

Rice Experiment Station

Centennial Field Day Celebration

1912 - 2012

“Whereas an agreement has been reached between the said Sacramento Valley Grain Association and the Bureau of Plant Industry of the United States Government, whereby the said Bureau will undertake to establish and conduct a Cereal Field Station upon the lands hereinafter described, for the purpose of conducting experiments for the improvement of cereals as to yield, quality, disease resistance, etc. and to determine the best methods of cereal production in California.”

Deed of Trust
June 19, 1912



California Cooperative Rice Research Foundation, Inc.
University of California
United States Department of Agriculture
Cooperating

Rice Experiment Station
P.O. Box 306, Biggs, CA 95917

BOARD OF DIRECTORS
California Cooperative Rice Research Foundation, Inc.

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Foreword

By James R. Erdman¹

A stroll down the hallway of the California Rice Experiment Station is like a walk through the Sequoia Redwoods. This is where the giants stand. The success of the California rice industry can be traced directly to the pioneering spirit of these first brave souls who were willing to put the vast swamplands of the Sacramento Valley to productive use. These pioneers were followed by men and women who continue to refine and nurture a very unique industry.

Rice is a unique crop. It is the most widely grown grain in the world; 60% of the world's population eats rice twice daily. It can be grown where no other crops will grow; it is semi-aquatic and can be stored as a staple for many years. This diversity has led to the need for many different, yet interrelated disciplines of research. This approach has enabled us to have the successful research program we have today. Through the cooperative efforts of the USDA, University of California, California Rice Experiment Station, and contributions from private individuals, we have built a research program that is unequalled.



James R. Erdman

FOREWORD

RICE FOUNDATION

James R. Erdman Fills Director Post

BIGGS - George E. Lodi of Arbuckle recently submitted his resignation as a member of the Board of Directors of the California Cooperative Rice Research Foundation, Inc. The Foundation owns and administers the Rice Experiment Station.

Lodi who has served as a Director since 1952 resigned for reasons of health. The resignation was accepted with regrets by Chairman Leland O. Drew. The Directors expressed their appreciation for his years of service and for his valuable assistance in directing the operation of the Rice Experiment Station.

As a Director, Lodi served as vice-chairman and as a member of the building committee. In 1967 he received the Rice Industry Award in recognition for his many outstanding contributions to the welfare of the rice industry.

James R. Erdman, of Knights Landing, was unanimously selected by the Board to complete Lodi's term of office. Erdman was raised in Arbuckle and graduated from the University of California, Davis, in 1967

with a major in Agronomy. His farming operation in the Grimes-Arbuckle area consists of 1,200 acres of rice, wheat

and safflower. He also serves the rice industry as an alternate member of the Rice Research Board.



JAMES R. ERDMAN GEORGE E. LODI

James R. Erdman and George E. Lodi

It has been my pleasure to watch the waves of progress of the California rice industry as it continues to roll forward as an example of cooperative effort amongst diverse disciplines of research. The names of the individuals previously recognized in this industry clearly shout out this unique message: PLANT BREEDING, MARKETING, WEED CONTROL, FERTILIZER MANAGEMENT, PEST CONTROL, IRRIGATION MANAGEMENT, ENGINEERING, and SUSTAINABILITY.

We have come a long way these first 100 years: from hand crossing and back crossing to molecular engineering, from leveling with "Fresno Scrapers" to GPS leveling with satellites 250 miles in the sky. These advances were made possible by dedicated individuals who could envision a future for a fledgling industry a century ago. A look at the current research projects quickly tells us that we are on the continuing road for successful research with the California rice industry.



¹James R. Erdman joined the California Cooperative Rice Research Foundation Board of Directors in 1969 and was re-elected and continuously served as a director until resigning in 2004. In those 34 years he was Board Chairman (1985-87), provided leadership, addressed issues and budgets, and has seen staff hired and retired, and in 1986 travelled at his own expense to attend the 1st Hybrid Rice Symposium in China. In 2007 he returned to serve on the Rice Breeding Program Review Panel. He has been intimately involved in the growth and success of the Rice Experiment Station. Jim's father, Fritz Erdman, was the 1976 California Rice Industry Award Winner. Jim received the 2010 California Rice Industry Award for his decades of voluntary service to the Rice Experiment Station and the California Rice Industry.

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Our Centennial Sponsors:



Centennial Celebration & Rice Field Day Program

Registration 7:15 A.M.
 Under canopies by greenhouses

Sessions 8:00 - 10:00 A.M.
 Begin on the hour 8:00, 9:00, and 10:00

- Field Nursery Tour - (load canopied trucks by grain bins)
 - Breeding Program
 - Medium – V.C. Andaya
 - Short Grain – S.O. Samonte
 - Long Grain – F. Jodari
 - Pathology – J. Oster
 - New Options for Managing Rice Water Weevil and Other Invertebrate Pests of Rice – L. Godfrey
 - Weed Control Nursery (Headquarters site tour)
- Rice Presentations UC and USDA – (seated presentations in new warehouse)
 - Rice: The World’s Most Diverse Crop – J.E. Hill
 - Weed Control in Rice-Update – A.J. Fischer
 - USDA-ARS Rice Genetics Project – T. Tai
- Research Posters, Demonstrations, and Displays - (guests free to visit displays)
 - Poster and displays on lawn, research demo videos in new seed house, and equipment display in west fields

General Meeting 11:00 A.M.
 CCRRF Business Meeting – Sean Doherty
 Guest Speaker- Edward B. Knipling
 Administrator USDA-ARS
 RES Centennial Presentation – K.S. McKenzie

Lunch Noon

- Tri-tip, corn salad, fruit, and garlic bread
- California Rice
 - Premium Medium and Short Grain,
 - Basmati, Sushi, Chinese Fried, and Spanish
- Dessert
 - Homemade Ice Cream and Cookies
 - Mochi Ice Cream
- Music
 - Feather River Gypsies



Rice Experiment Station Historical Highlights²

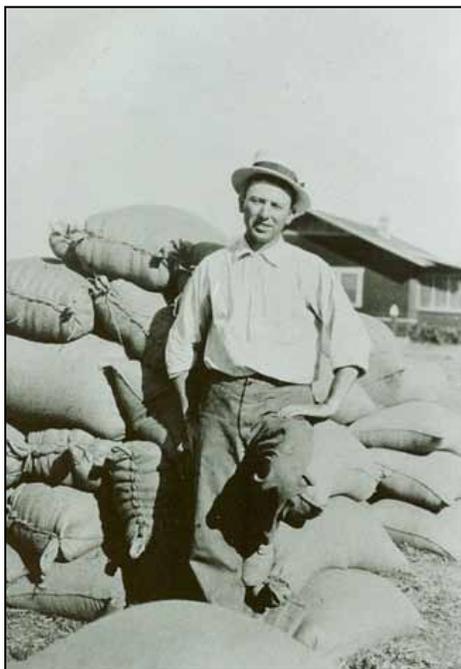
Establishment and the Early Years

Although rice production for California had been proposed and attempted since the mid-1800s, the event that in effect launched California rice production and the Rice Experiment Station (RES) was the maturing of a successful rice crop on 40 acres on the Crane Ranch, southwest of Biggs, California. The 1908 experiment was the work of W.W. Mackie, soil specialist with the USDA's Bureau of Soils Survey, and led to the assignment of C.E. Chambliss from the Bureau of Plant Industry to take charge of rice investigations for California. A 6-inch-tall glass display bottle that holds a sample of the short grain Japanese variety Kyushu from the successful harvest remains on display at RES.

From 1908 through 1911 Chambliss worked with farmers making plantings in the Sacramento and San Joaquin valleys. Difficulties in field management and getting results proved prohibitive. Chambliss identified the need to establish a "permanent cereal station" and further suggested an association be organized to provide the necessary land research support for this burgeoning new crop. Thus the Sacramento Valley Grain Association was formed. The directors were President J.M. Hastings (butcher and president of Sacramento Valley Bank in Biggs), Vice President C.E. Chatfield (local dry good merchant), Secretary H.S. Brough (Sacramento Valley Bank cashier), H.S. Brink (blacksmith and implement dealer), G.E. Harvey (rice grower, buyer, and realtor), and C.T. Tullock (Sutter Butte Canal Company irrigation engineer).



1st Rice grown to maturity-1908



E. L. Adams

1st Rice Experiment Station Superintendent ESW

The original membership included about 50 subscriptions ranging from \$10 to \$1,500; the latter donation was from the San Francisco Chamber of Commerce. Some other donors of interest included Sutter Basin Company, Richvale Land Company, Sacramento Brewing Co., and Buffalo Brewing Co. Over \$5,000 cash was collected for capital expenditures. Sutter Butte Canal Company provided the 56 acres of land on a \$1/year lease and further agreed to supply free water for the property in perpetuity. The Deed of Trust between the Sacramento Valley Grain Association and the Department of Plant Industry (see cover) established the first cereal field station on the Pacific Coast. This document has been preserved and is on display in the RES office.

Ernest L. Adams arrived in May 1912 and took over responsibilities as superintendent, serving until resigning in 1918 to pursue commercial rice production in Butte County. During his tenure, buildings, infrastructure, investigations, and California rice production all grew. Jenkins W. Jones served as superintendent from 1918 to 1930. He became a world renowned rice scientist, and his research led to such major contributions as water seeding. He made sure "Washington remembered California was in the rice business." Jones also shares honors with his predecessor Adams for the selection and release of Caloro and the next superintendent, Loren L. Davis (1930-

1947), for breeding Calrose. A. Hughes Williams then became superintendent from 1948 to 1952. This proved to be a period when the Association went through some very critical self-evaluation. Both Davis and Williams continued plant breeding for private industry in California and later released two popular varieties, Earlirose and Kokuhorose, respectively.



²Information taken from Rice in California, ed. Jack H. Wilson, Butte County Rice Growers Assoc. 1979 (especially Chapter III written by M.D. Morse and Gary M. Lindberg); and History of the Production and Marketing of Rice in California, 1955, Norris A. Bleyhl Ph.D. Thesis Univ. of Minnesota, and compiled by K. S. McKenzie for this Centennial Celebration and Rice Field Day.

The Need to Grow

Funding levels for the Rice Experiment Station were minimal. USDA provided a superintendent and financed research at a very limited level. The Association provided the land, buildings, and some equipment made possible by crop sale and the original subscriptions. In the 1920s the University of California became part of the cooperative effort and contributed modestly as well. With the end of World War II the country was changing and RES needed to change as well. The buildings and equipment, like many farms, were in bad condition and the Station needed to modernize. The prospect of securing significant funding increases from federal and state cooperators was unlikely, and the Association did not have the income or reserves to do the modernization and continue operations. The idea of forming a nonprofit (tax exempt) rice research corporation was conceived and would include representation from California's entire rice-growing region. The Sacramento Valley Grain Association was dissolved and the California Cooperative Rice Research Foundation, Inc. (CCRRF) was formed. This model generated support from growers for membership, rice mills initiated a one-quarter-cent assessment per bag of rough rice sales, the University involvement in administration increased, and the USDA continued to provide a plant breeder.

Dwight C. Finrock, from the University of California, took over as superintendent from 1953 to 1960 followed by Kenneth Mueller from 1960 to 1964 and then Morton D. Morse. The Foundation reimbursed the University for 40% of the superintendent's salary and benefits. Dr. J.R. Thysell, USDA, served as rice breeder from 1954 to 1965 and Dr. John R. Erickson was housed at the Station from 1967 to 1968. By 1960 the Station had grown to 130 acres but there was a need for continued improvement, and a statewide campaign raised \$100,000 for capital improvements. Mr. Johan Mastebroek was hired as a breeder by the Foundation in 1961.

Through the 1960s California rice growers began asking for more progress on varietal development. The industry had only Caloro and Colusa from the 1920s and Calrose in 1948. There was also a need for expanded rice research to address production issues. Several groups visited the rice research stations in Arkansas, Louisiana, Texas, and the newly formed International Rice Research Institute in the Philippines. They recognized the benefits of a well-funded and productive research program. "The Green Revolution" in cereals was starting and California rice growers wanted to participate and remain competitive. The stage was being set for the Station to become the home for an "accelerated rice improvement" program.



The California Rice Research Board is given a special section in this program because of the great impact it has had on the Rice Experiment Station. It continues as an inspiring accomplishment of many great leaders from CCRRF, the University of California, growers, and the industry that is now stretched over generations. This voluntary investment by California rice growers has been critical to the Station's ability to deliver a litany of rice varieties with improvements in yield, maturity, grain quality, and specialty types in as state where "the early attempts ended in failure."





An Accelerated Rice Breeding Program

In 1969 administration of the Rice Experiment Station changed, and Superintendent Morton Morse was now employed as director of RES and secretary to the CRRF board of directors. Dr. H. L. Carnahan was hired as director of Plant Breeding followed by plant breeder Dr. Shu Ten Tseng in 1970 and later Dr. Carl W. Johnson in 1972. The USDA position then was transferred to UC Davis and filled by Dr. J.N. Rutger in 1969. A rice pathologist, Jeffrey J. Oster was hired in 1980 to support disease resistance breeding effort. There was an expansion in support staff including breeding assistants, field crew, and casual labor to handle the foundation seed, plots, breeding lines and germplasm for RES.

The program grew and the varieties came: 24 by 1990, 35 by 2000, and numbered 43 releases for California growers in 2012. They have provided semidwarf height, early maturity, long as well as medium and short grain, and improvement in milling and cooking quality. Dr. D. Marlin Brandon took over as director and agronomist in 1985. The Lattemore and later Jenkins properties were acquired, significantly expanding the station. Construction of two new greenhouses and additional seed storage also occurred during this period.



CW Johnson, S. T. Tseng, and H.L. Carnahan weighing plots by hand.

Dr. Kent S. McKenzie was hired as a plant breeder in 1988 as Dr. Carnahan retired. He was appointed Station director in 2000 after Dr. Brandon passed away. Dr. Farman Jodari was hired at Dr. Tseng's retirement in 1999 to continue the long-grain breeding project. Dr. Virgilio C. Andaya joined the breeding team in 2007 to lead the short-grain project and now is in charge of the medium-grain (Calrose) project and is director of Plant Breeding. Dr. Stanley O. Samonte joined the program in 2012 to lead the short-grain and premium-quality project. Dr. Cynthia B. Andaya was hired in 2010 as a research scientist managing the DNA marker lab and rice quality lab. Two new breeding greenhouses, two refrigerated cold screening greenhouses, a DNA marker lab, a cooking lab, and more bin storage have been added to the facility in the past five years. Table 1 is a timeline summary of the staffing and facilities at RES.



