (background) strains to determine how plant maturity affected the rate of development and the distance of spread of rice blast from foci in Arkansas. Rice plants, approximately four or seven weeks old, of the susceptible cultivar 'M204' were inoculated with *P. grisea* in the greenhouse. Plants were then transplanted as foci (0.1 m^2) to the centers of 12.5-m^2 plots of M204 which also were either four or seven weeks old. The number of leaf blast lesions per plant were recorded weekly at distances of 0.3, 1.6, 3.1, 4.7, and 6.3 m from the focal centers (0.1 m^2) in each plot. Disease developed rapidly both years on the focal transplants within one week after symptom expression, resulting in approximately six lesions per plant. However, disease development from foci differed considerably on plants of the different ages based on calculations of apparent infection rates and overall lesion development. On 4-week-old plants, disease was observed earlier, at greater distances from the focus, increased more rapidly and was more severe than on the 7-week-old plants. For example, the apparent infection rates (r) recorded from the time of initial disease development to that recorded 18 days later at distances 0.3 to 3.1 m from the focus averaged 0.19 for the 4-week-old plants and 0.10 for the 7-week-old plants. The maximum number of lesions recorded at all distances in 1997 and 1998 were significantly higher on the 4-week-old plants than on the 7-week-old plants.

INTRODUCTION

Rice blast is one of the most destructive diseases of rice (*Oryza sativa* L.) worldwide and can cause significant yield reductions (Kingsolver, *et al.*, 1984; Torres & Teng, 1993). The pathogen, *Pyricularia grisea* Cav. (*Magnaporthe grisea* [Hebert] Barr.), infects rice plants from seedling stages through grain formation, causing symptoms on leaves, collars, and necks (Kingsolver *et al.*, 1984). Rice blast is more severe in temperate and subtropical ecosystems but can be a problem in other environments if blast susceptible cultivars are widely grown and / or if effective management strategies are not implemented (Kingsolver *et al.*, 1984; Cloud & Lee, 1993).

The epidemiology of rice blast disease has been thoroughly investigated in many countries, but many components of rice blast epidemics are not fully understood (Bonman, 1992; Kim, 1987; Kingsolver *et al.*, 1984). Furthermore, the spatial and temporal aspects of rice blast in Arkansas have not been quantified and may differ from that of other geographical areas because of different environmental conditions, host resistance, pathogen races, and management and production practices. A better understanding of the temporal and spatial dynamics of rice blast disease throughout the season may assist in developing recommendations suitable and effective for managing rice blast in Arkansas (Cloud & Lee, 1993; Teng, 1994; Zadoks & van den Bosch, 1994). Integrated pest management (IPM) strategies have been emphasized for many years, but many factors of rice blast development must be addressed before implementation is accomplished (Teng, 1994). For example, the risk and potential of disease spread of rice blast must be addressed before implementing an IPM program that uses spot treatments with fungicides. Also, the effects and interactions of various management strategies (i.e. water and nitrogen fertilization management) and plant maturity on the spread of rice blast must be examined carefully before making recommendations to growers (Teng, 1994). The effect of plant maturity (adult resistance) on the development of rice blast under field conditions must be better understood to determine the potential risks of disease spread and subsequent epidemics (Bastiaans, 1993; Kahn & Libby, 1958; Koh *et al.*, 1987; Roumen *et al.*, 1992). Therefore, the objectives of this research were to determine how plant maturity and focal strength affect the rate and distance of rice blast development from foci in Arkansas.

PROCEDURES

Field Experiments

All field experiments were conducted at the University of Arkansas Pine Tree Branch Experiment Station at Colt, in 1997 and 1998. The susceptible cultivar 'M204' was drill-seeded on two different dates at 18.2 kg/ha in 12.5 x 12.5-m plots of 72 rows spaced 17 cm apart. The first and second seeding dates represented plants that would be either four weeks (50% plant emergence on 2 June 1997 or 3 June 1998) or seven weeks old (50% plant emergence on 13 May 1997 or 6 May 1998) at the time infested plants were placed as foci. In order to minimize the interplot spread of *P. grisea*, a 3-m barrier plot of 'Kaybonnet', a cultivar resistant to rice blast, surrounded each experimental plot of M204.

Degree day thermal units (DD50s) were calculated each year to estimate the physiological maturity of M204 plants within the experimental area throughout the season (Helms, 1990). The cultivar M204 typically requires 2200 to 2500 DD50 units to reach full maturity. Accumulations of DD50 units ranging from 100 to 1250 typically signify plants in the vegetative growth stage, while accumulations ranging above 1250 typically signify plants in the reproductive growth stages.

Inoculation of Plants in Foci

Six to eight seeds of M204 were sown into each (6 x 6-cm) cell of a 12-celled peat pot strip (Jiffy-strips [Hummert International])containing soil (Crowley silt loam) combined with vermiculite at a 2:1 ratio. Two blocks of plants (180 cells per block) that were either four or seven weeks old at the time of transplanting, were sown on 10 May or 30 May in 1997 and 3 May or 1 June in 1998. Seedlings were grown under greenhouse conditions at 24 to 30°C and were fertilized every two weeks after seedling emergence with ammonium sulfate (0.04-g / pot) up until the day of transplanting in the field. Greenhouse inoculated plants, four and seven weeks old, were transplanted as foci (~144 plants / 0.1 m^2) in the centers of the 12.5-m^2 plots that contained the same age plants (either 4- or 7-week-old plants).

Cultures of a sulfate non-utilizing strain (*sul*) of *P. grisea*, isolate 18 / 1 (race IC-17), were grown on rice bran agar (RBA) (20-g rice bran [Riceland Foods Inc., Stuttgart]; 15 g agar [Sigma] and 1000 ml of distilled water) for 7 to 10 days at 25°C with 12 hours of light (20W Blacklight [Sylvania]). Conidia from cultures of the *sul* strain were harvested with distilled water and adjusted to 80,000 conidia / ml using a hemacytometer. Silwet L77 (0.01%) was added to the spore suspension prior to inoculation. One hundred milliliters of this conidial suspension was sprayed onto each block of 4- or 7-week-old plants of 160 cells using an air-assist spray apparatus. Plants were placed in a dew chamber at 100% RH for 16 hours at 21°C following inoculations. Plants were removed from the dew chamber and placed on benches in the greenhouse and incubated for three days in 1997 and for five days in 1998 at 28°C before being transplanted to the field. Symptoms were not observed on transplants until after transplantation to the field in 1997 but were observed on transplants in 1998.

Disease Progress

The number of leaf blast lesions per plant in 1997 and 1998 were determined every five or six days at distances of 0.3, 1.6, 3.1, 4.7, and 6.3 m from the initial foci. Treatments (4- and 7-week-old plants) were organized in a randomized complete block design with six replications per treatment. The means of the number of lesions per plant at all distances for each treatment were used to construct disease progress curves. Apparent infection rates and maximum leaf blast incidence (recorded as the mean number of lesions per plant) were obtained and analyzed using the GLM and the protected LSD procedures in SAS (SAS Institute, 1990). The velocity of disease spread (isopath movement) was calculated from each sampling point (0.3 to 6.7 m) during the first 18 days of disease development. The rate of isopath movement outward from the foci was recorded as meters / day.

