RICE FIELD DAY

Wednesday, August 30, 2017

Herbicide Tolerant Rice Nursery

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

Rice Experiment Station

P.O. Box 306, Biggs, CA 95917-0306

About the Cover

The photo shows one of the water-seeded large plot yield tests of M-206 and 4 experimental lines that have resistance to the herbicide oxyfluorfen (GoalTender® and Goal®2XL). This mutation, named ROXY, was discovered by the RES Breeding Program in 2014 and has been the subject of genetic studies, breeding, and field weed testing beginning in 2015 at RES and with cooperating research off-station. The cover photo was taken July 14, 2017 and shows the empty plots of oxyfluorfen susceptible M-206 and the accompanying weed control. The basin received pre-plant application of 2 pints/acre GoalTender®. Research reporting on ROXY is included in this program, both field tours, and also the poster session.

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2017 Rice Field Day Program

7:30—8:30 Registration and Poster Viewing

Posters and Demonstrations

1. Genetic Characterization of Weedy Rice in California (T. De Leon, C. Andaya, V. Andaya, P. Sanchez, K. McKenzie, K. Al-Khatib, L. Espino, T. Blank, R. Mutters, M. Leinfelder-Miles, B. Linquist, W. Brim-DeForest)

2. Key Phenotypic Traits of Weedy Rice in California (T. De Leon, K. Al-Khatib, L. Espino, T. Blank, R. Mutters, M. Leinfelder-Miles, B. Linquist, A. Godar, W. Brim-DeForest)

3. Winged Water Primrose (*Ludwigia decurens*): identification and control in Butte County (W. Brim-DeForest, A. Hettinger, E. Padgett)

4. ALS-Resistant Smallflower: New Screening Reveals Multiple Resistance Found Throughout Grower-Submitted Samples (A. Ceseski, A.S. Godar, K. McCauley, K. Al-Khatib)

5. Rice Waste Discharge Requirement: Pesticide Monitoring Requirements Under the Order and Compliance Reporting for Growers (CRC)

6. Rice Pesticide Program- Thiobencarb Monitoring Results and Potential Changes to Management Practices (CRC)

7. Thiobencarb Management Practices & Permit Conditions per DPR Enforcement Compendium and Registrant Stewardship Materials (CRC)

8. Rice Pesticide Use Matrix: Summarizes Rice Pesticide Use in CA (CRC)

9. Herbicide Resistance Stewardship Chart and Handout (CRC)

10. Intrepid 2F Section 18 for Armyworm Control. Materials and Information Growers Must Provide to Resubmit Section 18 in 2018 (CRC)

11. A Closer Examination of Cultural Management Tactics for Tadpole Shrimp (*Triops longicaudatus*) in California Rice (J.B. Bloese , K. Goding , L. Espino, L.D. Godfrey)

12. RCPP Rice Stewardship: Sustaining the Future of Rice (Craig Garner)

13. Subsurface Water Losses: Seepage and Percolation in California Rice Fields (G. LaHue, B.A. Linquist)

14. The Role of Nitrification in Rice Systems to Support Nitrogen Use Efficiency (W.R. Horwath, J.L. Mazza Rodrigues, R. Ye, P. Gong)

15. To Topdress, Or Not to Topdress, That is the Question (T. Rehman, A. Reis, N. Akbar, B. Linquist)

16. Potassium Availability and Fixation in California Rice Fields (J.C. Campbell, R.J. Southard, B.A. Linquist)

17. Decreasing Arsenic in Rice Grains with Alternate Wetting and Drying (AWD) Irrigation (D. Carrijo, N. Akbar, C. Li, S. Parikh, P. Green, B. Linquist)

18. Genetic Mapping of the Oxyfluorfen Resistance in Rice (C. Andaya, K. McKenzie, G. Yeltatzie and V. Andaya)

19. PAR Intercepted and Grain Yield of Very High Yielding Rice Lines (S.O.PB. Samonte, V.C. Andaya, P.L. Sanchez, C.B. Andaya, and K.S. McKenzie)

20. Identification of Useful Grain Quality Characteristics in Rice Mutants Using TILLING and Forward Genetics (H. Kim, A. Chun, M. Yoon, and T.H. Tai)