Centennial Dedication June 19, 2012 by Native Sons of Golden West



Staffing & Facilities Timeline

Staffing and Facilities at the Rice Experiment Station									
Time Period	1912 to 1969	1970-1975	1976-1980	1981-1985	1986-1988	1989-1995	1996-2000	2001-2012	
Plant Breeders	Chambliss (L.A) Adams, Jones, Davis, Williams Mastenbroek	Camahan (Dir.) Tseng Johnson	Camahan (Dir.) Tseng Johnson	Camahan (Dir.) Tseng Johnson	Camahan (Dir.) Tseng Johnson	Tseng Johnson McKenzie	Tseng-- - Jodlari Johnson McKenzie	Johnson Ret. '08 Jodlari Campbell 2002-3 Jiang 4/2005-2006 Andaya 4/2007- Lage 7/2007-9 Samonte 2/2012	
Plant Pathologist				Oster	Oster	Oster	Oster	Oster	
Research Scientist								C. Andaya 1/2010	
Breeding Assistants	1	3	4	4	4	4	4	5	
Field Staff	3	3	3	3	3	3	3	4	
RES Director	... Finfrock- Mueller-Morse	Morse	Morse	Morse	Brandon	Brandon	Brandon-McKenzie	McKenzie	
USDA - ARS	...Thyssel-Erickson	Rutger (UCD)	Rutger (UCD)	Rutger (UCD)	Rutger (UCD)	Mackill (UCD)	Mackill (UCD)	Tai (UCD)	
UC	Oelke (Weeds)	Seaman (RES)	Seaman (RES)	Seaman (RES)	vacant	vacant	→ Fischer (UCD)	→	
Facility Acreage	130	+235 = 365	→	→	→	→	+ 100 = 478	→	
Research Facilities	Greenhouse 1-3	Breeding Lab Greenhouse 4 Hawaii Nursery		Breeding Lab Addition			Greenhouse 5CD C(path) D(weeds)	Greenhouse5AB (breeding) Refrigeration of 3-4, DNA lab, Cooking lab Private Hawaii Nursery	
Varieties Released	Colusa, Caloro, Calrose, CS-M3	CS-S4, S6, M5	Calrose76, M7 M9, L-201 Calmochi-201, M-201, M-101 M-301, S-201	M-302, M-401 Calmochi-202 M-201, L-202 Calmochi-101 M-202	A-301, M-102 M-203, S-101 M-103, S-301 Plant Variety Protection (PVP)	L-203, M-204	S-102, A-201, L-204 L-205, Calmati-201 Calhikari-201, M-402, M-104, M-205	M-206, M-207, M-208, L-206, Calmati-202 Calamylo-201 M-105	Calhikari-202
							(PVP + Patents)		

History of the Station Lands

by Tim Kelleher³

The Station's land was originally "loaned" to the Sacramento Valley Grain Association, Inc. by William Sheldon of San Francisco, who apparently owned the land in 1912. Sheldon granted the Association use of the parcels immediately under and around the current Station site for 40 years to conduct experiments to determine the best methods for cereal production in California. This "loan" was made through a Deed of Trust signed June 19, 1912 covering Richvale Colony No. 10, Lots 167, 168, 173 and 176, the consideration being "Ten Dollars."

The Station's first land purchase was on April 11, 1930. The Station's predecessor, the Sacramento Valley Grain Association, Inc. purchased from John M. Armstrong the 42-acre piece bordered by State Highway 162 on the north, South Pacific Railroad on the west, and Riceton Road on the east, for the princely sum of \$10. Six years later, the fields lying immediately south of the current Station's headquarters and west of the South Pacific Railroad were purchased. Richvale Colony No. 10, Lot 175, was purchased from Mattie Gorham, administratrix of the estate of Leverett Henry Gorham. This purchase was through a court bid which took place on December 28, 1935. The Association was the highest bidder at \$490, or approximately \$30 per acre. On April 17, 1936, Lot 174 was purchased from Alex Olsson, a widower, but no amount is stated for the purchase price.

On December 12, 1942, the Association purchased the land that was originally "loaned" the Association in 1912, Lots 167, 168, 173 and 176, totaling approximately 60 acres, from the Sutter Butte Canal Co. for \$50. How the canal company acquired these parcels from William Sheldon is not known, but probably resulted from nonpayment of assessments, which was fairly common during the 1930s.

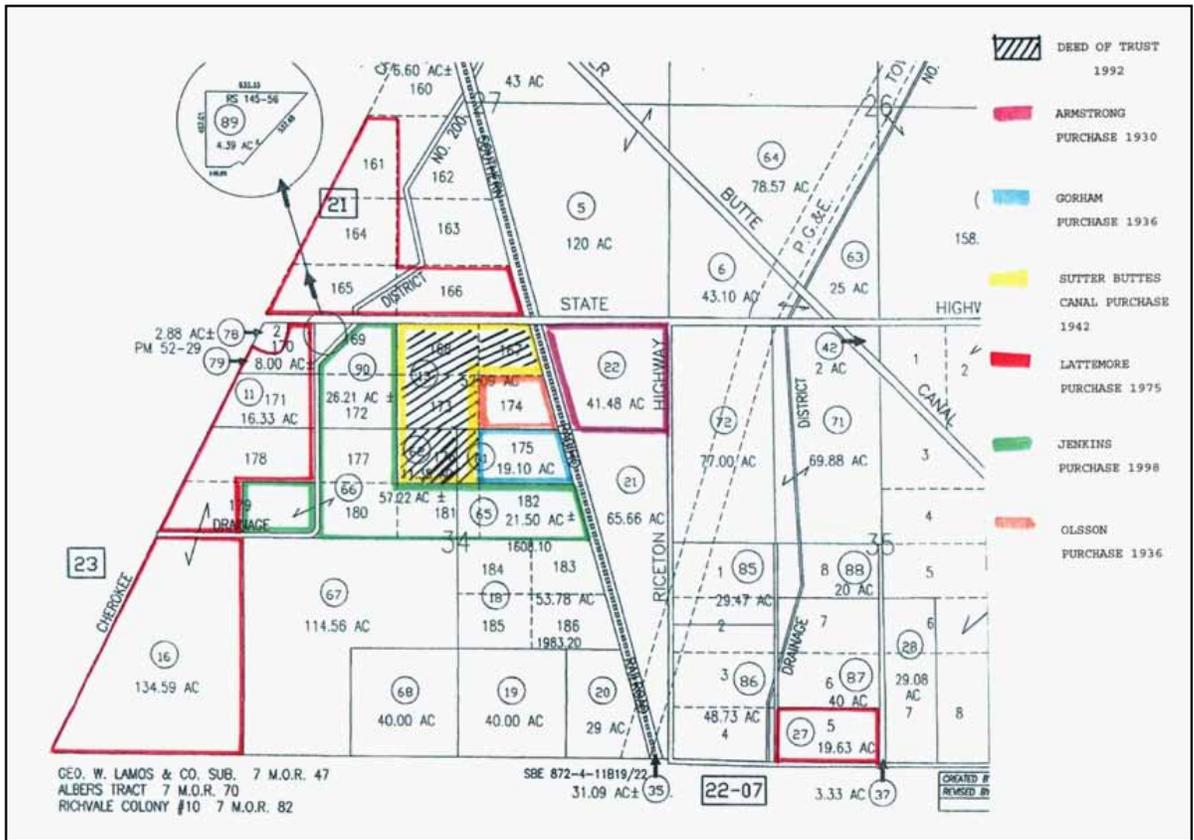
In 1975 the Station purchased the Hamilton Road piece on January 2, and also the Lattemore property, which lies east of Cherokee Canal on both the north and south sides of State Highway 162. This purchase more than doubled the Station's acreage.

The final acquisition came on November 18, 1998. I had the privilege of working with Marlin Brandon to acquire the Jenkins property that lay both within and on the southerly border of the Station's property. This was made possible through a bit of horse trading. Jim Warren wanted to sell his property, which lay east of Riceton Road and north of Hamilton Road. At Marlin's urging the Station Board agreed to buy Jim's piece with the goal being to then trade it for Alvin and Onnolee Jenkins' property. The Warren piece was purchased February 19, 1998, and after some negotiations, Alvin and Onnolee agreed to sell their property in part in exchange for Jim Warren's piece and in part for cash. The end result was that the Station acquired the Jenkins property on January 28, 1999. This consisted of Lots 169, 172, 177, the east portion of Lot 179, and Lots 180, 181 and 182. This purchase filled in the land within and around the Station, permitting today's full use and helping to ensure the integrity of its seed program.



³Tim Kelleher serves as legal counsel for the California Cooperative Rice Research Foundation and principal partner of Rice Lawyers, Inc. He served on the Federal Crop Insurance Board of Directors, the BUCRA Board where he was also Chairman, and the California Rice Research Board. Tim's family has grown rice in the Biggs area since the 1930's.

History of Station Lands



Map that tracks land purchases for the Rice Experiment Station.



Aerial view of headquarters Spring 2012



Recollections

by Dennis Lindberg⁴

My father David Lindberg came to California in 1912 and grew his first rice crop in 1913. His efforts and those of his fellow rice farmers were hit and miss and are described in detail in the book “Rice In California,” available at Butte County Rice Growers Association in Richvale, California. Needless to say, some very trying times ensued and many farmers went broke or got discouraged and left. For those who stayed and toughed it out, and with the help of knowledge obtained from research conducted by personnel at the California Cooperative Research Foundation’s Rice Experiment Station, the California rice industry has grown to a measure of success hardly imagined in those early years.



Dennis O. Lindberg CRC



Tractors and binders-1920's EWS

My first inkling of rice research occurred when I attended the Richvale Grammar School in the 1930s. During those years, the Rice Field Day participants would adjourn from the Rice Station activities to the school auditorium for lunch provided by Richvale Farm Bureau ladies. Even to the young of mind it was an indication something important was going on. In the adjoining playground area, various dealers had equipment on display including steel-wheel, wooden-framed bundle wagons used to haul shocked rice to the stationary harvesters. In our innocence, my schoolmates and I had fun wheeling those wagons around the playground.

The Deed of Trust (i.e., Mission Statement) that appears on the cover of this publication is just as appropriate today as when it was written 100 years ago, although no mention is made of the cereal crop which would prevail. The potential for adequate water for surface irrigation and the heavy clay adobe soil prevalent in the area dictated that the ultimate choice be rice.



Rice threshing scene EWS

⁴ Dennis Lindberg grew up in Richvale, up the street from the Rice Experiment Station. He received the 2002 California Rice Industry Award; is a local Richvale historian, author, musician, and metal sculptor; and is growing his 71st rice crop.



So now comes a review of those 100 years of diligent effort contributed by some very dedicated people, and none were more important than those who served as superintendent (director) of what was to ultimately become California's Rice Experiment Station. It has been my pleasure and privilege to have known and had personal contact with the majority of those individuals. Some of those encounters are described here.

Brief Encounters with Past Directors of the California Rice Experiment Station



Wagons loaded with rice sacks

EWS

Ernest Adams – I was not even born when he came to California, but by my teen years I was well aware of his multiple contributions to the rice industry at large. Passing by his farm one day while hunting waterfowl, my buddy and I drove to the ranch headquarters to ask permission to hunt some geese we saw landing. Directed to corrals nearby, we found him observing some hogs he was raising. Quiet and unassuming in demeanor, he very generously granted us permission. Our hunt was a success.

Loren Davis – Having grown my first rice crop in 1942, I remember Loren as the first to mention cool temperature damage to rice, particularly east toward the foothills. In 1944 I harvested some experimental wild rice he and Lewis Evans grew off the Station. Loren, an accomplished athlete, played softball with us on a field where Butte County Rice Growers Association flat storage bins are now located. He drove to the games in a 1920's Maxwell (Jack Benny style) open touring car he had restored. It was beautiful! I wish I had one like it.

Dwight Finfrock – During Dwight's tenure (and later under breeders Mastenbroek, Carnahan, and Johnson), medium-grain varieties were well on the way to replacing short grain as the dominant rice variety produced in California due to improved yield potential and market acceptability. I recall one day I asked Dwight to look at a field of Calrose infested with what turned out to be army worms, the first I had ever seen. While we were inspecting what looked like an excellent crop that eventually yielded 60-sack (hundred weights per acre) Dwight said to me, "Dennis! If we can control the weeds, we can grow 100-sack rice." I was admittedly somewhat skeptical – and am happy to say that time has proven him right.

Morton Morse – Morton served the most years of any director to date. It was his challenge to implement the 1969 Rice Referendum vote otherwise known as the "Accelerated Rice Research Program," which called for high-yielding, short-stature rice varieties. Breeders Carnahan, Johnson, and Tseng were hired during Morton's tenure to carry out those responsibilities. Morton was an avid pheasant hunter, and we enjoyed many hunts together in the company of our Brittany hunting dogs.

Marlin Brandon – The promise and possibility of 100-sack yields came to fruition while Marlin was director. My fondest memories of him include his patience with me when I asked questions about panicle initiation, maturity dates, and the hardest decision I struggle with every year, which is when to drain the water before harvest. Marlin carefully wrote down on a yellow-lined notepad the dates requested except for 'when to drain,' explaining that is dependent on soil types and how long it takes to dry out.

Kent McKenzie – The tremendous success in the past 100 years at the California Rice Experiment Station was achieved by the efforts of many people. None is more deserving than Kent who indeed has brought progress and professionalism to be admired. Just one look around the Station and you can see what I mean – and 100-sack yields occur now on a regular basis. It is one thing to increase yields and yet another to maintain disease resistance, milling quality, and market acceptance at the same time. "Mission accomplished!" I share with you a memorable moment that occurred during a visit we had after a recently hired medium-grain plant breeder resigned. When I asked who would replace the breeder, without hesitation, Kent said, "You're looking at him!"



Rice Breeding Program

Medium and Short Grain Breeding

by Virgilio C. Andaya and Stanley Omar P.B. Samonte ⁵

Rome was not built in a day, as the saying goes, and so is true for the California rice industry. Each of the rice varieties developed and released by the Rice Experiment Station (RES) in a span of a century (see Pedigree Schematic), from Colusa to the latest variety Calhikari-202, played a role in building a rice industry that stands proudly today. The history of rice varieties developed and grown throughout these years, retold by farmers and researchers who ran RES since its infancy, is very interesting and inspiring. The earliest varieties have long been out of production, but never forgotten, for they served as important building blocks, even to the newest rice varieties.

During the mid-1910s to late 1960s, there were only three major public rice varieties grown in California: Colusa, Caloro, and Calrose. Caloro and Colusa (released in 1917 and 1921, respectively) were “pearl” varieties, now commonly known as short grains. The short-grain rice variety was the predominant type in the earlier years up until the development of Calrose, a rough-hulled, medium-grain rice released in 1948. From then on, the medium-grain variety took hold and served as the focus for varietal improvement. It was only in 1968 that an improved type of Calrose with smooth hulls was released and named CS-M3.