RESULTS AND DISCUSSION

Greenhouse inoculated plants were introduced as foci on 22 June 1997 and 25 June 1998. Accumulations of 1090 and 1278 DD50 units (~panicle initiation stage) for the 7-week-old plants (plants that emerged on 13 May 1997 or 6 May 1998) and 660 and 724 DD50 units (active tillering stage) for the 4-week-old plants (plants that emerged on 2 June 1997 or 3 June 1998) were recorded at the time of focal transplanting. In 1997, leaf blast was visible on the focal transplants three days after transplanting, resulting in 45 lesions / focus (approx. 0.3 lesions / plant) on the 4-week-old plants (second seeding) and 90 lesions / focus (approx. 0.6 lesions / plant) in the 7-week-old plants (first seeding). However, in 1998, leaf blast lesions already were visible on the focal transplants at the time of transplanting, resulting in 110 lesions / focus (approx. 0.8 lesions / plant) on the younger plants and 170 lesions / focus (1.2 lesions / plant) on the older plants. Disease increased rapidly both years on the focal transplants during the first 10 d after transplanting in both the 4-week and 7-week-old plants, in that six and five lesions / plant were recorded on the 4-week and 7-week-old foci in 1997 and 1998. Two weeks after transplanting, the 4-week-old foci were severely diseased (> 50% plant mortality), while the 7-week-old plants in foci either maintained or declined in the number of lesions per plant (data not shown). These data are consistent with other epidemiological studies on focal expansion of rice blast in that disease appears to develop most rapidly at the focus early in the season before spreading outward (Kingsolver *et al.*, 1984; Zadoks & van den Bosch, 1994). Source strength (amount of inoculum) at the focus early in the season is a key component of the disease cycle that determines the trend and shape of disease progress throughout the season (Bastiaans, 1993; Zadoks & van den Bosch, 1994).

Disease Progress

In 1997 and 1998, there was significantly more disease on the 4-week-old plants than on the 7-week-old plants. The mean number of leaf blast lesions per plant were significantly higher in the younger plants at all five sampling points (0.3 to 6.3 m) from the focus than on the older plants (Fig. 1). In 1997, the maximum number of lesions per plant observed (approximately 30 days after transplanting [DAT]) on the 4-week-old plants at the sampling points 0.3, 1.6, 3.1, 4.7, and 6.3 m was 46, 32, 24, 14, and 12 lesions per plant, respectively, while the maximum number of leaf blast lesions observed on the 7-week-old plants was only 12, 12, 4, 2, and 0.5 lesions per plant, respectively (Fig 1). Similarly, in 1998, the maximum number of leaf blast lesions per plant recorded approximately 25 DAT on the 4-week-old plants at sampling points 0.3, 1.6, 3.1, 4.7, and 6.3 m was 48, 41, 21, 15, and 10 lesions / plant, respectively; significantly higher than the maximum number of leaf blast lesions per plant observed on the 7-week-old plants (15, 10, 4, 1, and 0 lesions / plant, respectively) (Fig. 1). Roumen *et al.* (1992), in greenhouse studies, reported that leaf blast infections on maturing rice plants (reproductive growth stages) exhibited reduced infection efficiency, decreased lesion size and sporulation compared to those observed on younger plants in vegetative growth stages.

The first leaf blast symptoms observed 4.7 or 6.3 m from the focus were detected earlier on the 4-week-old plants than on the 7-week-old plants (Fig. 1). For example, in 1997, more than two leaf blast lesions per plant were observed at 4.7 and 6.3 m from the focus after 18 and 24 DAT, respectively, in the 4-week-old plants and after 30 to 36 DAT, respectively, in the 7-week-old plants. Similar results were observed in 1998, however an incidence level of leaf blast greater than two lesions per plant was not observed at distances 4.7 and 6.3 m from the focus on the 7-week-old plants during the year.

Apparent infection rates were calculated for the five sampling distances in the cultivar M204, to determine the effect of age related resistance on disease development. In 1997 and 1998, the apparent infection rates (r) were similar for sampling points 0.3, 1.6 and 3.1 m from the focus for the first 18 days after transplanting for both the 4-week and 7-week-old plants (Table 1). Furthermore, the apparent infection rates (r = 0.14 and 0.11) observed in the 7-week-old plants for sampling points 0.3 and 1.6 m from the focus, respectively, were similar to those observed at sampling points 4.7 and 6.3 m in the 4-week-old plants (Tables 1 & 2). In 1997, plant maturities observed in the 7-week-old plants at sampling points closest (0.3 to 1.6 m) to the focus were similar to those observed in the 4-week-old plants at the greatest distances (4.7 to 6.3 m) from the focus, in that accumulations of DD50 units were similar (ranging from approximately 1000 to 1200 DD50 units in both the 4- and 7-week-old plants) (Fig. 2). However, in 1998, there were some differences in plant maturity during initial disease development at sampling points 4.7 and 6.3 m in the 4-week-old plants and 0.3 and 1.6 m in the 7-week-old plants (1300 to1450 DD50 units in the 4-week-old plants and 1500 to 1700 DD50 units in the 7-week-old plants) (Figs. 1 & 2).

A simple unimodal disease progress curve described leaf blast development in both 1997 and 1998. The mean number of lesions per plant increased to the highest levels at the panicle primordia stages (1200 to 1400 DD50 units), then declined gradually thereafter (Fig. 2). In 1997 and 1998, significant differences were observed between the five sampling distances for maximum number of leaf blast lesions per plant (Table 2). Furthermore, there were significantly more lesions observed on the 4-week-old plants than on the 7-week-old plants when measuring maximum number of leaf blast lesions per plant (Table 2). Similarly, at the end of the season leaf blast incidences were generally higher in the 4-week-old plants than in the 7-week-old plants. In 1997, disease at the end of the season on the 4-week-old plants for the five sampling points 0.3, 1.6, 3.1, 4.7, and 6.3 m was 24, 22, 15, 12, and 11 lesions / plant, respectively, while the mean number of lesions recorded on the 7-week-old plants was 1, 5, 2, 3, and two lesions / plant, respectively (Fig. 1). In 1998, the mean number of lesions per plant at the sampling points 0.3, 1.6, 3.1, 4.7, and 6.3 m from the focus were also higher in the 4-week-old plants (25, 25, 12, 12, and 10 lesions / plant, respectively) than on the 7-week-old plants (5, 5, 0, 1, and 0 lesions / plant, respectively) (Fig. 1). These findings are consistent with those reported by Bastiaans (1993), Roumen *et al.* (1992), and Koh *et al.* (1987) who observed the effects of adult resistance on individual rice plants, in that disease development on the older plants (reproductive growth stages) were generally less severe than disease development observed on younger plants in vegetative growth stages.

The velocity of disease spread measured as the rate of isopath movement from the foci, from sampling points ranged from 0.35 to 0.52 m / day and from 0.15 to 0.32 m / day in the 4-week-old plants in 1997 and 1998, respectively, and from 0.21 to 0.26 m / day and from 0.10 to 0.15 m / day in the 7-week-old plants in 1997 and 1998, respectively. These findings are consistent with those previously reported by Kim (1987), in that the velocity of disease spread for rice blast was between 0.2 and 0.4 m / day. Again, our findings suggest that disease spread is more rapid when initial leaf blast occurs during the early vegetative stages.

SIGNIFICANCE OF FINDINGS

Field experiments were conducted in 1997 and 1998 to determine how plant maturity affected the rate of incidence and distance of spread of rice blast development from foci. Rice blast development was significantly faster in the 4-week-old plants (vegetative growth stages) than on the 7-week-old plants (reproductive growth stages), in that disease appeared earlier at greater distances (4.7 to 6.3 m) from the focus, increased more rapidly and was more severe on the 4-week-old plants. These data indicate that plant maturity reduces the rate of disease development from foci and the spread of the disease. To our knowledge, this is the first report on the affects of age on the spatial and temporal dynamics of rice blast disease within a population of rice plants within a field.