21. Identification and Characterization of Reduced Epicuticular Wax Mutants in Rice (T.H. Tai and H. Kim)

8:30 - 9:15 a.m. GENERAL SESSION

Welcome by Bert Manuel, Chairman, CCRRF

CCRRF Business Meeting

- Financial Report,
  Lance Benson, Treasurer, CCRRF

- Directors Nomination Committee Report,
  Kent McKenzie, RES

- Rice Research Trust Report,
  Aaron Scheidel, Vice Chairman, RRT

- D. Marlin Brandon Rice Research Fellowship
  Kent McKenzie, RES

- California Rice Research Board Report,
  Jason Bowen, Chairman, CRRB

- California Rice Industry Award Presentation,
  Gary Enos, Vice Chairman, CCRRF

9:20 - 10:45 a.m. MAIN STATION TOUR
Two tours occur simultaneously and repeat.

Blue & Green Groups to Trucks

Rice Variety Development
(V.C. Andaya, K. S. McKenzie, S.O. Samonte, and P.L. Sanchez, RES)

10:30 - 10:45 a.m. Refreshments – Under Carport

10:45 - Noon Repeat Station Tour with Red & White Groups

9:20 - 10:45 a.m. HAMILTON ROAD TOUR

Two tours occur simultaneously and repeat.

Red & White Groups to Buses

Weed Control in CA Rice: Evaluation of New Weed Control Tools
(K. Al-Khatib, A.S. Godar, M. Lee, A. Ceseski, K.E. McCauley, J.R. Stogsdill, W. Brim-DeForest, B.A. Linquist, L. Espino, and R.G. Mutters, UCD and UCCE)

10:30 - 10:45 a.m. Refreshments – Research Building Canopy

10:45 - Noon **Repeat Hamilton Road Tour with Blue & Green Groups**

Noon **Luncheon Concludes Program**

Lunch will be served in the New Research Building with seating at the tables on the lawns under the canopies

2.0 hours of Continuing Education credit for this 2017 Rice Field Day has been requested from Cal/EPA Department of Pesticide Regulation

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Disclaimer

Trade names of some products have been used to simplify information. No endorsement of named products is intended nor is criticism implied of similar products not mentioned.

Introduction
By Bert Manuel

On behalf of the Board of Directors, staff and UC cooperators, welcome to Rice Field Day 2017. Field Day is our annual opportunity to highlight the research that is underway at the Rice Experiment Station for the California Rice Industry. It is also the annual business meeting for the grower/owners of the California Cooperative Rice Research Foundation.

The California rice industry has survived a severe drought only to be followed by record breaking rain and snow, the failure of the Oroville Dam spillways and evacuation, levee erosion, delayed and prevented rice planting in 2017. We have remain true to our charge at RES and just like our rice grower owners we got it planted as best we could and continue forward. This has been possible with the continued financial support from the California Rice Research Board as well as the Foundation and the Rice Research Trust and a committed staff.

The highlight of the day's actives are the field tours where you are able to hear from the researchers and see the breeding nurseries on the main station as well as weed control research at the Hamilton Road site.

Dr. Virgilio “Butz” Andaya, Director of Plant Breeding, is overseeing the medium grain and long grain program and will be reporting on those projects. Dr. Stanley Samonte will present his work on premium quality and short grain varieties. Rice pathologist, Dr. Paul Sanchez will be reporting his supporting research. Director Kent McKenzie will be reporting on the RES discovery and research on a herbicide resistant rice trait, ROXY.

Dr. Kassim Al-Khatib, UC Davis Professor, heads the UC rice weed control project and will be speaking to you on a walking tour of the weed research nursery at the Hamilton Road site.

The Rice Experiment Station remains committed to the production of clean, weed and disease free foundation seed for the California rice growers. We continue work in cooperation with the Foundation Seed and Certification Services and the California Crop Improvement Association. The certified seed program is an essential part of maintaining genetic purity in our varieties and insuring the highest quality seed is available to the industry. Planting only certified seed of all RES varieties is our policy if an effort to stem the spread of weedy

red rice. The seed program is self-supporting and is not funded by the Rice Research Board.