V. C. Andaya-Field Day

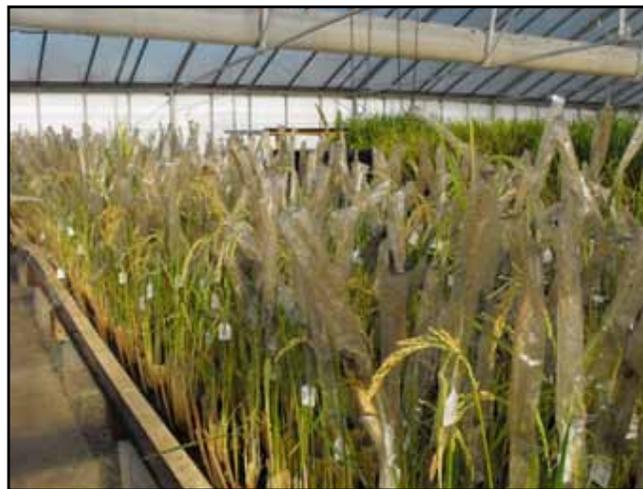


S. O. Samonte-Collecting field notes.

With the accelerated breeding program initiated in 1969, under the leadership of the late Dr. Howard L. Carnahan as the director of Plant Breeding, the amount of crosses made at the station increased significantly. Basic breeding objectives included developing varieties with higher grain yields, lodging resistance, early maturity, short-stature, improved grain quality, increased seedling vigor, and resistance to blanking. The development of short-statured rice (IR8) by the International Rice Research Institute (IRRI) and the isolation of Calrose mutants (D7, D31, etc.) by Dr. Neil Rutger of the USDA were milestones in rice breeding. Rapid progress in breeding for better-yielding, semi-dwarf rice followed and culminated in the first semi-dwarf, medium-grain varietal releases in California in the mid-1970s:

Calrose-76, M7, and M9. A rapid succession of varietal releases followed, resulting in nine new varieties by the end of the 1970s.

Varieties come and go at a continuous rate. Old varieties are replaced with new ones having better attributes and significant advantages in yield, quality, or disease resistance. The longevity of a variety is mainly determined by farmers who grow them; some varieties last only a year after commercial release, while others last a quarter of a century or more. From the medium-grains breeding program, the more significant and famous variety that came out since 1969 was M-202 (released in 1985), which dominated the rice acreage for more than 20 years. At some point, perhaps M-202 reached a planted acreage upwards of 80%. M-202 was produced from a cross between a close relative of M9 and the very early maturing M-101. The M-202 popularity



Greenhouse bench with new crosses.

⁵ Virgilio Andaya is director of Plant Breeding and Stanley Omar Samonte is project leader for the Premium Quality and Short Grains at RES.





and variety of choice was challenged only with the release of M-205 in 2000 and M-206 in 2003, but it was not until the later years of the 2000s that the three were about equally planted in more than 90% of California's rice acreage. M-206 became a standard for high milling yields. Other notable releases are M-103 in 1989 and M-104 in 2000. Both are cold tolerant and very early maturing, making it possible to successfully grow rice in areas affected by low temperature stress that induce blanking, especially in the Delta. In response to the discovery of blast infection in California in the mid-90s, M-207 and M-208 were released in 2005 and 2006 with the blast resistant gene Pi-z.



Labor crew staking large plots.

Even with the dominance of Calrose in the California rice industry, breeding for short grains remained an important component of the breeding program at RES. It took more than 50 years to develop CS-S4 as a viable replacement for Colusa. Serving only as a "transition variety," CS-S4 was quickly replaced by S4, which at one point in the late 1970s was planted to 30% of rice acreage. In 1980, the first smooth-hulled, short-statured, early-maturing short grain S-201 was released with grain yields about 10 hundred weight higher than that of S6. S-201 was later followed by a very early maturing S-101 and an intermediate maturing S-301. Sweet rices Calmochi-201 and Calmochi-202 were also developed at the time, but it was not until 1985 that Calmochi-101 was released and became the dominant sweet rice to this day because of its quality as well as its high level of cold tolerance. Calmochi-101 also served as one of the parents of S-102 that was released in 1996 and is still in commercial production.

Starting in the 1990s, the California rice industry underwent considerable changes due to new regulations and requirements for better quality rice. The first premium quality short-grain rice Calhikari-201 was released in 1999, with Koshihikari as its parental source for cooking quality. It was not until 2012 that Calhikari-202 was released, a variety that has better grain quality and yield. Other varieties coming out of the short grains breeding project were the first low amylose variety Calamylo-201 in 2006, an Arborio-type germplasm 89Y235 in 1989, and a premium quality medium grain M-402 in 1999.



Hand water-seeding 4x6 plots in stormy weather in 2011.

Breeding goals and challenges are many and too varied for one or few breeders to accomplish or overcome. What made RES so successful is its deep dedication, continuity of mission, and multi-disciplinary and coordinated approach to breeding. What started as a few breeding goals in the 1960s – such as short-stature, early maturity, adaptation to cold environment, and better agronomic characteristics – have now been modified to face new environmental and market challenges, such as developing varieties that have better resistance to blast, better tolerance to new herbicides, higher milling yields, better grain and cooking quality, increased and stable yield, and being responsive to changing consumer preferences on taste, seed size, plumpness, shape, translucency, or uniformity.

The ability to foresee the varietal needs 10 or more years in advance is crucial, as is the application of new breeding tools to accomplish the goals. RES is continually developing capabilities to improve its breeding efficiency. Mutation breeding is commonly done to generate new and useful variants such as earliness or perhaps herbicide resistance. The use of DNA markers in the selection for disease resistance and grain quality is now routine. The Grain Quality Lab has been improved with new equipment to screen for seed attributes and chalkiness. Temperature-controlled greenhouses are used for screening for blanking resistance and for rapid generation advance. Future challenges may include breaching the yield plateau, incorporating effective blast resistance genes to counter emerging blast races, and improving water-use efficiency. As always, RES strives to ensure the development of excellent rice varieties to cater to present and future needs of the California rice farmer.



V.C Andaya water-seeding 10x20 plots.



Precision drill seeding F₂ at San Joaquin cold nursery-H. Toor and P. Deol.



Gleaner large plot harvest by W. VanGilder & H. Wright.



Almaco plot harvester with single operator and computer data collection.

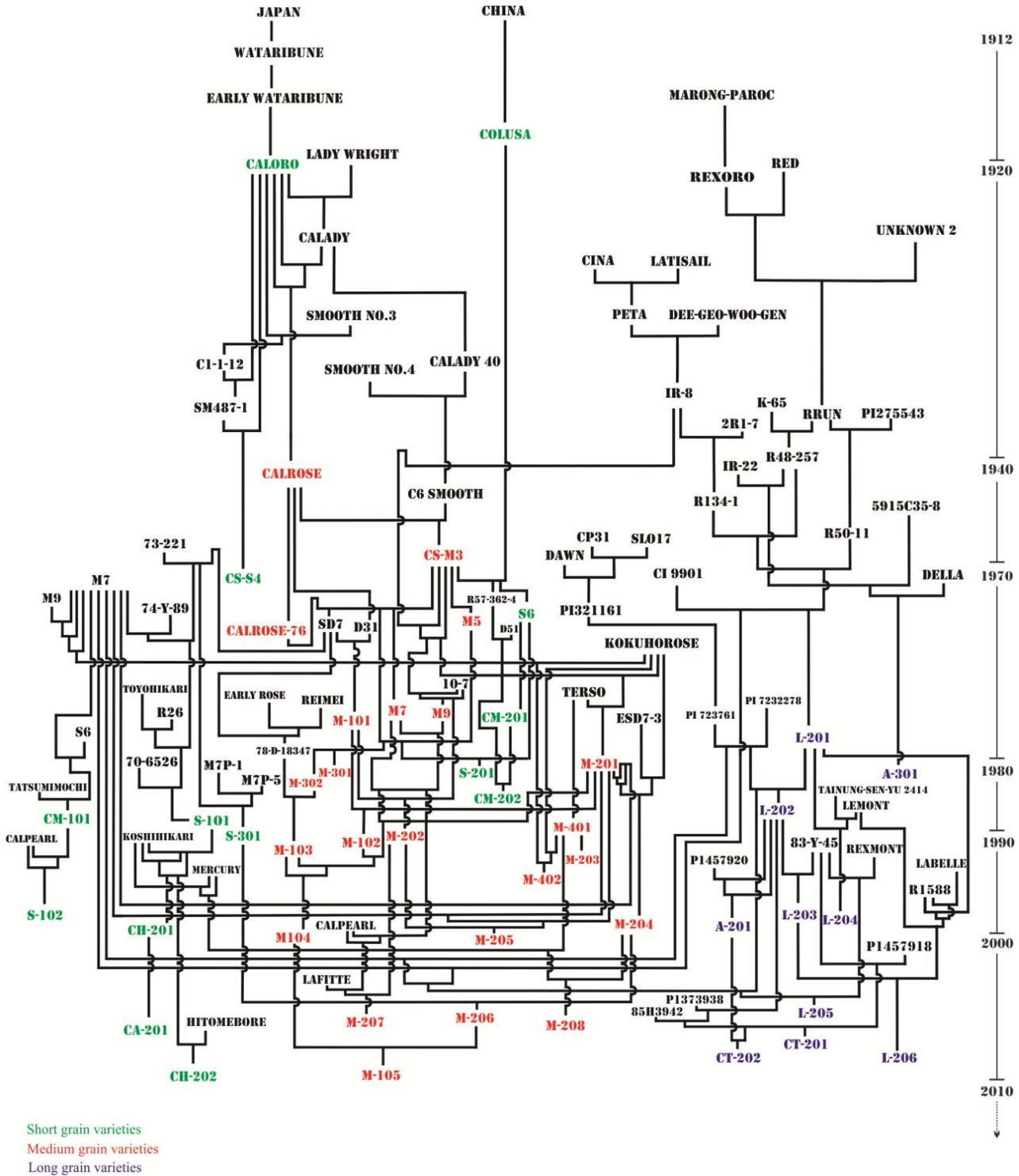


Brown rice samples and panicle selection in the winter.

Grain classes			
	Short	Medium	Long
			
L/W ratio	< 2	2 - 3	> 3
Amylose %	16	17	22
Alkali value	6	7	4
Setback	20	- 40	40
Texture	Moist	Moist	Dry

Major U.S. market types and quality characteristics.





Pedigree Schematic of RES-released California Rice Varieties

(revised from Bockelman, Wesenberg, Dilday, and Yan *In: Rice: Origin, Technology, and Production*, 2003 John Wiley and Sons, Inc.)



Calrose Rice –A California Legacy

by Kent S. McKenzie & Carl W. Johnson ⁶

Commercial rice production in California was established in 1912 along with the founding of the Rice Experiment Station (RES) near Biggs, California. In the previous few years, scientists with the USDA's Bureau of Plant Industries tested and identified a few plant introductions that successfully produced a rice crop in small plantings in the heavy clay soils of the Northern Sacramento Valley. Not only were the yields so high that their validity was questioned by rice producers elsewhere in the United States, but the grain quality was good enough to win awards at some agricultural expositions. In the following few years, selections of two short grain introductions were identified and named Caloro and Colusa. They became the predominant California rice varieties for the next 50 years.



K.S. McKenzie-Field Day

By the 1930s there had been rapid development in related disciplines, and applied plant breeding was beginning to emerge and make its mark in areas like hybrid corn and cereal breeding. Genetics, with its laws of inheritance, were better understood and scientific breeding methods helped develop new varieties through hybridization (cross-pollination) and selection. This brought plant breeders knowledge and tools to use “directed evolution” to develop improved varieties, rather than just relying on introductions from other places and random variability created in materials due to natural out-crossing or mutations. Planned cross-pollination, followed by the natural self-pollination and selection of rice until the traits become fixed and true breeding, was now being used to develop varieties in the Southern United States and undertaken at RES. This pedigree breeding method that led to the development of Calrose continues to be the predominant method for varietal improvement at RES.

Calrose was developed by Jenkins W. Jones and Loren L. Davis and released from RES to growers in 1948 to complement the California short-grain varieties. It was a selection made from a cross of Caloro to Calady that was backcrossed to Caloro. Calady was a medium-grain selection developed in California from a cross of Caloro and Lady Wright. The latter was a long-grain variety released by S. L. Wright of Louisiana, the developer of the medium-grain Blue Rose that was the predominant medium grain in the Southern United States until late 1940. The pedigree of Calrose is written as follows Caloro/Calady//Caloro. Calrose is similar to Caloro in agronomic characteristics but the kernels are more transparent than Caloro, have better milling quality, and have



C.W. Johnson and Faye Johnson- 2004 Rice Industry Award

a vitreous texture similar to Blue Rose. The name “rose” indicates medium-grain shape and “Cal” to indicate California origin and production. Calrose and its progeny are classified by race as “temperate japonicas” in contrast to tropical japonicas (Southern United States long grains) and indicas (tropical varieties).

California rice marketing groups had urged RES breeders to focus on developing medium-grain varieties for California since U.S. domestic consumption was mostly long or medium grains. Medium grains in general were better adapted to the cool temperatures that occur in the spring and fall than the long grains that are more tropical. The success of the older varieties at that time was based primarily on total field yield, and quality received secondary importance. Calrose acreage began increasing rapidly after a very cool year in 1954 that was a yield disaster for Caloro. Fortunately, Calrose had very acceptable

⁶ Kent S. McKenzie is the current director of the RES and Carl W. Johnson was the Calrose rice breeder at RES from 1974 until his retirement in 2008 and recipient of the 2004 California Rice Industry Award.



cooking and taste properties. By 1960 Calrose was grown on 30% of California rice acreage and by 1975 70%. Its success can be attributed to a combination of its adaptation, productivity, grain quality, the California climate, and successful marketing. Thus, Calrose allowed California to transition to a medium-grain type, capture the western Blue Rose market, become the dominant U.S. medium-grain rice producing state, and achieve world market recognition.

With Calrose as a foundation variety and the establishment in 1969 of a grower-funded accelerated rice breeding program at RES, breeders began to improve the adaptation and productivity of Calrose as well other rice varieties for the other market classes (long, medium, short, waxy, etc.). Major trait improvement included development of smooth hulls that improve handling, short straw (semidwarf) height, early and very early maturing varieties, and most recently improvement is milling yield and stability. With each trait addition, incremental improvements were made in field performance while remaining in the Calrose quality framework. This grain quality is the combination of physical and chemical quality characteristics passed down and enhanced from Calrose and the climate, soils, and water of California rice growing regions. New releases from RES are subject to physicochemical and cooking tests, grower and marketer input, and evaluation to ensure new varieties remain true to type.

Over the years new varieties with the same or improved cooking properties as Calrose were released and then replaced the older medium-grain varieties in commercial production. Calrose, as a medium-grain class, was established and is still used to identify California medium-grain quality. After 64 years we have reached Calrose XX, have no interest in its retirement, and look forward to future improvements.