Integrated pest management (IPM) strategies have been emphasized for many years, however, there are many factors that affect rice blast development that must be addressed before IPM strategies can be implemented. For example, a better understanding of the temporal and spatial dynamics of rice blast disease throughout the season may assist in developing and recommending suitable and effective management strategies for controlling rice blast. The recognition of the potential risk for the spread of the disease in younger plants (vegetative growth stages) may contribute to a better scouting regimen that will assist in the application of disease control strategies. For example, one IPM strategy that has been suggested for controlling rice blast in Arkansas is the use of spot treatments with effective fungicides. However, the risk and potential for spread of rice blast must be addressed before this strategy can be implemented to insure efficacies. Even though the overall issue of plant age / adult resistance has been addressed in these studies, further research must address issues regarding the effect of cultivar specific adult resistance, the effect of various environmental factors on disease spread, the effect of cultural practices, and the interaction of all the above on the epidemiology of rice blast.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Mr. Roger Eason, Mr. Shawn Clark, and the personnel at the University of Arkansas Pine Tree Branch Experiment Station at Colt. We also acknowledge the support of the Rice Research and Promotion Board, without which this work would not have been possible.

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Table 1. Calculated apparent infection rates for leaf blast development on 4- and 7-week-old plants of M204 at five sampling distances from the foci during the first 18 days of disease development.

	1997		1998	
	Rate[z]		Rate	
Distance[y]	4-wk-old plants[x]	7-wk-old plants[w]	4-wk-old plants[x]	7-wk-old plants[w]
0.3 m	0.21	0.14	0.21	0.14
1.6 m	0.19	0.13	0.21	0.11
3.1 m	0.17	0.07	0.17	0.08
4.7 m	0.14	0.01	0.14	0.00
6.3 m	0.13	0.00	0.12	0.00
LSD[v]	0.03	0.03	0.02	0.03
LSD[u]	0.03		0.02	

[z] Apparent infection rate for the first 18 days of leaf blast development.
[y] Distance from the focus (m).
[x] Rice plants emerged on 2 June 1997 (second seeding) or 3 June 1998.
[w] Rice plants emerged on 13 May 1997 (first seeding) or 6 May 1998.
[v] Protected LSD's for each column.
[u] Protected LSD's for both columns and rows within years.

Table 2. The maximum number of leaf blast lesions recorded from 4- and 7-week-old plants of M204 at five sampling distances from the foci.

	1997		1998	
	Lesion number[z]		Lesion number	
Distance[y]	4-wk-old plants[x]	7-wk-old plants[w]	4-wk-old plants[x]	7-wk-old plants[w]
0.3 m	46	12	48	15
1.6 m	32	12	41	10
3.1 m	24	4	21	4
4.7 m	14	2	15	1
6.3 m	12	<1	10	0
LSD[v]	6	3	7	4
LSD[u]	5		6	

[z] Apparent infection rate for the first 18 days of leaf blast development.
[y] Distance from the focus (m).
[x] Rice plants emerged on 2 June 1997 (second seeding) or 3 June 1998.
[w] Rice plants emerged on 13 May 1997 (first seeding) or 6 May 1998.
[v] Protected LSD's for each column.
[u] Protected LSD's for both columns and rows within years.

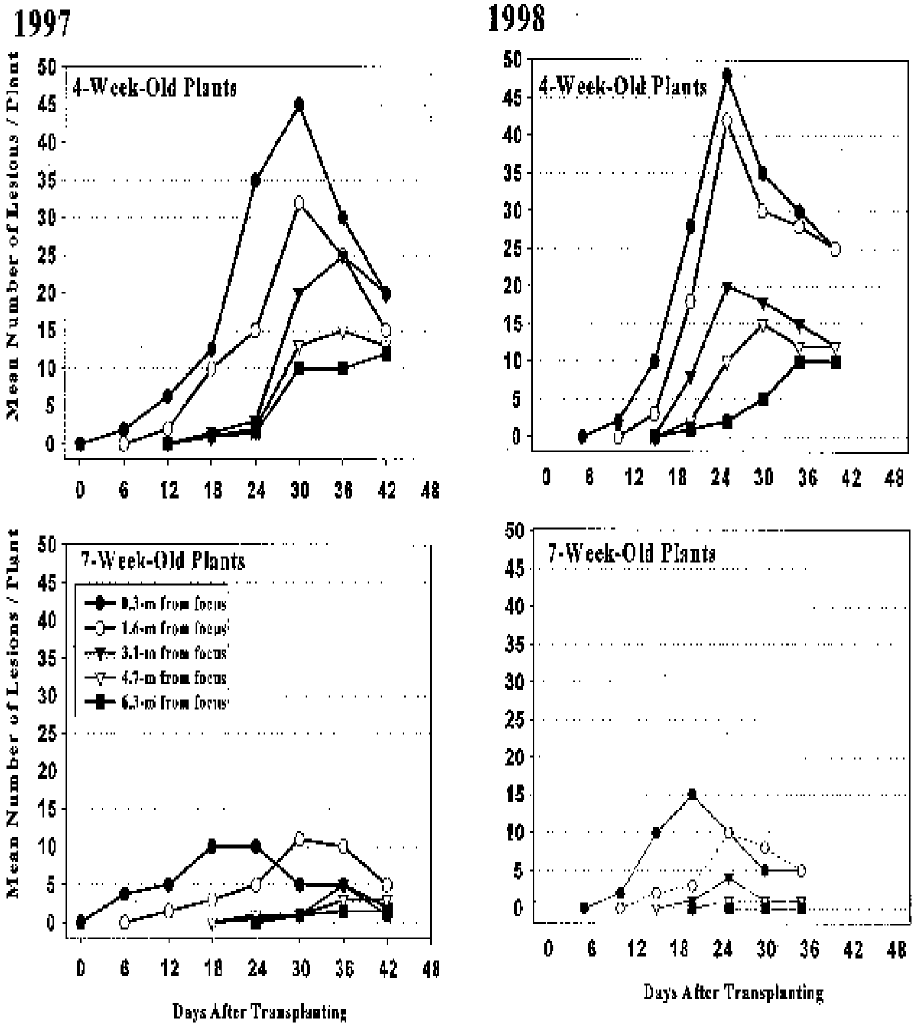

Fig. 1. Disease progress curves for leaf blast constructed from the mean number of lesions per plant found on the rice cultivar M204 that emerged on 2 June 1997 (4-week-old plants) and 13 May 1997 (7-week-old plants) or on 3 June 1998 and 6 May 1998 at distances of 0.3, 1.6, 3.1, 4.7, and 6.3 m from the foci. The x-axis is the number of days after transplanting the foci.