I would like to acknowledge the many businesses and growers who support Rice Field Day through financial donations, agro chemicals and use of trucks for our tours. This year we have also included equipment displays from several sponsors. This industry support is very important to the success of the Field Day. The supporters are listed in your program and we thank them again for their assistance. Lastly thanks to all of the RES staff and UC that work very hard to make Rice Field Day successful.

Thank you for attending Rice Field Day and supporting our research programs. If you have any questions about Field Day or the Rice Experiment Station, please take the opportunity to talk with the Directors and his staff. There is a great deal of useful information on display today and I invite you to visit the displays and posters as well as taking the field tours.

D. Marlin Brandon Rice Research Fellowship

In 2000, a memorial fellowship was established to provide financial assistance to students pursuing careers in rice production science and technology as a tribute to Dr. D. Marlin Brandon, past Director and Agronomist at the Rice Experiment Station. 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 used to provide grants to the D. Marlin Brandon Rice Scholars. Twenty-five fellowships have been issued from 2000 to 2016.

D. Marlin Brandon Rice Scholars

William Carlson	2000
Nicholas Roncoroni	2001
David P. Cheetham	2002
Jennifer J. Keeling	2002
Kristie J. Pellerin	2003
Michael S. Bosworth	2003
Kristie J. Pellerin	2004
Leslie J. Snyder	2004
Gregory D. Van Dyke	2004
Leslie J. Snyder	2005
Louis G. Boddy	2006
Rebecca S. Bart	2006
Jennifer B. Williams	2007
Mark E. Lundy	2007
Louis G. Boddy	2008
Monika Krupa	2008
Cameron Pittelkow	2009
Charles Joseph Pfyl	2009
Maegen Simmonds	2009
Mark E. Lundy	2010
Cameron Pittelkow	2011
Whitney Brim-DeForest	2011
Matthew Espe	2015
Mathias Marcos	2015
Gabriel T. LaHue	2016

SUBMITTED POSTER ABSTRACTS

ALS-RESISTANT SMALLFLOWER: NEW SCREENING REVEALS MULTIPLE RESISTANCE FOUND THROUGHOUT GROWER-SUBMITTED SAMPLES

❖ A. Ceseski, A.S. Godar, K. McCauley, K. Al-Khatib, UC Davis

Control of sedges in California rice has been heavily reliant on acetolactase synthase (ALS) inhibiting herbicides for more than two decades. As a consequence, smallflower umbrella sedge (*Cyperus difformis* L.) populations resistant to ALS inhibitors are found throughout California's rice-growing region. Smallflower resistance to bensulfuron (Londax) was first reported in 1995, only four years after that herbicide was introduced. Since then, every ALS inhibitor registered for use in California rice has had cases of resistance reported in smallflower, with many populations exhibiting cross-resistance or multiple resistance.

The present study seeks to illustrate the current extent of smallflower resistance to ALS herbicides throughout the California rice growing region. Sixty-three grower-submitted smallflower samples from the 2015-2016 seasons were screened for resistance to four ALS herbicides: bensulfuron-methyl (Londax), halosulfuron-methyl (Halomax), bispyribac (Regiment), and penoxsulam (Granite). Herbicides were administered to plants at the three-leaf stage at two rates each: 1x (field rate) and 3x, to predict whether resistance to certain herbicides could derive from mutations to the target ALS gene, or from enhanced herbicide metabolism.

A total of six different resistance and cross-resistance patterns were discovered, covering a range of severities of resistance to each herbicide. Sixty-two populations were resistant to bensulfuron, of which 48 were strongly resistant at both rates, suggesting resistance due to an insensitive ALS enzyme. Only three populations were resistant to bensulfuron only, which indicates that cross-resistance is widespread. Two populations were resistant to all treatments, suggesting a substitution at residue 574 of the ALS gene, which is known to confer resistance to all known ALS herbicide chemistries. Ten populations exhibited strong resistance to bensulfuron but susceptibility to halosulfuron, both of which are herbicides of the same class. One population was strongly resistant to all treatments at both rates *except* halosulfuron. This pattern should not be explained by a single mutation in the ALS gene alone; a combination of enzyme insensitivity and enhanced metabolism may be present in this population. Fourteen populations were either only moderately resistant or susceptible at the higher rate of bensulfuron, and exhibited

variable resistance or susceptibility to the other herbicides, which suggests enhanced metabolism as the principal mechanism of resistance for those populations.