Founding California Medium Grain

New "Calrose" Release



Long Grains

by Farman Jodari ⁷

Since the inception of the Rice Experiment Station (RES) in 1912, rice breeders and scientists have realized the need for an early maturing, photoperiod insensitive, and cold tolerant long-grain variety for California. Earlier attempts using Southern long-grain varieties such as Fortuna, Edith, Patna, and Carolina gold were unsuccessful. USDA scientists subsequently devoted some effort to introducing long-grain germplasm lines from the USDA world collection, Southern United States breeding programs, and other countries. During the early 1930s Dr. J.W. Jones, USDA plant breeder, initiated rigorous crossing between the introduced long-grain germplasm lines and adapted medium- and short-grain varieties such as Caloro, Colusa, Calady, Calrose, and M7. During 1961 to 1973, RES plant breeder Johan Mastenbroek continued using a similar approach with the objective of further improving the adaptability of long-grain breeding lines. Some preliminary research was also devoted to developing male sterile lines for possible hybrid rice development. The majority of the emphasis, however, was on improving earliness, quality, short stature, seedling vigor, and protein content.

Dr. S. T. Tseng was recruited in 1970 by RES to increase efforts in the development of long-grain varieties for California. During the early years of that decade the search continued for the development of hybrid rice components. This work was discontinued later due to a lack of appropriate Japonica-based cytoplasmic male sterility (CMS) and restorer lines. The breeders had concluded that investing efforts in pure-line breeding would be more productive than improving characteristics related to the F1 seed set that was needed for hybrids.

During Dr. Tseng's tenure, new collection of carefully selected long-grain germplasm was introduced. Existing long-grain lines by this time had considerably improved adaptability from earlier crossing with medium- and short-grain varieties where further crossing was not needed. The primary breeding objective then was to incorporate Southern long-grain quality characteristics into adapted California long-grain lines. Eight varieties and one stem rot resistant germplasm line were released by Dr. Tseng: L-201 in 1979, L-202 in 1984, L-203 in 1991, L-204 in 1996, L-205 in 1999, aromatic type A-301 in 1987, aromatic type A-201 in 1996, basmati type Calmati-201 in 1999, and stem rot resistant germplasm line 87Y550 in 1994.

The released conventional long-grain varieties had achieved considerable yield advantage to the level of

medium grains such as M-202, especially in the warmer regions of California. Also cold tolerance and lodging resistance were major improvements. L-204 variety had shown good milling quality of about 65%, as well as a translucent bold grain shape. However, a subtle cooking-quality difference existed between L-204 and Southern long-grain varieties.

The current long-grain project since 1999 has placed special emphasis on improving cooking-quality attributes of long-grain breeding lines. Annually, all long-grain selections including specialty types are subjected to cooking tests and evaluated for desirable attributes. More advanced lines are quantitatively analyzed for amylose, gelatinization temperature, RVA profile, and most recently four DNA markers to determine their inherent cooking-quality types. The release of L-206



S. T. Tseng- 1998 Rice Industry Award

variety in 2006 has been the result of such extensive quality screening. Based on USDA rice quality lab reports, L-206 contains significantly less soluble starch during the cooking process and consequently has closer cooking quality to Southern long grain than the previous variety, L-204. These results agree with subjective taste tests as well as starch-pasting profile measurements. The majority of current long-grain breeding lines possess L-206



*F. Jodari
Hawaii Winter Nursery*



⁷ Farman Jodari is the long-grain project leader at RES.



S. T. Tseng testing for alkali spreading value.

cooking-quality type. L-206 yield potential is similar to medium grain variety M-206 in UCCE statewide yield tests, with the exception of cold locations. Average head rice milling yield of L-206, however, is 4% lower than M-206.

Long grains have historically shown high yield potential in warmer California rice regions. Over the years, yield levels of breeding lines have gradually increased, keeping pace with medium and short grains in the warmer regions. Milling and cooking quality issues and California mill and market acceptance, however, have prevented expanded production. Recently, experimental 06Y575, out yielded medium and short gain selections in most UCCE statewide test locations for the last 3 years, with average milling yield of % 65. However, because of a single grain quality trait difference and market acceptance this line is not being advanced. Further quality improvement is currently underway. The essential components of a competitive California long grain variety exist in the current long grain

germplasm collection. These components include grain yield levels that are competitive, milling yield levels of 64% or higher and cooking quality attributes that are similar to Southern long grains. Recombining these essential components has been and continues to be the core of long grain breeding efforts.

Breeding efforts for specialty long-grain varieties have expanded since 2008. Specialty types include soft cooking aromatic jasmine, elongating basmati, and to a lesser extent conventional aromatic types. Calmati-202 released in 2006 is a basmati-type variety with improved cooked grain elongation and texture. In 2012 experimental lines of all three specialty groups in advanced generations are being tested in-house and by marketing organizations for their quality attributes and marketability. Experimental lines 11Y158 (basmati), 11Y106 (jasmine), and 08Y1115 (conventional aromatic) are currently at headrow purification stage.



B. Deol preparing long grain panicles for selection by F. Jodari



Comparing characteristics of cooked Basmati rice, imported and breeding sample.



Demonstration plot of L-206.



High yielding experimental long grain 06Y575.



Disease Resistance

by Jeffrey J. Oster⁸

The pathologist assists the breeding program in assessing disease resistance levels in breeding materials and transferring disease resistance from donor sources to increase resistance in California varieties. Stem rot, blast, sheath spot, and bakanae are the diseases of concern, but bakanae is controlled with seed treatments.

Stem rot: Up to 25% losses due to stem rot have been recorded by Dr. Webster of UC Davis. The program began with a screening/breeding for resistance to stem rot. All statewide and preliminary entries were screened for stem rot resistance.

Progeny from crosses with M-101 and stem rot resistant *O. rufipogon* 100912 made at UC Davis were introduced into the breeding program in 1980. Significant progress has been made in the short and long grains, with the best entries yielding 15% to 20% more than current varieties in inoculated stem rot yield trials. However, no resistant medium-grain lines have been identified in recent years.

In 1997-98, six wild species accessions with resistance to stem rot were used in an immediate backcross program. After BC2, 10,000 transplants were grown out in 1999. Two lines derived from crosses with *O. nivara* 105316 were found with resistance equal to that of 87Y550.

In 2005, an immediate backcross program was started in summer of 2005 to transfer stem rot resistance derived from *Oryza rufipogon* 100912 and *O. nivara* 105316 into a medium grain (M-206) background.

In 2010-11, stem rot resistance genes from the *O. rufipogon* program were mapped. Fine mapping will be done on a new population in 2012-13. Hopefully, markers can be used to more accurately identify resistant material.



resistant rice. However, experience elsewhere in the world has shown that major gene resistance can break down within a few years of varietal release. It is desirable to have more than one major gene available to combat the blast disease. With this in mind, recently developed (2002-2004) rice accessions were imported from the International Rice Research Institute (IRRI). Lines with genes conferring broad spectrum race protection were incorporated by backcrossing into an M-206 background using conventional and molecular marker assisted



J.J. Oster preparing aggregate sheath spot inoculum.



Stem rot (left) and sheath spot (right)

Blast: Blast is probably the number one fungal disease of rice worldwide. Losses could be potentially large based on data from other parts of the world, but have not been well documented in California (estimates range from 10% to 20%). Blast was found in 1996, appeared to expand in acreage affected in 1997, but has been sporadic in occurrence until 2010-11, when the disease became more widespread.

Breeders started transferring resistance genes in 1997, but, after a number of years crossing, only the Piz gene remained in the medium-grain crossing program. New greenhouse facilities were built in 1998 to aid in this program. Varieties M-207 and M-208 with this resistance gene were released in 2005 and 2006, respectively. Major genes for disease resistance largely prevent development of disease lesions on



⁸ Jeff Oster is project leader of plant pathology at RES.

screening. All lines should be very close agronomically to M-206, but could have undesirable genes linked to the blast resistance gene. In 2011, blast resistance genes Pikh, Pi40, Pi33, and Pita2 were combined in individual lines using molecular markers. The reason for combining (or pyramiding) genes is to prevent the blast pathogen from overcoming the major gene resistance so easily.

Since 2010, a new blast race has been identified on M-208. Incidence was low (1 in 5,000 to 10,000 plants) in both 2010 and 2011. This race can attack both the Piz and Pikh genes, but not other resistance genes transferred from IRRI plant introductions.

Aggregate sheath spot: Sheath spot is widespread in California, but does not always reach the upper part of the rice canopy, where it can do damage. Based on yield loss information on similar diseases from other areas and symptoms observed in California, this disease could cause 7% to 10% yield loss fairly commonly.

All statewide entries are screened in the greenhouse against sheath spot. Field screening proved to be erratic due to climatic fluctuations. In addition, stem rot frequently prevented accurate rating by interfering with sheath spot development.

The *O. rufipogon* stem rot resistance source was also resistant to sheath spot, but not all progeny are resistant to both diseases. Attempts were made to transfer resistance from other potential sources of resistance, but efforts failed.

An additional greenhouse program was started in summer of 2005 to transfer sheath spot resistance derived from MCR01-0277, TeQing, and Jasmine 85 into medium- (M-206) and long-grain (L-205) backgrounds. These parents possess higher sheath spot resistance than *O. rufipogon*. Hopefully, markers developed by the RiceCAP program in the Southern United States can also be used to assist in the transfer of sheath spot resistance.

Bakanae: This disease was discovered in 1999. Stand losses of 30% to 40% were reported by 2002. Bleach seed treatment was developed by 2003. Station research led to successful implementation of inexpensive, effective seed treatment, identification of cultural control procedures, and estimation of yield loss. Currently, a seed treatment is being tested for use in organic rice.

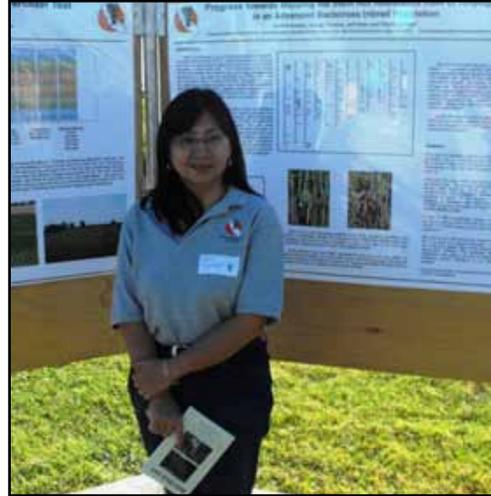
In the future, perhaps molecular markers will make it possible both to screen for disease resistance and to combine major genes for resistance to a single disease and then combine these resistance genes for various diseases into a single variety.



DNA Marker Applications

by Cynthia B. Andaya⁹

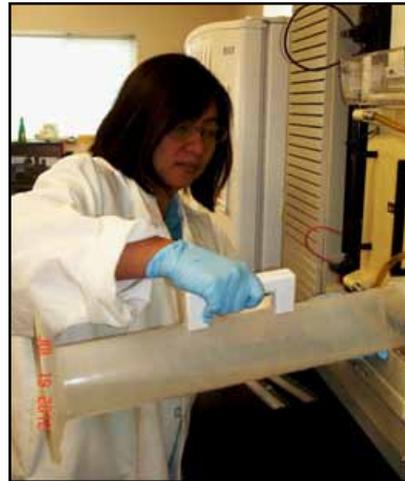
The advances in cellular and molecular biology in the last 50 years paved way for development of techniques and resources that are useful for the rice geneticist and breeders alike. Molecular markers or DNA markers are among such resources that breeders can utilize in their plant improvement program. Molecular marker (or DNA marker) is a fragment of DNA that is associated with a certain location within the genome. Molecular markers are identifiable sequences found at specific locations of the genomes and are transmitted from generation to generation, adhering to Mendel's law of inheritance. From the first publication of the rice molecular map in 1988 to the complete sequencing of the rice genome in 2005, different molecular marker types have been developed such as RFLP, AFLP, SSRs, and SNPs, to name a few. But no matter what type of DNA marker it is, it must be associated or linked to a particular trait of interest before it can be used for plant breeding purposes.



C.B. Andaya –Field Day poster display.

Prior to the advent of molecular markers, breeders depended exclusively on their visual evaluation of morphological and agronomic traits in their selection process. The availability of molecular markers in rice allowed rice researchers to do genetic mapping studies and identify markers linked to important traits such as disease and insect resistance, grain quality, and abiotic stresses such as drought and flood. While numerous rice genetic and mapping studies have been done, it is still up to the plant breeders to utilize this information and incorporate the molecular marker technology in their breeding program.

Molecular marker-aided selection (MAS) can complement conventional breeding by saving breeders time, allowing them to make informed genetic crosses, and enabling them to do early generation selection. Since DNA markers are neutral to environment variation, breeders can also do phenotypic evaluation of lines irrespective of varying environmental factors. Selection for resistance to diseases can also be carried out through DNA markers without need for pathogen inoculation thereby saving time and resources. More importantly, DNA markers can facilitate introgression of genes into elite cultivars prior to occurrence of certain races of diseases or biotypes of insects. Where purity and identity of varieties are in question, DNA markers can also be used to provide clarity.



*C.B. Andaya running
Rice Experiment Station DNA Sequencer.*

Rice Experiment Station (RES) recognized the potential of utilizing molecular marker technology early on. From 1995 to 2000, through pathologist Jeff Oster, RES cooperated with USDA scientist Dr. David Mackill to map stem rot resistance using AFLP markers by providing stem rot scores or ratings for analysis. In 2005, RES participated in the RiceCAP project, a USDA initiative, in the hopes of finding markers that they can use for selection in the long-grain project. Marker work for the RiceCAP project was done in cooperation with the USDA rice genetics laboratory of Dr. Thomas Tai in Davis, California. According to Dr. Farman Jodari, an attempt was made to do DNA marker work at RES in 2006 using agarose gel electrophoresis and ethidium bromide detection system. However, they analyzed only a few samples and found inconsistent marker data and wet chemistry results. As a result, marker work at the station was not actively pursued at that time.

In April 2007, RES hired Dr. Virgilio Andaya as a short-grain rice breeder. Aside from his plant breeding duties, Dr. Andaya was also assigned to establish a DNA marker lab to aid breeders in their selection process. Since there was no available space at that time, the pathology lab and the DNA marker lab shared a room in the RES office building. To show its resolve to integrate the DNA marker technology in the RES breeding program, the Station purchased an ABI 377 sequencer in February 2008. This machine is capable of high throughput

⁹ Cynthia Andaya is research scientist and manager of the DNA Marker Lab and the Rice Quality Lab at the RES.