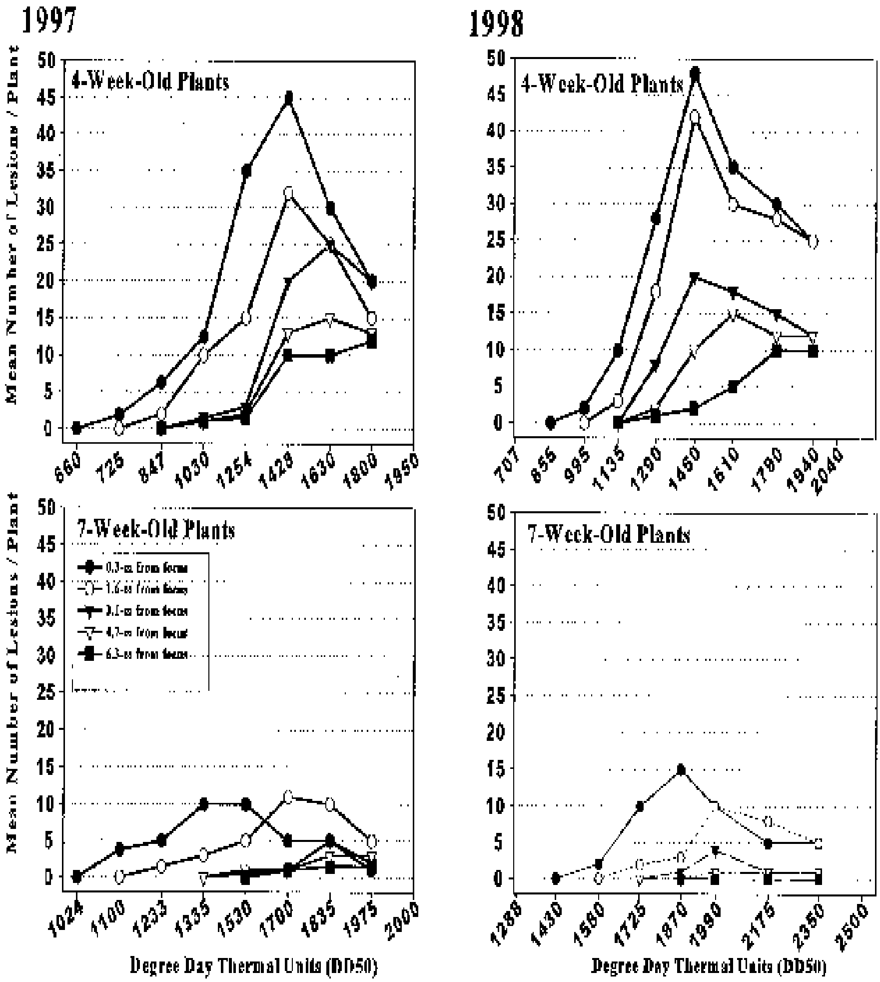

Fig. 2. Disease progress curves for leaf blast constructed from the mean number of lesions per plant found on the rice cultivar M204 that emerged on 2 June 1997 (4-week-old plants) and 13 May 1997 (7-week-old plants) or on 3 June 1998 and 6 May 1998 at distances of 0.3, 1.6, 3.1, 4.7, and 6.3 m from the foci. The x-axis is the accumulation of degree day thermal units (DD50s) beginning from plant emergence.

DEVELOPMENT OF BROWN RICE STATE DIAGRAMS FOR MAPPING OF DRYING PROCESSES

A.A. Perdon, T.J. Siebenmorgen, and A.G. Cnossen

ABSTRACT

Graphs relating glass transition temperature (T_g) to moisture content (MC), referred to as state diagrams, were generated for the cultivars 'Bengal' and 'Cypress' brown rice kernels. A thermomechanical analyzer was used to measure T_g. The brown rice T_g of individual kernels ranged from 17 to 58°C corresponding to a MC range from 27 to 3%. Subsequently, a typical drying process was mapped out on a state diagram generated with the combined T_g and MC data from both cultivars. This map indicated at what point in the drying process kernels would be expected to be in a glassy state (below T_g) or in a rubbery state (above T_g). The volumetric expansion coefficients (ßs) of kernels below and above T_g were also measured. Mean ßs for both cultivars were 0.9×10^{-4} $°C^{-1}$ in the glassy region and 4.7×10^{-4} $°C^{-1}$ in the rubbery region.

INTRODUCTION

Understanding the effects of postharvest operations before milling on kernel structure, particularly fissure formation, is important in controlling and optimizing process conditions. Fissuring, or cracking, resulting from hygroscopic stresses can occur in a kernel prior to milling (Kunze and Prasad, 1978; Kunze, 1979; Sharma and Kunze, 1982; Siebenmorgen *et al.*, 1992) or during postmilling operations (Nehus, 1997). Both conditions reduce head rice yield (HRY).

Severe drying conditions and/or subsequent exposure of the dried kernels to air at high relative humidities can increase the number of fissured kernels. Proposed theories on fissure formation are based on the response of rice when subjected to tensile and compressive stresses due to the existence of a moisture gradient within the kernel (Kunze and Choudhury, 1972).

The Effects of Moisture Content and Temperature on Rice Kernel Properties

The effect of water on rice thermal and physical properties is a key in understanding the drying process. Wratten *et al.* (1969) showed that the physical (length, width, thickness, volume, density, and specific gravity) and thermal (specific heat and thermal conductivity) properties of long- and medium-grain rice were linear functions of MC. Morita and Singh (1979) also found that short-grain rough rice kernel dimensions at 26°C, bulk density, and specific gravity varied linearly with MC. Short-grain rice was also found to shrink by an average of 12.3% when dried from 30 to 15% MC (Steffe and Singh, 1980). These findings account only for the effects of MC on material properties at constant temperature.

Rice properties are also affected by the kernel temperature. Arora *et al.* (1973) reported an increase in milled rice thermal expansion above 53°C and showed that more rice kernels fissure above this temperature. Muthukumarappan *et al.* (1992) found a uniform rate of expansion of rice up to 58°C.

The Rice Kernel as a Polymer

Integrating the effects of water and temperature on material property changes is important in understanding fissure formation during grain drying. Polymer science has been applied in studying the effects of temperature and MC changes during processing on food components, such as starch and protein (Slade and Levine, 1991; 1995). Starch, the primary component of rice kernels, is considered a partially crystalline, partially amorphous polymer whose thermal and material properties change depending on the temperature and moisture gradients generated during processing (Slade and Levine, 1991; 1995). Physical properties of amorphous materials change as they go through a glass transition temperature, or T_g. At temperatures below T_g, amorphous materials are glassy with high viscosity and density but low expansion coefficient. At temperatures above T_g, they are rubbery with a much higher expansion coefficient and lower density.

Moisture content changes during processing affect the T_g; as MC increases, T_g decreases. Plotting T_g against its corresponding MC will generate a state diagram that can be used to predict the mechanical properties of kernels at a particular temperature and MC. At a given MC, the temperature of the material relative to its T_g will determine whether kernels will be in the glassy or the rubbery state.

Few studies have been published on changes in thermal properties of rice below 25% MC. Among these, Nehus (1997) measured the milled rice thermal properties with a differential scanning calorimeter and reported that rice at 16 to 18% MC had a T_g around 55°C. The transition point between 50 and 60°C, shown by Arora *et al.* (1973) may be the T_g identified by Nehus (1997). If so, a glassy to rubbery state transition occurring within this temperature range, typically encountered during drying, will affect the material property changes in a rice kernel.

To understand rice kernel fissuring during drying, the changes of the material properties at and around T_g need to be investigated. Existence of a temperature and/or MC gradient within a kernel may generate regions with different magnitudes of mechanical properties, such as different expansion coefficients or kernel densities. The difference in magnitudes of these properties may be sufficient to create stresses that will cause the kernel to fissure.

OBJECTIVES

The objectives of this project were to measure the T_g of Bengal, a medium-grain rice, and Cypress, a long-grain rice, dried to different MCs. From these data, a state diagram was generated and used to map a typical drying process. Material properties, specifically the volumetric expansion coefficients (ßs) below T_g (glassy region) and above T_g (rubbery region) were also measured.

MATERIALS AND METHODS

Rough Rice Collection and Preparation

Multiple samples of Bengal and Cypress rice with harvest MCs ranging from 14 to 22% were harvested in 1997 from the University of Arkansas Rice Research and Extension Center at Stuttgart. After harvest, the rough rice samples were cleaned in a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, Minnesota). Each cleaned rough rice lot was dried to different MC levels in drying chambers. The drying air temperature and relative humidity (RH) were controlled by a PG&C 300 CFM Climate-Lab-AA control unit (Parameter Generation & Control Inc., Black Mountain, North Carolina). The drying air conditions were 60°C and 16.9% RH; 51°C and 24.9% RH; 43°C and 38.2% RH, resulting in equilibrium MCs of 5, 7, and 9%, respectively. Rice was removed from the drying chambers at different drying durations, resulting in samples with MCs ranging from 5 to 22%. These samples were placed in sealed plastic bags and stored at 4°C for at least 24 hours prior to further analysis. The MC of each rough rice sample was analyzed by drying duplicate samples for 24 hours in an oven set at 130°C (Jindal and Siebenmorgen, 1987).