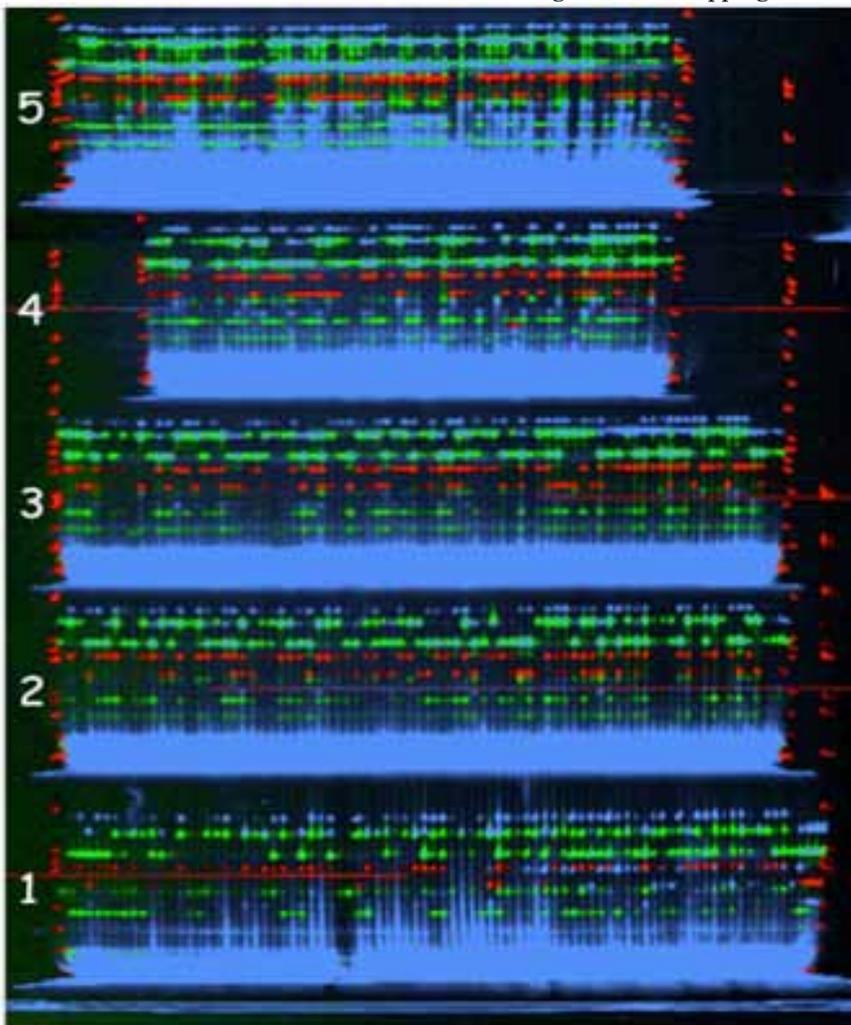


detection and genotyping analysis. Advanced lines were screened with microsatellite marker RM190 for the waxy gene that allows accurate classification of lines to specific grain quality groups. Materials from the medium-grain breeding program of Dr. Jacob Lage and from the backcrossing work by pathologist Jeff Oster were also screened for blast resistance using molecular markers.

Recognizing the importance of an onsite laboratory that can assist rice breeding efforts, a plan to build the DNA laboratory was conceptualized in November 2008. Construction started in early 2009 and the building was completed in April 2009. Prior to that, in February 2009, the Station hired a lab technician to assist Dr. Virgilio Andaya with the genotyping of thousands of samples from the breeders for blast and grain quality characteristics. In 2010, Dr. Cynthia Andaya was hired to genetically map the stem rot resistance in rice using microsatellite markers and to help in the management of the DNA marker lab. In 2011, the Station hired her on a full-time basis to perform activities in support of the different breeding programs and implement special projects. Leadership and management of the DNA lab was also turned over to her in early 2011 as Dr. Virgilio Andaya was involved in both the medium-grain and short-grain breeding programs. Starting in 2011, the DNA lab became involved in the following activities: mapping of stem rot resistance genes; pyramiding



G. Yeltatzie collecting leaf tissue for DNA extraction.



Marker-Aided Selection for Blast Resistance using 4 microsatellite markers: AP5930, RM224, RM 331 and RM7102. Picture shows 5 gel combs loaded in one single gel. Each lane in a comb represents an individual plant's genotypic score for the 4 DNA markers.

of blast resistance genes; marker-aided selection for the different grain types; fingerprinting various rice materials; and herbicide resistance discovery via mutation breeding.

From 2007 to 2011, RES established and built the manpower and facilities for what is now a fully functioning DNA marker laboratory to support the RES rice-breeding program. The lab will continue to pursue cost-effective methods to implement the Station's MAS by utilizing the available DNA markers for traits such as blast, grain quality, and herbicide resistance. When no such markers are available, as in the case of stem rot resistance, the lab will develop one. The DNA Marker Lab is an onsite, on-demand facility serving the interests of the California rice industry.

Rice Variety Testing – A Partnership with UCCE and RES

James E. Hill and John F. Williams¹⁰

The release of the rice variety IR-8 by the International Rice Research Institute (IRRI) in 1966 began the global green-revolution in rice and provided the impetus for the passage of the first marketing order for rice research in California. Rice variety improvement had been slow and California growers relied on the tall varieties Colusa, Caloro, and Earlirose which had been grown for many years. Success at IRRI made the California rice industry believe that it could be done here as well.

The California Rice Research Board was established in 1969 by a vote of the rice industry, under the provisions of the California Marketing Act of 1937 to fund research, including rice variety improvement. Additional rice breeders were hired at the Rice Experiment Station (RES) and a cooperative program was initiated with the University of California Agricultural Extension Service (now UCCE) to provide on-farm statewide testing of advanced lines. A third partner was a USDA rice geneticist at UC Davis who provided desirable traits to the RES breeders for use in adapted lines for UCCE to field test.

Originally, off-station plots were hand sown and hand harvested, limiting their size and validity. Considerable improvement came when a small, mobile rice combine (Massey Ferguson 39) was purchased from Germany, allowing for larger plots and more entries. Eventually, two MF 39s were in use, and the headers modified by the Sutter Welding and Equipment Company (SWECO) for harvesting small plots. As spare parts became impossible to get, the MF 39s were replaced with a custom machine built by SWECO. Over time, this machine too, was replaced with the current ALMACO SP 40 made specifically for small plots and modified for rice. The latter two machines greatly improved the efficiency of harvest with weighing and moisture measurement capabilities built into the system. Both of these combines were supported financially by the Rice Research Board.



J. F. Williams at breeding program review



UC associates Ray Wennig and John Stogsdill drill seeding a variety test in San Joaquin county.

1960s by UC Extension Specialist Milton Miller collaborating with UC Farm Advisors William Golden (Butte), John Lindt (Sutter), and Karl Ingebretsen (Colusa). In the first year of the marketing order, tests were overseen by Miller in cooperation with Carl Wick (Butte), John Lindt (Sutter), Marlin Brandon (Colusa) and Ron Baskettt (San Joaquin). As RES breeders increased the number of lines, the number of test locations was increased and the tests divided into three maturity classes to target specific rice environments. Calrose 76, developed by the USDA (Neil Rutger), was the first of several short-statured varieties to be released. Shortening the plant was a landmark achievement and the principle reason for yield increase in California because the ratio of grain to straw was higher and allowed for increased use of nitrogen without lodging. Calrose 76 was late maturing and never grown on substantial acreage, but it gave rise to early maturing short-stature varieties, such as the very popular M-201, released soon after Calrose 76.

During the 1970s Brandon was overseeing the statewide tests from UC Davis, having been intimately familiar with them from his work in Colusa County. At that time he was working with Carl Wick (Butte),



SWECO small plot combine harvesting entomology yield plots.

¹⁰James Hill is Associate Dean for International Programs of the College of Agricultural Sciences, UC Davis and rice specialist, and Jack Williams was a UC Cooperative Extension Farm Advisor and County Director for Sutter, Sacramento, Placer and Yuba counties.





Small plot rice combined custom built by Almaco for UC and Rice Research Board support.

Jack Williams (Sutter-Yuba), Ken Muller (Colusa), Jerry St Andre (Fresno), and Mick Canevari (San Joaquin). Beginning in 1980 the tests were overseen by UCCE Specialist Jim Hill working with many of the same UCCE advisors but with a change to Steve Scardaci (Colusa), Bill Weir (Merced), Marsha Campell (Stanislaus), and Dave Snell (Fresno). As rice acreage declined in the San Joaquin Valley, the statewide tests were concentrated more in the Sacramento Valley and San Joaquin County. More recently the statewide tests have been conducted by Cass Mutters (Butte), Chris Greer (Sutter-Yuba), and Luis Espino (Colusa).

Over the 40-plus years of this program, the statewide test results have provided essential information for variety release decisions. California rice average yields increased by 25% to 30%, grain quality improved, and marketing opportunities increased. An added benefit of testing on-farm is that UC advisors are familiar with potential varieties so that they are able to provide information to farmers as soon as new releases go into seed increase. In that regard, the program is unique among the rice states.



V. C. Andaya, F. Jodari, L. Espino, R. Wennig, R.G. Mutter, and C.A. Greer touring variety tests in grower fields.



USDA Rice Research in California

by Thomas H. Tai, J. Neil Rutger, and David J. Mackill ¹¹

The history of USDA rice breeding and genetics research in California began in 1908 with Charles E. Chambliss, who was appointed to head rice investigations at the USDA Bureau of Plant Industry in what was later renamed the Cereal Crops Research Branch. Although not stationed in California, Chambliss began testing rice on California farms in 1909 until the Biggs Rice Field Station was established in 1912 in cooperation with the grower-sponsored Sacramento Valley Grain Corporation.



Thomas Tai visiting with staff at Rice Experiment Station

1912-1969

With the establishment of the Rice Experiment Station in 1912, E. L. Adams of the USDA was appointed the first superintendent. After a few years, Adams resigned and went on to become a prominent rice farmer. Jenkins W. Jones succeeded Adams in 1918 and continued until 1931 when he was transferred to Washington. Jones was replaced by Loren L. Davis who transferred from Aberdeen, Idaho. Davis joined the California Cooperative Extension Service in 1947 and was succeeded by A. Hughes Williams who served until 1953. In 1953, the University of California assumed the administrative responsibilities of the Station and the cooperating farmers organization was renamed the California Cooperative Rice Research Foundation, Inc. The superintendent was jointly employed by the Foundation and the Agronomy Department of the University of California, Davis. The USDA assumed responsibility for the breeding program at Biggs with J. Rod Thysell, who was appointed agronomist in 1956, conducting breeding activities until 1966. Following Thysell, John R. Erickson was appointed as geneticist and served from 1967 to 1969 during which time he discovered the Bir-Co source of cytoplasmic male sterility.

1970-1989

Following the transfer of the USDA position from the Station to the Agronomy Department at UC Davis in 1969, J. Neil Rutger was appointed geneticist in 1970. Rutger and colleagues developed, through induced mutation, and released Calrose 76, the first semidwarf variety in California, on June 1, 1976. Calrose 76 has served as the ancestral source of semidwarfism for many additional varieties developed by RES breeders. Rutger and former visiting scientist C.H. Hu shared the 1986 California Rice Industry Award in recognition of their distinguished contributions to the advancement of the California rice industry. In addition to numerous research contributions, Rutger served as an adjunct professor and trained several prominent rice geneticists and breeders including H.P. Moon, Ken Foster, David J. Mackill (former USDA-Agricultural Research Service, IRRI, and Mars Global Foods), Kent S. McKenzie (RES Director), and Shannon Pinson (USDA-ARS). On January 1, 1989, Rutger transferred to an administrative position in Stoneville, Mississippi and in 1993 became the first director of the USDA-ARS Dale Bumpers National Rice Research Center (DB NRRC), Stuttgart, Arkansas before retiring as DB NRRC chief scientist in 2007.



J. N. Rutger with induced mutant Calrose 76, the first U.S. semidwarf table rice variety.

¹¹Thomas Tai is USDA Research Geneticists at UC Davis, J. Neil Rutger is USDA Research Leader (Retired), and David Mackill is Rice Specialist, Mars Food Global.



1991-2001

The early 1990s marked another transition as David J. Mackill replaced his Ph.D. advisor Rutger. During his tenure, Mackill began applying molecular tools such as DNA markers to assess genetic diversity in rice and developed the first intra-japonica molecular genetic map with his Ph.D. student Ed Redoña, who currently heads the International Network for Genetic Evaluation of Rice program at the International Rice Research Institute (IRRI). In addition to investigating important traits such as cold tolerance, stem rot resistance, and submergence tolerance, Mackill also established a basic core collection of rice germplasm and provided many materials to RES breeders. He also discovered the SUB1 QTL for submergence tolerance in rice and in 2001 became head of Plant Breeding at IRRI where he led the team responsible for breeding of SUB1-containing varieties that are helping millions in flood-prone Southeast Asia today. Virgilio Andaya, RES director of Plant Breeding, was among several Ph.D. students advised by Mackill at UC Davis. During this time, the USDA program received substantial funding from the Rice Research Board and support from the California rice industry was instrumental in obtaining increased base funding from Congress for the research program.



D. J. Mackill (right) with submergence tolerant rice developed for tropical flood prone areas of Southeast Asia.

2002-present

In March 2002, Thomas H. Tai transferred from the DB NRRC to lead the USDA-ARS rice genetics project at Davis. During the past decade, the project has been focused on development and application of molecular tools to investigate important traits for California rice production and to generate new genetic materials for use by RES breeders. In addition to research on seedling cold tolerance and grain quality traits, efforts are underway to exploit advances in DNA sequencing to develop markers and facilitate genetic studies in California rice varieties. New molecular technologies have also renewed interest in induced mutagenesis as a tool for gene discovery and breeding. Like his predecessors, Tai has served as an advisor to researchers who are making important contributions to the California rice industry, including former postdoctoral research associate Virgilio Andaya and Ph.D. student Cynthia Andaya (manager of RES DNA marker and grain quality labs). The USDA-ARS also assisted in the establishment of the RES DNA marker lab, and the project continues to enjoy the close cooperation of the RES and strong support of the Rice Research Board.



Rice Agronomy

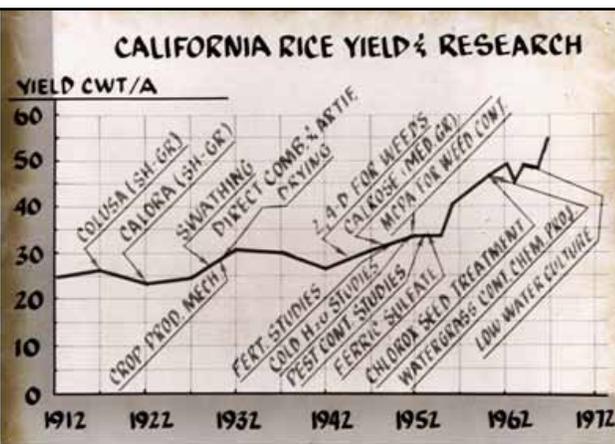
by Randal G. Mutters¹²

Much has changed since 1862 when the California State Legislature offered a reward of \$250 for the first thousand pounds of rice produced in California. The interest in rice was stimulated in part by the large influx of Asian immigrants and the abundance of seasonal wetlands that were unsuitable for cultivating most crops. For the remainder of the century, researchers and entrepreneurs alike focused on introducing long-grain varieties into California, but with no success. Field tests scattered from Los Angeles to Tehama counties failed to produce mature plants.

In 1906, while field testing crops suitable for reclaiming alkali soils near Fresno, William Mackie, U.S. Bureau of Soils, successfully grew a Japanese short-grain rice variety to maturity. This was the first definitive proof that rice could be successfully grown in California. After a failed attempt in 1907 to grow rice near Stockton, Mackie invited H.S. Brinks to field test rice near Biggs, California. With the assistance of a Japanese farmer and water supplied by the Sutter Butte Canal Company, Mackie planted the Japanese variety Kyushu, which yielded 3,000 lb/acre. In 1909 over 300 varieties were tested, and again the Japanese short grains were the most promising. The USDA conducted numerous field tests in cooperation with local ranchers interested in finding a crop suitable to the area's heavy adobe clay. In 1911, 55 acres of commercial rice were planted in Butte County yielding over 3,200 lb/acre. The area planted in rice jumped to 1,400 acres in 1912 with yields approaching 5,000 lb/acre and a gross return of \$100 per acre. Rice was suddenly a viable crop for the Sacramento Valley.



R.G. Mutters at Rice Field Day



Rice plantings in the area reached over 120,000 acres within the next few years with prices of \$7 per hundred weight in 1919. Much like planting rice on fresh ground today, the Sacramento Valley rice lands were productive with few problems. However, within a few years, the drill-and-dry seeded rice fields had become heavily infested with barnyard grass. Fields were sometimes abandoned after several years due to the dense weed growth. The first major agronomic change occurred in the mid-1920s when C.F. Dunshee, from UC Berkeley and working in Merced County, demonstrated that rice could be successfully water seeded in continuously flooded fields.

At first growers used horse- or tractor-drawn wagons with endgate spreaders to broadcast the seed into the water. This was a slow, laborious seeding method, but it enabled rice production to overcome the severe weed competition. The first aerial seeding with an airplane occurred in 1929. The availability of World War II surplus aircraft enabled aerial seeding of nearly all of California rice fields by 1950.

A third broad scale agronomic advancement was the complete mechanization of rice production along with the widespread availability of modern fertilizers in the 1950s. This change contributed to a steady increase in yields from 1950 to 1970; average yields increased from 2,500 to 4,500 lb/acre, respectively. Planted area also increased from about 225,000 acres to 350,000 acres during the same period.

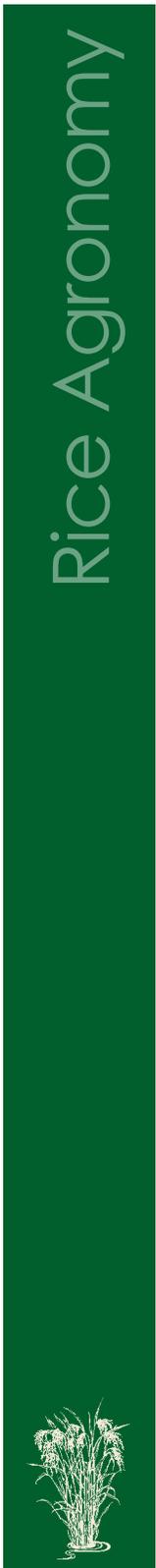
Perhaps the most striking agronomic change occurred as a result of the formation of the California



Early crop duster.

EWS

¹² Randal Mutters is a UC Cooperative Extension Farm Advisor for Butte County.



Cooperative Rice Research Foundation in 1968. The creation of the new organization resulted in an accelerated variety development program at the Rice Experiment Station (RES) and expanded research effort in collaboration with the University of California (UC). The development of the semidwarf, high-yield-potential varieties by RES enabled the development of more efficient agronomic practices. The new varieties, in tandem with Foundation-supported research conducted by the UC, resulted in average yields increasing from 4,500 to over 8,000 lb/acre by 1990. Innovative technology, such as laser-guided field leveling, improved many production efficiencies especially water use per unit of grain produced. During the same time period, environmental stewardship became increasingly integral to field management. For example, improved field water management reduced the amount of rice pesticides found in the Sacramento River by over 98%.



Modern turbine crop duster applies herbicide.



Deep plowing with an early tractor.

EWS



Injection of liquid nitrogen fertilizer (aqua) using GPS

The decade of the 1990s proved to be a challenging time. The demise of straw burning necessitated change in post-harvest agronomic practices. The transition to a system of incorporating the straw into the soil after harvest coincided with a period of erratic, if not declining yields. Fortunately, yields have been more stable in the 21st century and showing signs of improvement. The statewide average yield was 8,250 lb/acre in 2011 while area pool averages were over 9,000 lb/acre. Moreover, new varieties enable the harvest of rice at lower grain moisture; thus saving energy and drying costs while maintaining high milling yields.

Today, rice production in California is highly mechanized and technologically advanced. It requires only about four hours of labor per acre to produce over four tons of rice. In contrast, the non-mechanized systems in much of Asia requires more than 300 hours of labor per acre. The efficient, information-intensive farming system allows California rice growers to produce high quality rice while preserving long-term sustainability.



Harvest with a horse drawn binder.

EWS



Modern combine rice harvester emptying into a tractor pull bank-out wagon.



Rice Pathology

by Christopher A. Greer¹³

The early years of rice growing in California were much simpler times in regard to rice disease control. As early as 1920, Dr. Charles E. Chambliss of the USDA reported the following in the Farmer's Bulletin 1141:

"In the rice-growing sections of the Southern States the rice plant is subject to attack by four diseases and several species of injurious insects. None of these, nor any other species of fungi or insects, has been found in or reported to affect the rice crop of California."

In fact, no significant reports of diseases affecting commercial rice production in California were documented until the 1950s. Around this time, Rice Experiment Station (RES) Superintendent Dwight C. Finfrock responded to several farmers' complaints about poor stand establishment. A large percentage of the sown seed either never germinated or developed into stunted seedlings that died shortly after germination. Upon examining the non-germinated seed closely, he noted that most were colonized by a white fungal mycelium. Finfrock initiated a research program in collaboration with Dr. Byron R. Houston of the UC Davis Plant Pathology Department to identify the organisms responsible for the unknown seedling disease. This research resulted in the isolation of several different pathogenic fungi and potential seed treatment chemical control methods for the seedling disease complex. However, practical application of the seed treatment and lack of funding ended these research efforts.

Poor stand establishment associated with the seedling disease complex continued to persist and was even more pronounced in cool weather. Around 1965, Dr. Robert K. Webster and Dr. Dennis H. Hall of the UC Davis Plant Pathology Department took up the cause of identifying the organisms responsible for this disease complex and developing practical control strategies. They identified the causal fungi as *Achlya* and *Pythium* species and also determined that these organisms were present in all rice growing areas of the state. With support from the California Rice Research Board, safe and effective fungicide seed treatments were identified in put into commercial practice by 1976. Due to water quality and drain water disposal concerns, these fungicide seed soaks were later abandoned. Fortunately, the advent of laser land leveling in the 1970s and 1980s has resulted in more precise irrigation management that allows more uniform germination and seedling emergence that has largely avoided the necessity to utilize fungicide treatments for seedling disease management.

Rice stem rot disease (*Sclerotium oryzae*) is widespread throughout the rice growing regions of the world and has the potential to cause severe yield losses. E.C. Tullis et al. reported a few isolated incidences of rice stem rot in the Biggs and Richvale area in 1933, but no further reports were documented until about 1969 when several Richvale area growers observed dried out and dying rice plants in their fields late in the growing season. Dr. Robert K. Webster and his associates identified the disease as stem rot and initiated a research program with the assistance of the California Rice Research Board to investigate this disease and develop effective management programs. An early survey determined that stem rot occurred to some extent in most of the major rice growing counties in California and that yield losses associated with this disease could be as high as 22% in individual fields.

It was also noted that stem rot was significantly more severe in fields where growers had been incorporating rice straw into the soil following harvest rather than burning rice straw for crop residue management. Webster et al. successfully demonstrated that field burning was an effective practice for reducing stem rot incidence because it minimized the inoculum levels that were carried over to the following season. Other cultural practices were also shown to be effective in minimizing disease losses due to stem rot disease. These practices include avoiding



C. A. Greer at UC test plots in grower field.



Growth of fungal hyphae from rotten seed.



¹³ Christopher Greer is a UC Cooperative Extension Rice Farming Systems Advisor Yuba, Sutter and Sacramento and Placer counties.



R. K. Webster inspects plants with rice blast with breeder C.W. Johnson

flag leaf prior to grain filling and in severe case may actually progress up to the developing panicle and result in incomplete panicle emergence and/or partially filled panicles. Dr. Webster and associates isolated and characterized the causal fungus of this disease in the early 1980s. They determined that similar to stem rot disease, the most effective means of management is to limit the amount of inoculum that carries over from one year to the next. Dr. Christopher A. Greer, University of California Cooperative Extension (UCCE), has continued fungicide trials for aggregate sheath spot that he first started as Dr. Webster's graduate student. He has demonstrated that late season fungicide applications prior to heading may be effective in limiting the advancement of lesions to the flag leaf and panicle. Such applications are common and may preserve rice quality under heavy disease pressure.

Kernel smut (*Tilletia barclayana*) is another rice disease that is known to occur worldwide and was first reported in the United States in 1899 in South Carolina. Dr. Webster and colleagues first observed this disease in California in 1981 and through surveys determined kernel smut was widespread throughout the California rice industry by 1983. They observed that excessive nitrogen fertilization favors disease development and that long-grain rice varieties (currently less than 1% of California rice acreage) are much more susceptible to kernel smut than are medium- and short-grain rice varieties.

Rice blast disease (*Pyricularia grisea*) is one of the most destructive and feared rice diseases worldwide. California was one of the very few rice growing areas in the world to avoid this disease until 1996. Many speculated that the absence of the disease prior to this time was due to California's isolation from other rice growing regions and/or that environmental conditions did not favor disease development. The two major tools for rice blast disease management around the world are planting blast resistant rice varieties and fungicide applications, neither of which was available to California rice growers in 1996.



Classic diamond-shaped lesion of leaf blast disease



Rotten neck symptoms of rice blast disease include reddish-brown lesion at the panicle neck node and an unfilled panicle

Dr. Webster and Dr. Greer visited two rice fields in Glenn County near harvest at the request of UCCE Farm Advisor Steve Scardaci to examine patterns within the fields where plants were dead and many of the panicles were completely blank resulting in significant yield losses. Drs. Webster and Greer initiated a research program to characterize the occurrence, distribution, epidemiology, cultivar reaction, and management of the rice blast disease under California conditions. They determined that tolerance to rice blast disease of the widely grown California rice varieties differed but no complete resistance existed in any of the varieties at that time. By measuring microclimate conditions in rice fields and trapping *Pyricularia grisea* spores they also determined that California environmental conditions are permissive to rice blast disease development but not optimal for widespread epidemics.

Genetic studies of the pathogen determined that all tested isolates collected from California rice during the 1996 to 1999 growing seasons

were very closely related and of a single pathogenic race (IG-1), indicating that the pathogen was most likely introduced into California prior to 1996. University of California collaborators worked closely with RES breeders to evaluate blast resistant varieties in commercial fields prior to the release of the blast race IG-1 resistant M-208. Current management options for rice blast in California are based on limited use of M-208 in areas where the disease is endemic and applications of registered fungicides to protect the emerging panicle from infection.

Bakanae disease (*Gibberella fujikuroi*) is another example of an introduced disease in California rice. This disease is widespread in Asia and may cause significant yield losses. *Gibberella fujikuroi* produces a plant growth hormone, gibberellin, which produces elongated, slender pale leaves in affected seedlings that led to the name “foolish seedling disease.” This pathogen may also cause a root and crown rot which is often not evident in our California water seeded system until heading, when the entire plant collapses and produces no filled grain. Bakanae is primarily a seed-borne disease, with seed being infested at harvest from the large volume of fungal spores that are produced on infected tillers.

Bakanae was first reported in California in 1999 by Webster and colleagues. They documented the rapid spread of this pathogen and disease throughout the California industry. An extensive seed lot survey in 2002 found the pathogen in over 90% of those tested. They determined that higher temperatures and excessive rates of nitrogen appear to favor bakanae development. A collaborative effort between UC scientists, RES scientists, the CRRB, and the California Rice Commission was successful in rapidly evaluating and testing seed treatment options for bakanae disease management. The most efficacious and economical product, Ultra Clorox, was registered for use as a rice seed soak and remains a standard production practice in minimizing detrimental effects of bakanae disease on rice.



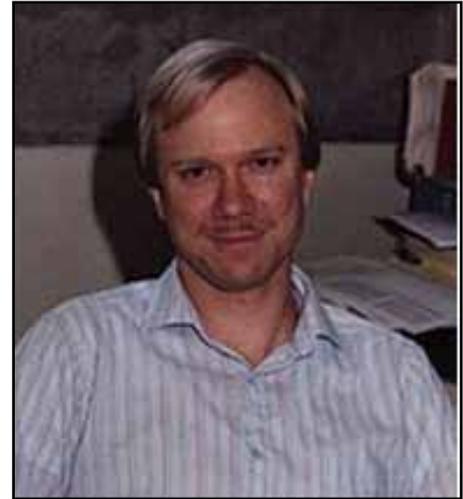
*Early season symptoms of bakanae disease:
Normal, healthy seedlings on the left and
abnormally elongated diseased seedlings on
the right*



History and Management of Invertebrate Pests in Rice

by Larry Godfrey and Luis Espino ¹⁴

The California rice industry has flourished over the years partially due to the excellent growing conditions – full sunlight, hot temperatures, and lack of precipitation in the summer – and the long history of fruitful research. The absence of an extensive list of yield and quality-limiting insect pests has also benefited rice production in California. The leafhopper and planthopper rice pests that are devastating in many of the Asian production areas, and the associated plant diseases they vector, are fortunately absent in California. Even compared with rice production in the rest of the United States, we are missing some key insect pests such as the rice stink bug and several species of stem borers. The rice stink bug can be especially detrimental to grain quality and market value. Even with these “exceptions,” we still have a suite of invertebrate pests that must be managed to maximize productivity and returns in California rice production. Besides true insects, the entomology research team has also addressed other invertebrates (organisms related to insects but not actually insects) including crayfish and tadpole shrimp.