Individual Kernel Thermal Properties

Rice kernels were randomly sampled, at least in duplicate, from each rough rice sample and hand-hulled. Brown rice T_g was measured with a Perkin-Elmer TMA7 thermomechanical analyzer (TMA) (Perkin-Elmer, Norwalk, Connecticut), and cooled with a dry ice-ethanol mixture. After measuring the dimensions, the whole kernel was placed in a quartz dilatometer (7.1 mm i.d., PE No. N519-0763). The dilatometer was filled with aluminum oxide (Al_2O_3), and covered. The dilatometer was placed in the sample holder of the TMA, and an expansion probe was used to record volume change in the sample during heating (Perkin-Elmer, 1995). The sample was held isothermally at -15°C for 5 minutes and then heated from 10°C to 65°C at a rate of 5°C / minutes. The temperature at which the volume drastically changed was considered the T_g. An illustration of the procedure to determine T_g is given in Fig. 1. The coefficients of volumetric expansion in the glassy region ($ß_G$) and in the rubbery region ($ß_R$) were also measured from the thermogram (Fig 1). The MC of each kernel, after TMA measurement, was analyzed by placing the kernel in a porcelain spot plate and drying the sample for two hours in an oven set at 130°C.

A state diagram for each cultivar was constructed by plotting the TMA-measured T_gs of the individual kernels against their corresponding MCs. Statistical analysis of the correlation of kernel MC to its corresponding T_g was conducted using JMP IN and SAS Version 6.12 (SAS Institute, Cary, North Carolina). In all analysis, p-values (P) < 0.05 were considered to be significant.

RESULTS AND DISCUSSION

TMA Measurements

Figure 2 shows the measured T_gs and corresponding MCs of individual brown rice kernels of Bengal and Cypress. The resulting relationships represent the state diagrams for each cultivar. As expected, individual kernel T_g for both Bengal and Cypress increased as MC decreased. The correlations of T_g to MC were significant: -0.73 for Bengal and -0.62 for Cypress (P for both correlations was <0.001).

The mean coefficients of volumetric expansion (ß), as measured with the TMA, for individual kernels from both cultivars are shown in Table 1. The relative magnitude in change in the coefficients below and above a glass transition was expressed as the ratio of ß in the rubbery state over the corresponding ß at the glassy state ($ß_R$ / $ß_G$). Combining the data for both cultivars, the $ß_R$ / $ß_G$ ranged from 0.4 to 24.5 with a mean of 6.0. The magnitude of the differences between the ßs of brown rice in the glassy state to that in the rubbery state may contribute to the stress a kernel is subjected to during drying.

Brown Rice State Diagram and Rice Drying

A hypothetical rice drying process was mapped out on the combined state diagram generated for Bengal and Cypress (Fig. 3). At a typical harvest MC around 16 to 22%, kernels will be glassy at typical temperatures at harvest (around 25°C) since the mean T_g of 36°C is above this temperature. As MC decreases during drying, the mean T_g increases. However, the temperature of the kernels also increases during drying and depending on the drying air temperature, the kernels, or regions within the kernel, will either be glassy or rubbery as defined by their respective T_g. After drying to the target MC and cooling, the kernels will again go through a glass transition and become glassy as the kernel temperature decreases.

The results obtained from measuring the thermal properties of individual brown rice kernels may be applied in understanding the mechanism of rice kernel fissuring. The MC gradient existing within a kernel during drying could produce regions within the kernel with different T_gs. Depending on the temperature, the kernel may be glassy throughout, rubbery throughout, or may have regions that are in one state while adjoining regions are in the other state. The differences in magnitude between the ßs in the glassy state and in the rubbery state may produce differential stresses within a kernel. The kernel may be able to withstand some stress but when a stress limit is reached, the kernel may fissure. Rice kernel fissuring has been shown to be affected by cultivar, harvest MC, and drying conditions (Chen *et al.*, 1997). The effect of these factors on kernel fissures, HRY, and thermal properties (T_g and ß) is being quantified and the results will be integrated with the brown rice state diagram to more fully understand rice fissure formation.

CONCLUSIONS

The glass transition temperatures of individual kernels of Bengal and Cypress brown rice at different moisture contents were measured using a thermomechanical analyzer. The measured T_gs were used to generate state diagrams for both cultivars. The glass transition temperature increased as MC decreased. The brown rice kernel volumetric expansion coefficients in the glassy region were much lower than the ßs in the rubbery region. Mapping a hypothetical drying process onto the brown rice state diagram and realizing the differences in thermal and hygroscopic properties within a kernel relative to the glass transition temperature may help understand the mechanism of rice fissure formation.

SIGNIFICANCE OF FINDINGS

Understanding the effects of postharvest operations on kernel structure, particularly fissure formation, is important in controlling and optimizing process conditions. Integrating the effects of water and temperature on kernel material property changes is important in understanding fissure formation during drying. Mapping a hypothetical drying process onto the brown rice state diagram and realizing the differences in thermal and hygroscopic properties within a kernel relative to the glass transition region may help understand the mechanism of rice fissure formation and resultant milling quality reductions.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Arkansas Rice Research and Promotion Board, the U of A Rice Processing Program Industry Alliance Group, and the Institute of Food Science and Engineering for the financial support and equipment donations necessary for this project.

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Table 1. Mean volumetric expansion coefficients (ßs)[z] for individual brown rice kernels[y] of Bengal and Cypress in the glassy region ($ß_G$) and in the rubbery region ($ß_R$).

Cultivar	$ß_G$ (* $10^{-4}C^{-1}$)	$ß_R$ (* $10^{-4}C^{-1}$)	$ß_R/ß_G$
Bengal	0.86[a] (0.04)	5.03[a] (0.17)	6.43[a]
Cypress	0.89[a] (0.04)	4.28[b] (0.15)	5.61[b]

[z] Using LSD at α = 0.05, means within a column superscripted by the same letter are not significantly different from each other. Value in parenthesis is the standard error of the mean.
[y] Number of kernels measured for Bengal and Cypress were 120 and 100, respectively

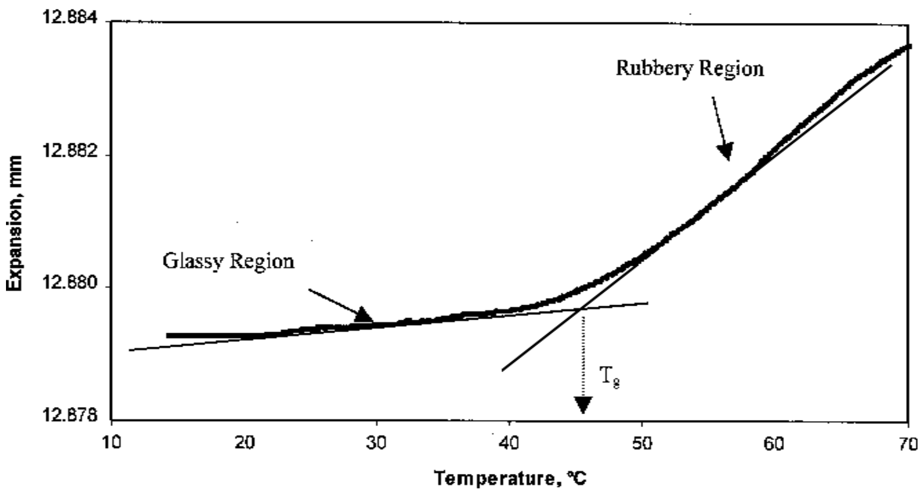

Fig. 1. A typical thermomechanical analyzer thermogram of brown rice illustrating the assignment of the glass transition temperature (T_g) and the different regions around T_g.