L. Godfrey



L. Espino

Crayfish, tadpole shrimp, and seed midge have historically been early-season rice pests which potentially inhibit seedling establishment. Better adapted varieties which establish faster and the use of shallower water have lessened the severity of these pests in the last ~20 years. They are still pests that must be managed in several fields in some years, but the standard insecticide treatment that was commonplace in the 1960s and ‘70s is no longer required. Armyworms are another insect that is an occasional pest of rice today and has been throughout the years.

The rice leafminer has been a pest of rice in California for the last 90 to 100 years. Severe outbreaks and high yield losses occurred in the 1920s and a severe outbreak with 10% to 20% yield losses was reported in

1953. Water management (production with lower water levels) and effective insecticides were used to mitigate this pest in the 1950s and ‘60s. Two species of small parasitic wasps attack this pest and additionally reduced the problems with it. Even in the 1990s most fields had a low, non-economic level of rice leafminer. However, in recent years, this pest is often not seen, even at a low level, in many fields.

The most severe insect pest of rice in the state, the rice water weevil, has been present for over 60 years. It was first reported in 1959 and likely was introduced from the Southern United States production area a few years earlier; this pest was initially found over a 20-by-20-mile area in Butte County. The rice water weevil has been the subject of constant research since the 1960s. Without effective control measures, yield losses of up to 30% have been recorded. While research investigated and developed effective insecticides for rice water weevil, entomologists and the rice industry quickly determined that strict reliance on insecticides was not a viable option. Given the environmentally sensitive nature of the rice agro-ecosystem, insecticides had to be developed and used strategically. Research also concentrated on cultural control measures (altering



Larva and pupa of rice water weevil feeding on roots.

¹⁴Larry Godfrey is a UC Extension Specialist and Entomologist, Department of Entomology, UC Davis; Luis Espino is a rice farm advisor, Colusa County.



Adult rice water weevil feeding on rice leaf.

levee vegetation, altering rice production methods, etc.), biological control, evaluation of rice germplasm, optimizing application methods (field borer treatments), etc. Overall, an integrated pest management (IPM) method was the most cost-effective approach to dealing with the rice water weevil.

Over the years, one of the strengths of the UC Davis, Department of Entomology rice entomology IPM research program (Lange, Grigarick, and Godfrey over the years) has been the opportunity to work with scientists with expertise in other disciplines (biological control, plant breeders, mosquito biologists,

agronomists, weed scientists, etc.) in order to develop robust research and management programs. Farm Advisors have cooperated with the entomology team to ensure that the research is applicable to grower field conditions and that the research is delivered to growers in a useable form. This aspect has been particularly strengthened in recent years by including an entomologist as Farm Advisor. The second feature of the entomology program has been a track record of excellent staff researchers, including graduate students, post-doctoral students, and staff research associates). These individuals have greatly facilitated the research productivity and been trained so they have contributed to agricultural research in California and nationwide. For instance, of the seven university rice research and extension scientists in the United States, three were trained at UC Davis (one intensively in the rice program and one working in part on rice). In the last 30 years, approximately 8 individuals whom worked in university/USDA, 5 in industry, and 2 in government research positions have “gotten their feet wet” working in the California rice entomology research program.

In summary, success in designing cost-effective pest management programs for invertebrate pests of rice through interactions with other rice research scientists and educating young scientists remain the strengths of the rice invertebrate research program. However, the success of the program has been greatly facilitated by the ability of regulatory agencies and the industry to keep potentially severe insect pests from invading the state.



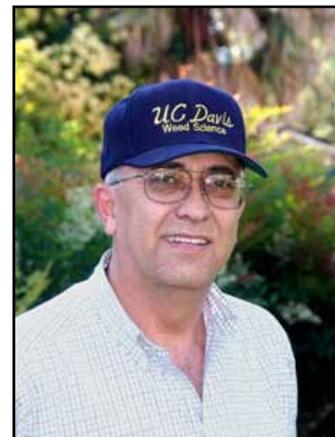
UC research associates in entomology test plots.



Rice Weeds – A Never Ending Saga

James E. Hill and Albert J. Fischer¹⁵

Of all pests, weeds have been the bane of rice growers from the beginning of rice production in California. Initially rice was grown in California by broadcasting seed, harrowing the seed into the soil and intermittently irrigating to establish the stand. With no herbicides available one can only imagine the problems with barnyard-grass. In fact, by 1923 rice weed management pioneer Dr. Jenkins Jones reported with Carroll Dunshee that “practically all the old lands—and these constitute the major portion of the rice acreage—are quite foul with watergrass.” Much of this land had to be abandoned for growing rice. Meanwhile, Jones was researching rice versus barnyard-grass (what he called watergrass) germination and discovered that a continuous floodwater of about four inches deep would greatly suppress barnyard-grass whereas the rice would emerge normally. This, along with the advent of aerial seeding, led to the system of growing rice under a continuous flood.



A. J. Fischer

While the barnyard-grass problem was largely solved by water seeding, other weeds came into the system, most notably the aquatic obligate weeds such as broadleaves and sedges. In addition to these weeds, two large seeded relatives to barnyard-grass also entered the system, most likely introduced from Japan where they had flourished for generations. These true



Water grass—a problem weed

watergrass species, unlike the smaller seeded barnyard-grass, could survive under continuous flooding. Further, one of them was also known as a rice mimic having been selected through eons of hand weeding in transplanted rice to the point that it could hardly be distinguished from rice. Interestingly, the watergrasses were not easily seen until heading with the old tall varieties but with the introduction of semidwarf types, the watergrasses and barnyard-grass were easily distinguishable by early to mid-season, towering over the new shorter rice types.

In the late 1940s and early 1950s the herbicide 2,4-D, and later one of its derivatives MCPA, were introduced to California rice. Then Colusa County Farm Advisor Karl Ingebretsen conducted much of the pioneering work on these phenoxy herbicides. Later, propanil was introduced to control a number of weeds including the grass species. However, drift from propanil in rice was injuring prunes and soon had to be deregistered for California rice. Dr. Dave Bayer and Dr. Norman Akesson of UC Davis pioneered much of the early work towards mitigation of propanil drift. Fortunately, through their pioneering work and that of the private sector developing new formulations, new application technology, and ground application, propanil was reintroduced on a restricted basis. Meanwhile, in the absence of propanil, the registration of Ordram and Bolero coupled to MCPA provided a standby for rice weed control. Dr. Don Seaman and Dr. Bayer provided much of the research that led to the registration of these herbicides for California rice.

In the 1980s, the first of the so-called ALS inhibitor herbicides was introduced as Londax. Dr. Bayer and Dr. Jim Hill led the research to adapt this herbicide to the California rice production system.



J.E. Hill seeding weed control test plots.



¹⁵ James Hill is Associate Dean for International Programs of the College of Agricultural Sciences at UC Davis and Rice Specialist and Albert Fischer is Melvin D. Androus Endowed Professor for Weed Science in Rice.

With a combination of Londax and one of the grass herbicides, rice weed control reached its pinnacle in California. Within three years, however, four important weed species began to show resistance to Londax, putting rice weed control on a downhill slide. It was an omen of future problems.

Reliance on the few available herbicides meant repeated use of a given herbicide over seasons. Resistance to several herbicides thus also evolved in the watergrasses and barnyard-grass. A vigorous research effort supported by the Rice Research Board was led by Dr. Albert Fischer in collaboration with a UCCE team of Cass Mutters, Jack Williams, Chris Greer, Luis Espino, and Jim Hill, as well as the rice industry, to deal with this problem. Thus the herbicide portfolio available to growers became expanded, basic knowledge on the mechanism of resistance enabled adequate management prescriptions and herbicide stewardship, and a multidisciplinary rice systems project was implemented to develop alternative management practices in rice-only rotational systems.

The battle on resistance will be hard to win, but this work has paved the way to help keep growers in front of the problem. From its very beginning, the rice industry has struggled with weed problems and successfully found solutions through the application of research.



Uncontrolled aquatic weeds



UC Weed control research plot at the Rice Experiment Station



The Rice Production System—A Benefit to Society

by James E. Hill, Bruce A. Linquist and Roberta Firoved ¹⁶

Urbanization in the Sacramento Valley has placed increased pressure on the California rice industry to address environmental concerns. Such concerns are wide ranging and include air quality, water quality, water use, fertilizer use, greenhouse gas production (global warming), the use of plant protection materials as well as others. In turn, the industry has responded by funding research at UC Davis, the California Rice Commission and elsewhere to proactively address these problems, and advocate for reasonable, science-based solutions. As a result, the rice industry has in many ways become the model for how best to respond to the environmental issues facing agriculture.



Grower M. Rue and J.E. Hill discussing rice development stages.

Water Quality: Water quality has been and remains a major issue facing rice growers. Concerns about the quality of rice field water runoff began with fish kills, primarily carp, in the 1970's. This was followed by concerns about drinking water taste complaints at the City of Sacramento intakes. A metabolite of then recently registered herbicide thiobencarb was identified as the culprit for the nuisance of off-taste in municipal drinking water.



B. A. Linquist collecting data on water use.

The response to negative rice pesticide issues in the surface water was addressed through collaboration by UC Davis, UC Cooperative Extension, Rice Research Board, Department of Fish & Game, Department of Food & Agriculture (now Department of Pesticide Regulation), county agricultural commissioners, State Water Resources Control Board, Central Valley Regional Water Quality Control Board, California rice industry and California rice growers. The rice industry response began through a “Hold Your Water” initiative with the University of California providing research on herbicide dissipation and educational programs on rice irrigation technology for better water management. Irrigation districts installed recirculating pumps among other technologies, to minimize drainage and protect

water quality. Additionally, the industry was active in working with regulatory agencies for a “doable” program on a timescale that would provide for implementation. Within ten years the industry had reduced chemical runoff by more than 98%, mitigating any negative environmental impacts - a remarkable achievement for a non-point source problem. Although water quality remains an issue for other potential constituents, the rice industry is far better positioned to address them because of its experience and forward thinking on how to proactively manage regulatory issues.



R. Firoved of California Rice Commission

The model in managing thiobencarb and molinate became the foundation for the California rice industry to establish the only commodity specific coalition under the Irrigated Lands Regulatory Program – a surface water program for discharges from irrigated agriculture. The same concept of a rice specific program will apply as agriculture responds to waste discharge requirements through the expansion of a Long-term Irrigated Lands Regulatory Program to include surface and ground water.



¹⁶James Hill is Associate Dean for International Programs of the College of Agricultural Sciences and rice specialist, Bruce Linquist is a professional researcher at UC Davis, and Roberta Firoved is Industry Affairs Manager for the California Rice Commission.

Water Use: To the uninformed, flooded fields leave the impression that rice is a heavy user of water. Rice is grown on very heavy clay soils or on soils with an underlying claypan. Lighter textured soils are unsuitable for rice because water percolates too rapidly to maintain warm temperatures that allow rice to grow properly. Many experiments have measured evapotranspiration in rice and the conclusions are that rice uses about 3.5 acre feet of water, about the same as other summer crops



Early rice box for irrigation

EWS

with a similar duration. Delivered water is about 5.5 acre feet, however, 1.5 acre feet or less percolates through the soil and eventually helps recharge the aquifers with the remaining 0.5 to 1.5 acre feet as runoff. Experiments have also concluded that water use in dry/drill seeding with intermittent irrigation in California, where rainfall is negligible during the growing season, uses similar amounts of water.

The California rice industry wrote an Environmental Sustainability report documenting that the overall water use has declined since the early 1980s from about 5.75 acre feet to 4.2 acre feet – a 27% reduction. In addition, water use efficiency has increased 1.6 acre feet/ton to 1 acre feet/ton – a 33% increase in efficiency most likely due to increases in yield.

Rice Straw Disposal: After considerable public pressure over air quality, the burning of rice straw was reduced over a 13 year period in the 90's and early 2000's. Rice growers and wildlife groups responded by disposing of straw by winter flooding rather than burning, thus providing valuable habitat for migrating waterfowl in the Pacific Flyway. About half of California ricefields are now winter flooded providing a patchwork quilt of water depths and non-flooded fields that match the needs of many different species of water birds. This program has been a win-win for rice growers and environmental advocates. Rice straw burning is now around 12-15% of the acreage, even less than the allowable 25% of acreage.

These are just a few examples of how the rice industry has responded to public concerns about their agricultural practices. The industry continues to respond to a myriad of environmental issues by supporting research and education to address them and by educating the public about rice production and its benefits to society.



Snow and Speckled Breast geese overwintering in flooded rice field

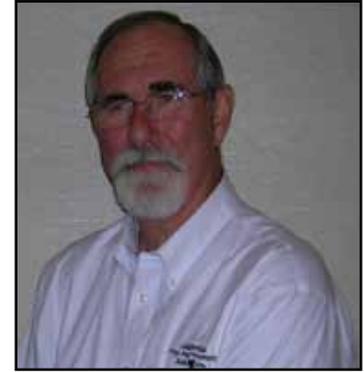
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Seed Certification of Rice in California

by Robert Stewart ¹⁷

Seed certification has been an integral part of the California rice industry for many years, and is run by the California Crop Improvement Association (CCIA), located at the University of California, Davis. The roles of seed growers, California Cooperative Rice Research Foundation, Inc. (CCRRF), Rice Experiment Station at Biggs, and the CCIA help provide pure seed of varieties developed and grown in and for California.



R. F. Stewart

Records show the CCIA has established seed certification standards for rice in California since the 1950s. In the early days only three varieties were eligible for certification: Colusa (1600), developed and released in 1918; Caloro, developed and released in 1921; and Calrose, developed and released in 1948. Then Earlirose, a popular variety for cool areas and late plantings, was developed in 1965. These were the major rice varieties certified and grown in California until the early 1970s.

In 1969, rice producers established the “California Rice Research Marketing Order” by referendum, which was renewed in 1973 and 1978, along with a special assessment rate to generate additional funds for rice residue management established in 1980. From then on, the variety picture for the California grower began to change significantly.

In the 1970s RES rapidly released new lines starting with CS-M3 and CS-S4 and continuing on to result in 13 improved rice varieties released from 1974 to 1981. To maintain the genetic quality of all these lines, the rice industry relied on the CCIA and their certification program to closely control and monitor with an inspection system designed to provide varietal identity.



Foundation Seed harvest at the Rice Experiment Station

In the case of publically developed varieties, the CCIA closely coordinates the seed program in cooperation of the CCRRF, University of California, USDA, and the California Department of Food and Agriculture. The CCIA program has a close relationship with the Rice Experiment Station, being a participant in final approval for cooperative release, providing oversight and certification for the headrow-breeders- foundation seed production at RES, and allocating Foundation Seed to California rice seed growers.

Under the current release program, varieties developed by the station have Plant Variety Protection and Utility Patents and are subject to certification to maintain the best varietal quality for rice seed. Today the CCIA certifies over 20,000 acres of the latest 17 varieties released by RES and grown by the rice seed industry.



Unloading seed for drying at the Rice Experiment Station



Cleaning foundation seed in winter at the Rice Experiment Station

¹⁷ Robert Stewart is Program Advisor for the California Crop Improvement Association.