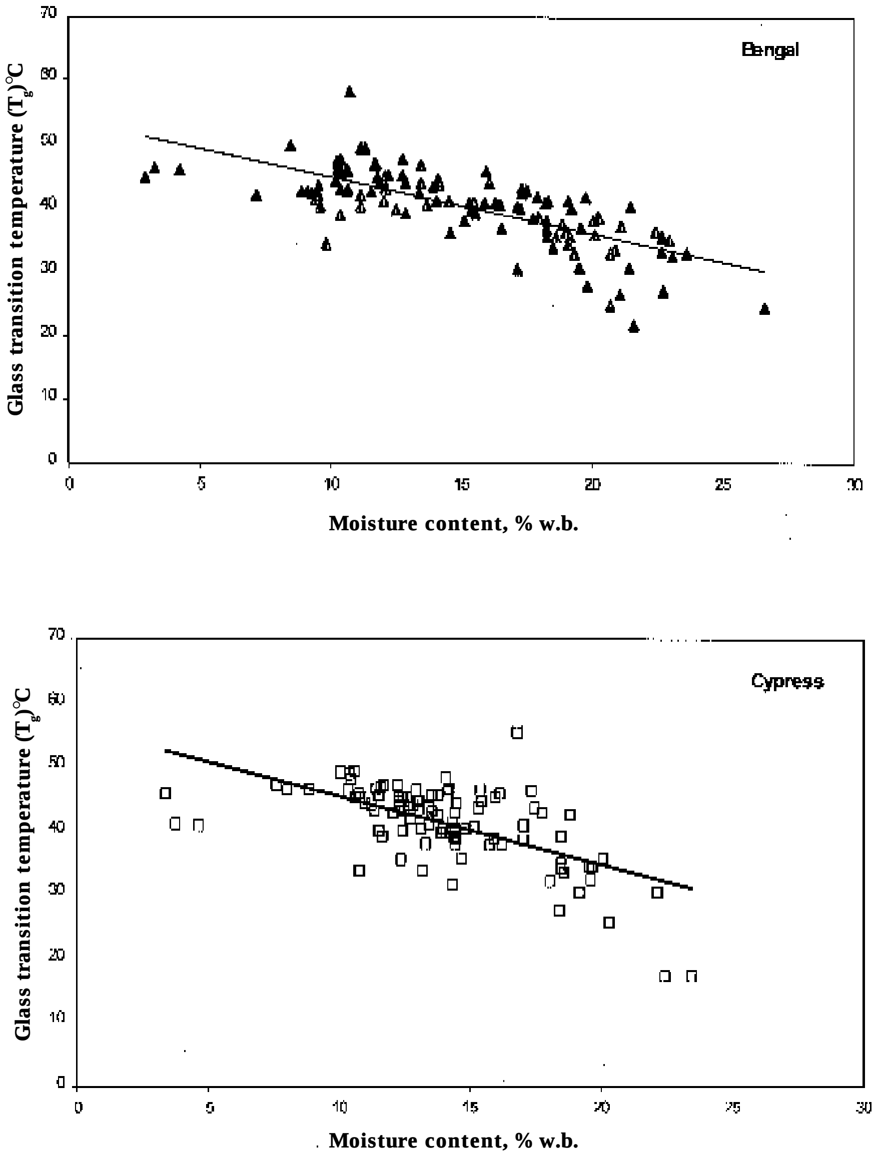

Fig. 2. Individual kernel glass transition temperatures and corresponding moisture contents of Bengal and Cypress brown rice.

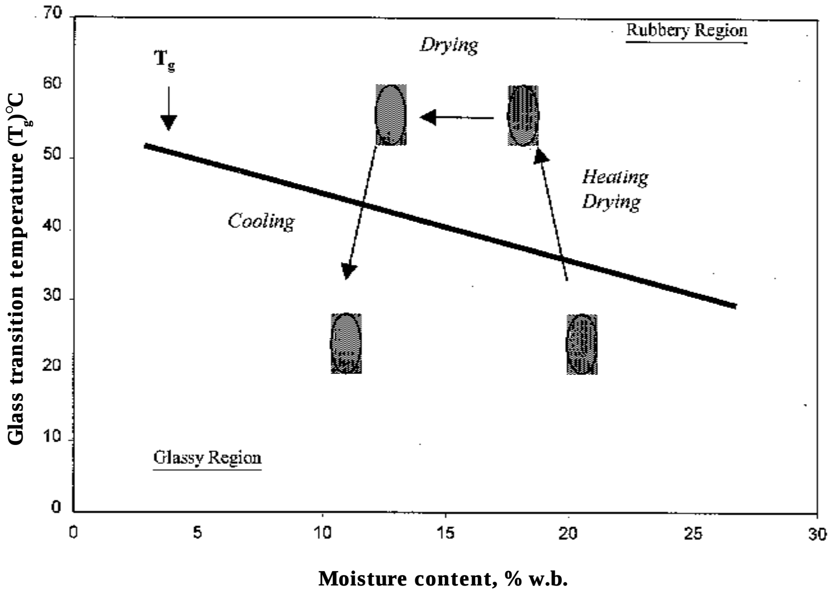

Fig. 3. Hypothetical drying process for rice kernels plotted on a state diagram generated by pooling glass transition data for Bengal and Cypress rice.

FACTORS INFLUENCING POTASSIUM UPTAKE BY RICE

H.J. Pulley, C.A. Beyrouty, E.E. Gbur, and R.J. Norman

ABSTRACT

Reasons for more frequent potassium (K) deficiencies in field-grown 'Bengal' and 'Cypress' compared to other commonly grown rice cultivars were investigated. A K depletion study in nutrient solution was conducted on seven rice cultivars at maximum tillering. Bengal produced a root surface area (RSA) that was 1.8 times greater than the average RSA of the other cultivars in the study. This large RSA would likely be confined to a small volume of soil in the field resulting in rapid depletion of soil K. In contrast, the RSA of Cypress was smaller than Bengal and only 1.1 times larger than the average of the other cultivars. However, Cypress absorbed K at a much faster rate per unit RSA than most of the cultivars studied. When the size of the root system and the rate of K uptake were considered, Cypress absorbed a greater quantity of K per unit time than the other cultivars. Thus, it would appear that the rate of K uptake and size of the root system are important parameters affecting susceptibility to K deficiency.

INTRODUCTION

Potassium deficiencies in rice have been observed under field conditions, but the symptoms appear to be cultivar specific. Essentially no data are available that provide an explanation for why some cultivars are more sensitive to K deficiencies than others. This lack of data reflects the fact that K deficiencies in rice have not been a concern until recently. Cultivar specific nutrient deficiencies are usually attributed to differences in root systems, with nutrient deficient cultivars having larger root systems. However, there is no quantifiable evidence to support this explanation. In fact, work by Teo *et al.* (1995b) showed no differences in the length of roots of field-grown midseason rice cultivars 'Mars', 'Katy', and 'Lemont'. We have found that early maturing cultivars produce a smaller root system than midseason cultivars, probably because of the limited time for vegetative development during the season (Beyrouty *et al.*, 1993). Teo *et al.* (1995a) found from a field evaluation of a nutrient uptake model that two plant related factors most influenced K uptake by rice. One factor, referred to as Imax, is the maximum rate at which rice roots absorb K from the soil solution when K is not limiting. The other factor is the root surface area. These findings suggest that cultivars which absorb high levels of K either have large root systems or absorb K at a fast rate per unit RSA. We hypothesize that cultivars with either of these rooting characteristics may deplete low K soils quicker than other cultivars, resulting in K deficiencies. We conducted a study on several rice cultivars to test this hypothesis.

PROCEDURES

Rice was grown in a controlled environment with a 16-hour day temperature of 30°C and an 8-hour night temperature of 27°C. Seeds of each cultivar were germinated in pots filled with gravel and water. Ten days after germination, one seedling was placed into a 4-L pot containing quarter-strength nutrient solution (Yoshida *et al.*, 1976). This solution was changed every four days and pH was maintained at 5.0. At first tiller (approximately 10 days after transplanting), the plants were grown in half-strength nutrient solution which was changed every two days. Plants were transferred to full-strength solution at active tillering (20 days after transplanting). Plants were allowed to grow for 60 days prior to the initiation of a K depletion.