California Rice Research Board

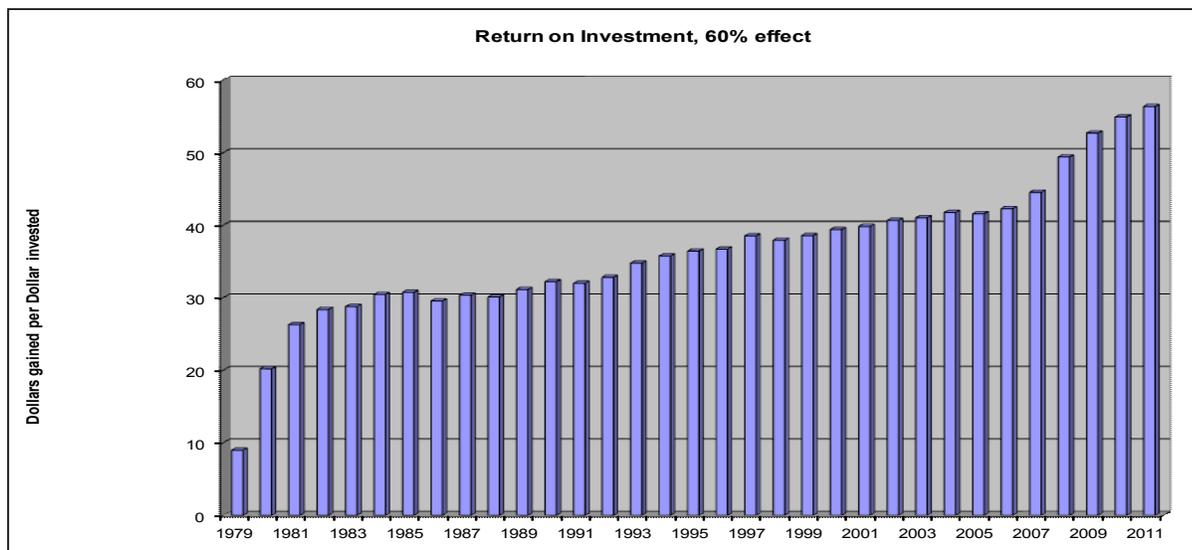
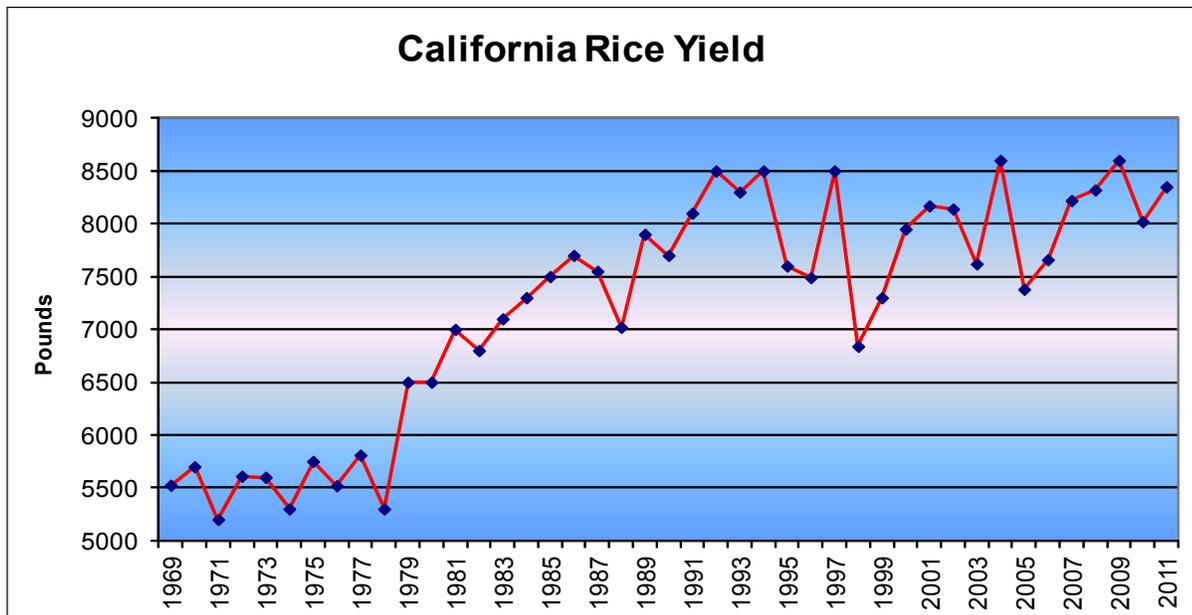
by Dana Dickey¹⁸

The outlook was grim in the late 1960s. Since 1912 rice research had been limping along with little funding and limited progress. The research had kept rice as one of the prominent crops in California; however, times were changing and expectations were rising.

No new varieties had been released since 1948, lodging was prevalent, propanil drift was showing up, and open-field burning was gaining public attention. Various growers and marketers had been visiting the research programs worldwide and were surprised at what they found. The southern states had research budgets from two- to more than five-times greater than the California effort. These states had high-yielding, short-statured, stiff-straw varieties along with superior new cultural practices. As a result of these observations, growers returned with an urgency to accelerate the California research effort to remain competitive.



D. Dickey at Rice Field Day



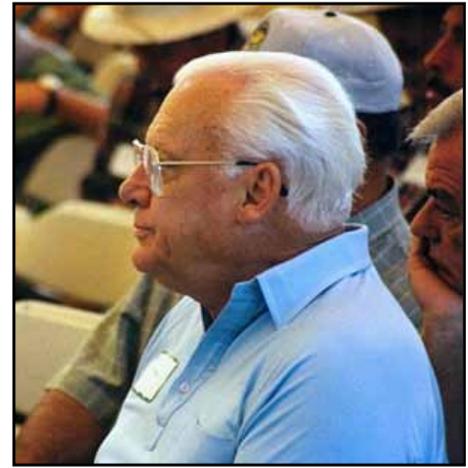
¹⁸ Dana Dickey is the manager of the California Rice Research Board.



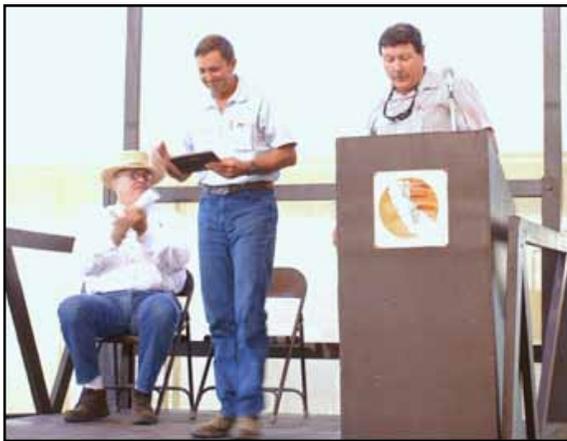


In late 1968 committees were formed to coordinate an effort to establish a Rice Research Board (RRB) to fund the research efforts for California rice. Growers were polled, program language was written and refined, lists compiled, informational meetings held in anticipation of a vote to establish the Rice Research Program. Finally in June of 1969 growers received the Proposed Rice Referendum to vote on a research program with a maximum assessment rate of 2.5 cents per hundred weight. In August votes were tallied and 79% of the industry approved. By September the RRB was up and running.

The objectives in those early years look rather familiar: 1) better varieties with desirable qualities; 2) economical residue management; 3) control of weeds, disease and pests; 4) better agronomic systems; and 5) better facilities and efficient, economical research.



Mel Androus 1990 Rice Industry Award Winner



Rice Research Board Chair Mike Daddow thanks retiring Chair Tom McClellan at Rice Field Day

What has occurred during those years since 1969 with the Rice Research Board? Several things can be observed. The rice industry has poured money into research: \$68 million since the RRB was formed, with nearly \$40 million of that into the Rice Experiment Station. Has it been worth it? Let's start by looking at yields. During the 1970s the average yield was about 5,500 lbs/ac. Breeders had been busy improving varieties and the first ones came into use in 1979. Yield went up to 6,500 lbs/ac that year. Improvement continued till the early 1990s when yields reached 8,500 lbs/ac. The loss of Londax, restrictions to burning, and the weather made the '90s a rough decade for yield. In the last five seasons yield has stabilized between 80-85 sacks/ac even with some very challenging spring weather. Quality is also hitting values that were not seen as possible only a short time ago.

Clearly, yield only helps if you are making money with that yield. What has been the result of your \$40 million dollar investment to your bottom line? If we attribute 60% of the production gains to the breeding efforts (a Marlin Brandon estimate) since 1970, then the breeding efforts alone have given California growers a \$2 billion cumulative income increase using average annual prices for California rice. This rises to \$3.7 billion additional overall if you consider all improvement factors. To put it in an easier-to-grasp form, for every dollar you invest each year, you presently get \$50 in return each year through greater yield – and thus profits. This is only part of the picture! Even greater gains have been realized through the efforts of the researchers at UC Davis and the USDA, such as work in weed control, insect control, water efficiency and quality, agronomic practices, post-harvest quality, fertility optimization, minor mineral inputs, algae, burning, incorporation, alternative uses for rice straw, and dozens of other research topics important to growers.

These areas of research are important to California growers because the RRB remains a grower-directed program. Your representatives select what research will be performed each year while watching over your funds with care. Support for the RRB remains high because it demonstrates results applicable to grower needs.



California Rice, A Century of Impact and Innovation

by Charley Mathews¹⁹

Mark Twain once stated “Farming is simply gambling with dirt.” Fortunately for millions of consumers, plus countless appreciative herons, egrets, and ducks, California rice farmers have gambled and won in cultivating the world’s most productive rice fields.

Keys to a successful industry can be traced to climate, abundant natural resources, and importantly a commitment to research. As the Rice Experiment Station (RES) and California rice celebrate 100 successful years, it’s important to recognize just how important a role industry-funded research has played in this winning equation.



California Rice



Charley Mathews CRC

Through decades of focused effort, rice breeders have developed varieties perfectly suited to California’s Mediterranean climate. Growers can thank the efforts of breeders over the years for impressive increases in yields. Since the 1980s, California’s per-acre rice production has grown by about 30 percent. Semidwarf varieties were developed and proliferated, allowing for rice crops that produce less plant material and more rice.

The practical challenges of growing a crop have also been addressed. Weed and insect control, lodging, stand establishment, and cold tolerance have all been successful through work done by researchers at RES and by the USDA and UC Davis researchers working daily at the Station.

Not only have yields increased steadily and agronomics improved, breeders have developed world-class quality. Travel abroad and rice varieties developed in Biggs – like Calrose, M-401, and Calmochi are known throughout the world for their consistency, grain quality, and great taste.

The traits that have brought about a successful, sustainable California rice industry are those that will help maintain the crop for generations to come. Through their expertise and perseverance, researchers will continue their invaluable role in providing rice varieties that exceed customers expectations, are water efficient and resistant to pests, and produce grain that is sought after by discriminating consumers far and wide.

The California Rice Commission is dedicated to doing its part helping rice farmers and handlers succeed in the public and regulatory fields. The commission began in 1999 and operates under the overview of the California Department of Food and Agriculture. By statute, the commission represents all growers and handlers of rice in the state.

Challenges being addressed by the commission include the ever-tightening and costly water quality regulations, continued pressure on the availability of crop protection tools, competition for water, and the need to connect with urban Californians that are largely ignorant of where their food comes from.



Stilt, part of the wildlife thriving in California rice fields. CRC

Fortunately, past successes provide well-founded optimism moving forward. The California Rice Commission remains at the forefront of navigating through regulatory challenges, creating an exciting new area of financial incentives for wildlife protection and educating important audiences on the immense value rice has in California.

The legacy of California rice is solid. Just as Mark Twain quoted more than a century ago, there will always be risks in growing rice. Fortunately, this industry is well equipped to continue to thrive.



¹⁹ Charley Mathews is a rice grower and Chairman of the Board for the California Rice Commission.

Rice Research Trust

The Rice Research Trust was established to receive “gifts and bequests of money, real and personal property to be held and disbursed to support scientific research for the benefit and best interests of the rice industry.”

The Rice Research Trust, a not-for-profit organization, is closely affiliated with the California Cooperative Rice Research Foundation, Inc. (CCRRF), a not-for-profit grower-owned organization that owns and operates the Rice Experiment Station (RES), in Biggs, California. The elected members of the CCRRF board of directors also serve as trustees of the Rice Research Trust.



Wintersteiger precision F₂ nursery drill seeder.

Through the generous donations of friends and supporters of rice research for California, an investment portfolio has been established that provides a revenue stream used to supplement rice research activities at RES. In the early years the trustees managed the assets, but the size and complexity of holding now requires a professional firm to manage the Trust’s investment portfolio.

The grants from the Rice Research Trust have been used to purchase land, equipment, and supplies, and support research activities on an annual basis. Research equipment and plant breeding and genetics research are relatively expensive undertakings. The need for financial support to supplement grower funding by the California Rice Research Board has grown complex as increasingly difficult challenges are faced by California rice growers. In addition, a memorial fellowship in memory of Dr. Marlin Brandon, past director and agronomist at RES, was established in 2000 to provide financial assistance to students pursuing careers in rice production science and technology. The California Rice Research Board made a one-time donation to the Rice Research Trust of \$52,500 with \$2,500 used for the 2000 fellowship. The Rice Research Trust contributed an additional \$50,000 and established a fellowship account. Interest from investments on the \$100,000 principal is being used to fund the fellowships awarded annually at Rice Field Day.

Who are the donors?

The donors have been individual rice growers, family farms, and corporations that have participated and benefited from rice improvement in California. Many make frequent or even annual donations. The Rice Research Trust has received donations from approximately 1,000 different sources.

Are donations deductible?

Yes. The Rice Research Trust is a registered not-for-profit charitable trust, 501(c)3, registered in the State of California.

How are donations acknowledged?

Donors will receive a written letter from the secretary of the Trust acknowledging their donation. When a donor’s one-time or cumulative contribution reaches \$500, a bronze panel with their name (or a designee) will be added to the outdoor display area at the Rice Experiment Station.

What is the range of donation amounts?

Donors have contributed over a broad range. In recent years contributions have averaged about \$200 and historically ranged from \$20 to \$50,000. Contributions of securities have been given as well and are all welcomed.

Is there any oversight or auditing?

The Rice Research Trust is audited annually by a professional accounting firm. The chairman of the Trust presents a summary each year at Rice Field Day.

How significant are the expenses?

The Trust has no employees, no facilities, and the trustees are volunteers. RES staff handles the secretarial and bookkeeping requirements at no cost to the Trust. Operational expenditures include supplies, fees, audit, postage, and handling.



Renovation of greenhouses at Rice Experiment Station in 2009.



*D. Marlin Brandon and wife Jean
1997 Rice Industry Award*



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