At 24 hours prior to the depletion, plants were transferred to 2-L pots and starved of K by replacing the nutrient solution with solution that did not contain K. The solution was then replaced with solution that contained 40 umol/L of K as K_2SO_4. The solution was sampled for 13 hours with a peristaltic pump set to collect 0.2 mL/min into a fraction collector set to change at 30-minute intervals. Potassium concentrations in solution samples were measured by atomic absorption spectrophotometry.

Upon completion of the depletion, plants were harvested and shoots were separated from roots. Fresh root weights were determined and root lengths were measured by the line intersect method (Tennant, 1975). Root surface area was calculated as described by Barber (1995). Dry weights were measured on root and shoot tissue. A depletion curve was developed and Imax was calculated as explained by Claassen and Barber (1974).

RESULTS AND DISCUSSION

Of the seven cultivars selected for this study, Bengal and Cypress expressed a greater frequency of K deficiency symptoms in the field (Table 1). We focused our attention on comparing the size of the root system and the rate of K uptake by these two cultivars with other cultivars that showed less frequent K deficiency in the field.

The average RSA for all cultivars except Bengal ranged from 0.8 to 1.43 m^2 per plant. In contrast, average RSA for Bengal was 2.25 m^2 per plant. Thus, it would appear that Bengal develops a much larger root system than the other commonly grown rice cultivars. Our studies have shown that nearly 74% of the rice root system and 74% of K uptake occurs in the upper 2 inches of the soil profile (Teo *et al.*, 1995a). It is expected that there would be a denser population of roots near the soil surface for Bengal than for the other cultivars studied. The greater density of Bengal roots with more exposed RSA could likely result in more rapid depletion of K from limited soil volumes.

Such a large root system for Bengal was unexpected since our previous research showed that rice cultivars within similar maturity groups did not differ in size of root systems. Since Bengal is a short-season cultivar, it was anticipated to produce a smaller RSA than the midseason cultivars such as Cypress, Katy, and Lemont as found by Beyrouty *et al.* (1993). Often, root length development is in concert with shoot development, such that cultivars with larger root systems will also produce larger shoots. In our study, we found the average shoot to root dry weight ratios for all cultivars, except Bengal, ranged from 8.1 to 10.4. The average shoot to root ratio for Bengal was 6.8. Thus, it would appear that Bengal allocates more photoassimilate to the development of a larger root system and less assimilate to the shoot compared to the other rice cultivars.

The RSA of Cypress was only 61% of the RSA produced by Bengal. However, the rate of K absorption per unit area of root, referred to as the Imax, was 4.5 times greater than for Bengal (Table 1). Although Cypress was not found to have the highest Imax of the cultivars studied, it did absorb more total K per unit time when we accounted for the size of the root system. Thus, the combination of a relatively high Imax and relatively large root system for Cypress resulted in more rapid K uptake than the other cultivars.

SIGNIFICANCE OF FINDINGS

Data would suggest that differences in susceptibility to K deficiency is attributed to size of the root system and the rate at which K is absorbed by roots. Other factors that may also be important are the minimum soil solution K concentration necessary for K uptake to begin and plant metabolic reactions that might influence uptake that we have not considered. The greater frequency of K deficiency by Bengal may be attributed to a larger RSA, while the reason for Cypress' susceptibility to K deficiency may be associated with the rapid rate of K absorption by its roots. These two cultivars would likely show K deficiency on soils that are low in solution K and have a low capacity to replenish K absorbed by plants.

ACKNOWLEDGMENTS

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

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Table 1. Root system and K uptake of seven rice cultivars grown in nutrient solution.

Cultivar	S/R[z]	Root surface area	Imax[y]	K uptake	K deficiency[x]
		---m^2---	nmol m^{-2} s^{-1}	μmol hr^{-1}	
Bengal	6.8	2.15	3.64	1097	very frequent
Cypress	9.3	1.31	16.63	3054	very frequent
Lemont	8.2	1.17	12.25	2018	occasional
Katy	9.3	0.80	22.35	2503	seldom
Mars	8.4	1.43	6.60	1322	seldom
LaGrue	8.1	1.43	7.01	1410	seldom
Kaybonnet	10.4	1.00	13.17	1843	seldom

[z] S/R = dry weight ratio of shoot to root.
[y] Imax = maximum rate roots absorb K when K is not limiting.
[x] K deficiency = frequency of visual K deficiency symptoms in the field (Nathan Slaton, personal communication).

'WELLS', A HIGH-YIELDING, LONG-GRAIN RICE CULTIVAR

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ABSTRACT

'Wells' is a new short-season, high-yielding, long-grain rice cultivar derived from the cross of 'Newbonnet' / 3 / 'Lebonnet' / CI 9902 / / 'Labelle' (cross no. 890481), made at the Rice Research and Extension Center, Stuttgart, in 1989. Wells has been approved for release to qualified seed growers for the summer of 1999. The major advantages of this cultivar over 'LaGrue' are its shorter plant height, moderate resistance to kernel smut, and increased total milled rice yield. Wells, like LaGrue, has extremely high yield potential, stiff straw, and large kernel size. The major disadvantages of Wells are its average head rice yield, even though it is more stable than that of LaGrue, and rice blast susceptibility, similar to that of LaGrue. Wells is similar in maturity to LaGrue and is moderately susceptible to sheath blight.

INTRODUCTION

Wells was developed in the rice improvement program at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, and has been released to qualified seed growers for the 1999 growing season. Wells, like LaGrue, has extremely high yield potential and will offer the Arkansas rice producers another extremely high yielding alternative cultivar. Wells was developed with the use of rice grower check-off funds distributed by the Arkansas Rice Research and Promotion Board.

PROCEDURES

Wells originated from the cross 'Newbonnet' / 3 / 'Lebonnet' / CI 9902 / / 'Labelle' (cross no. 890481), made at the Rice Research and Extension Center, Stuttgart, in 1989. Newbonnet, released in 1983 (Johnston *et al.*, 1984), is a high-yielding, excellent milling cultivar, susceptible to rice blast. Lebonnet, released in 1974 (Bollich *et al.*, 1975), is a large kernel, long-grain rice cultivar. CI 9902 is a short stature, lodging resistant, rice blast resistant, long-grain selection developed at Crowley, Louisiana, and has the pedigree 'Dawn' / 245717 / 3 / 13-D / / 'Rexoro' / Unknown. Labelle is a long-grain cultivar released in 1972 (Bollich *et al.*, 1973). The experimental designation for early evaluation of Wells was STG93L08-93, starting with a bulk of F_6 seed from the 1993 panicle row L08-93. Wells was tested in the Arkansas Rice Performance Trials (ARPT) during 1996-1998 and the Cooperative Uniform Regional Rice Nursery (URRN) during 1996-1998 as entry RU9601053 (RU number indicated Cooperative Uniform Regional Rice Nursery; 96 indicates year entered; 01 indicates Stuttgart, Arkansas; and 053 its entry number).

In 1996, the ARPT was conducted at five locations in Arkansas: RREC; Northeast Research and Extension Center, Keiser (NEREC); Pine Tree Branch Experiment Station, Colt (PTBES); Southeast Branch Experiment Station, Rohwer (SEBES); and a Jackson County (JC) producer field near Tupelo, Arkansas, and one location in Missouri, Campbell (Missouri), with three replications per location. In 1997, the ARPT was grown at the five locations in Arkansas. In 1998, the ARPT was grown at the RREC, NEREC, PTBES, and SEBES, with three replications per location, to reduce soil heterogeneity effects and to decrease the amount of experimental error. Wells was also grown in group III of the Uniform Regional Rice Nursery (URRN) at RREC; Stoneville, Mississippi; Beaumont, Texas; and Crowley, Louisiana, 1996-1998. Data collected from these tests included plant height, maturity, lodging, individual kernel weight, percent head rice, percent total milled rice, and grain yield adjusted to 12% moisture as well as disease reaction information. Cultural practices varied somewhat among locations, but overall the trials were grown under conditions of high productivity as recommended by the University of Arkansas Cooperative Extension Service Rice Production Handbook (CES, 1996). Agronomic and milling data are presented in Tables 1 and 2. Disease ratings, which are indications of potential damage under conditions favorable for development of specific diseases, have been reported on a scale from 0 = least susceptible, to 9 = most susceptible. Straw strength is a relative estimate based on observations of lodging in field tests using the scale from 0 = very strong straw, to 9 = very weak straw, totally lodged. Cultural practices varied somewhat among locations, but in general the tests were grown under conditions of high productivity.

RESULTS AND DISCUSSION

Data, presented by year, are given in Table 1 for Wells and other cultivars grown in the ARPT. Rough rice grain yields of Wells have been consistently ranked one of the highest in the ARPT, being equivalent to those of LaGrue and greater than those of 'Kaybonnet', 'Cypress' and Newbonnet in all three years and 'Drew' in two of the three years. In 15 ARPT tests (1996-1998), Wells, LaGrue, Kaybonnet, Drew, Cypress, and Newbonnet averaged yields of 168, 169, 143, 159, 148, and 156 bu / acre (12% moisture), respectively. Wells also performed favorably in the URRN from 1996 to 1998 (Table 2), having higher yields in all years than Kaybonnet, Drew, and Cypress. In the URRN, direct comparisons can be made with LaGrue because they were both in maturity group II and the others were in maturity group III. Wells is similar in maturity to LaGrue. Wells, like LaGrue and Newbonnet, has greater straw strength, an indicator of lodging resistance, than Katy and Kaybonnet. On a relative straw strength scale (0 = very strong straw, 9 = very weak straw) Wells, LaGrue, Newbonnet, Drew, Katy, Kaybonnet, Cypress, and Lemont rated 3, 3, 3, 4, 5, 5, 2, and 1, respectively. Based on the data in Tables 1 and 2, Wells averages approximately 40 to 41 inches in plant height compared to LaGrue and Cypress at 45 and 39 inches, respectively.

Wells, like LaGrue, is susceptible to rice blast (*Pyricularia grisea* [Cooke] Sacc.) races IB-1, IB-33, IB-49, IC-17, IE-1, and IE-1K with summary ratings in greenhouse tests of 4-5, 7, 7-8, 7-8, 5-6, and 6, respectively, using the standard disease scale of 0 = immune, 9 = maximum disease susceptibility. Unlike LaGrue, however, Wells is resistant to the blast races IB-45, IB-54, IG-1, and IH-1 with a greenhouse disease rating of 1 for each race. Wells, rated moderately susceptible (MS) to susceptible (S) for rice blast, and appears to be more tolerant to blast under field conditions than LaGrue which is rated as being S to very susceptible (VS). Wells is rated moderately susceptible to susceptible (MS-S) to sheath blight (*Rhizoctonia solani* Kühn) which compares favorably with LaGrue (S), Kaybonnet (MS), Cypress (S-VS), and Drew (MS). Wells is rated MR to kernel smut (*Tilletia barclayana* [Bref.] Sacc. & Syd. in Sacc.) which compares to LaGrue (VS), Kaybonnet (MS), Cypress (VS), and Drew (MS). Wells is rated MS to stem rot, MR to leaf smut (*Entyloma oryzae* Syd. & P. Syd.), R to brown spot (*Cochliobolus miyabeanus* [Ito & Kuribayashi in Ito] Drechs. ex Dastur), R to narrow brown leaf spot (*Cercospora oryzae* Miyake), and S to false smut (*Ustilaginoidea virens* [Cooke] Takah). Wells, like Newbonnet and Cypress, appears to be relatively susceptible to discolored kernels caused by the rice stink bug (*Oebalus pugnax*).

Milling yields (percent whole kernel / percent total milled rice) at 12% moisture from the ARPT, 1996-1998, (Table 1) averaged 62 / 73, 63 / 71, 64 / 72, 66 / 72, 65 / 72, and 66 / 72 for Wells, LaGrue, Kaybonnet, Drew, Cypress, and Newbonnet, respectively. Milling yields for the URRN (Table 2.) during the same period of time, 1996 to 1998, averaged 58 / 70, 54 / 68, 62 / 69, 61 / 69, and 62 / 69 for Wells, LaGrue, Kaybonnet, Drew, and Cypress, respectively.

Plants of Wells have erect culms, green erect leaves, and glabrous lemma, palea, and leaf blades. The lemma and palea are straw colored with colorless and purple colored apiculi, and some short tip awns on the lemma at maturity. The purple apiculi color often fades to straw color at maturity. Kernels are similar in size to the large kernels of LaGrue. The individual kernel size of Wells averaged from these tests in Tables 1 and 2, was slightly larger, 19.0 mg than that of LaGrue at 18.4 mg. The endosperm of Wells is nonglutinous and nonaromatic with a light brown pericarp. Results from the Cooperative Regional Rice Quality Laboratory at Beaumont, Texas, indicate that Wells has typical U.S. long-grain cooking quality characteristics as described by Webb *et al.* (1985). Wells has an average apparent starch amylose content of 21.2% and an intermediate gelatinization temperature (70 - 75°C), as indicated by an average alkali (17 g kg^{-1} KOH) spreading reaction of 3.8.

In nitrogen fertility studies, Wells responded similarly or better when the nitrogen fertilizer was applied in a single preflood application compared to the traditional three-way split application method. Grain yields of Wells peaked when 120 to 150 lb nitrogen (N) / acre were applied at three locations.

SIGNIFICANCE OF FINDINGS

The release of Wells offers producers a new extremely high-yielding, large-kerneled, shorter-strawed alternative, which has the added benefits over LaGrue of moderate resistance to kernel smut, higher total milled rice yields, more stable head rice yields, and slightly better field tolerance to rice blast. Wells also maintains the relatively good levels of sheath blight tolerance found in the Arkansas cultivars being moderately susceptible to sheath blight.

LITERATURE CITED

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Table 1. Three-year average agronomic and other data from the 1996-1998 Arkansas Rice Performance Trials for Wells and other cultivars.

	Yield							
Cultivar	1996	1997	1998	mean[z]	Height	50% Heading	Kernel wt.	Milling
	---------- (bu/acre)[y] ----------				(inches)	(days)	(mg)	(HD/TOT)[x]
Wells	176	171	151	168	40	84	18.8	62/73
LaGrue	177	167	159	169	45	84	18.3	63/71
Kaybonnet	144	146	139	143	44	84	15.2	64/72
Drew	160	159	157	159	47	86	16.1	66/72
Cypress	149	148	147	148	39	86	17.3	65/72
Newbonnet	157	161	147	156	45	87	15.7	66/72
C.V. (.05)	9.5	7.2	9.6					

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

[y] A bushel of rice weighs 45 lb.

[x] Milling data are in percent head rice / total rice.

Table 2. Three-year average agronomic and other data for Wells and other cultivars from the 1996-1998 Uniform Regional Rice Nurseries.

	Yield							
Cultivar	1996	1997	1998	mean[z]	Height	50% Heading	Kernel wt.[y]	Milling[x]
	(bu/acre)[w]				(inches)	(days)	(mg)	(HD/TOT)
Wells	197	180	195	191	41	85	19.9	57/70
LaGrue	201	181	177	86	45	85	18.8	54/68
Kaybonnet	184	166	160	170	45	84	15.1	62/69
Drew	183	165	167	172	46	86	16.8	61/69
Cypress	180	164	166	170	39	86	17.7	62/69

[z] Mean of the four locations (Stuttgart, Arkansas; Crowley, Louisiana; Stoneville, Mississippi; and Beaumont, Texas) for each year of the Uniform Regional Rice Nursery (URRN).

[y] Data from Stuttgart, Arkansas, URRN location only.

[x] Data from Mississippi not included for 1998. Milling data are in percent head rice / total rice.

[w] A bushel of rice weighs 45 lb.