The results of this study confirm that smallflower cross-resistance to ALS herbicides is widespread in California rice fields, and is also quite variable. Knowledge of the type of cross-resistance present in individual fields will enable growers to tailor their rice herbicide programs more precisely. Further research will seek to determine the precise mechanisms of resistance in select populations.

A CLOSER EXAMINATION OF CULTURAL MANAGEMENT TACTICS FOR TADPOLE SHRIMP (*TRIOPS LONGICAUDATUS*) IN CALIFORNIA RICE

❖ J.B. Bloese, K. Goding, L. Espino & L.D. Godfrey (UC Davis and UCCE)

Tadpole shrimp *(Triops longicaudatus*; TPS) is a vernal pool crustacean, native to the western hemisphere. Historically, population levels seldom caused economic damage in rice. However, mandatory changes in cultural cultivation practices have coincided with the shift of TPS from a periodic pest to a significant pest. The Connelly Areias-Chandler Rice Straw Burning Reduction Act of 1991 mandated that rice straw burning in the Sacramento Valley be phased down to a maximum of 25% of total acreage burned by 2001 (Bird et al., 2002). The effects of cultural management practices were evaluated for their impact on the population dynamics of TPS. A mesocosm study was conducted to compare the effects of three winter cultivation practices (Fallow, Burn, & Flood). Soil samples were collected before and after treatments were applied; treatments lasted six months. The flooding treatment was significant at the P=0.10 level, however, there was no significant difference in TPS hatching rate for burning and fallow treatments. This preliminary study suggests that reductions in burning is not the primary reason TPS have emerged as a significant pest, but flooding may be effective at managing TPS.

RCPP RICE STEWARDSHIP: SUSTAINING THE FUTURE OF RICE

❖ C. Garner (Ducks Unlimited, Inc.)

The RCPP Rice Stewardship – Sustaining the Future of Rice is a collaborative project between the Natural Resources Conservation Service (NRCS) and Ducks Unlimited (DU). The project seeks to provide financial and technical assistance to rice farmers to help improve the efficiency of irrigation water use and minimize water quality impacts in California's Central Valley. Funds will be provided

to landowners through NRCS' Environmental Quality Incentives Program (EQIP).

Because rice is 100 percent irrigated and having adequate supplies of water is fundamental to production, the Rice Stewardship Project's main priority is increased water quantity. The secondary priority for the Project is improved water quality, specifically improving on-farm production that will maximize fertilizer uptake, minimize nutrient losses, and prevent pesticide losses on working rice fields.

SUBSURFACE WATER LOSSES: SEEPAGE AND PERCOLATION IN CALIFORNIA RICE FIELDS

❖ G. LaHue & B.A. Linquist (UC Davis)

California rice fields receive 54 inches of applied water on average, more than almost any other crop grown in California. However, the evapotranspiration or consumptive water use by rice is similar to many other crops at around 34 inches. The discrepancy between applied water and consumptive water use is due to variable tailwater drainage as well as seepage and percolation losses. Here we define percolation as downward water movement below the root zone and seepage as lateral water movement at the borders of a rice field. Given the growing pressure to reduce agricultural water use, it is important to understand and quantify these subsurface water loss pathways. In this study, we used 12-inch diameter percolation rings to measure percolation rates in several rice fields distributed throughout the Sacramento Valley. Rings had flexible plastic bags attached to maintain the water height inside the ring at the field water height, while preventing the exchange of water between the field and the ring. Seepage measurements were also made on a variety of levees using nested three-sided metal frames connected to bottles that maintained a constant height of ponded water equal to the field water height. Our results show that percolation is consistently low throughout the Sacramento Valley, ranging from less than 0.3 inches per season to approximately 2 inches per season. It should be noted however that the majority of percolation losses may occur in a very small area of the field if there is significant variation in soil texture or structure. Lateral seepage losses through field border levees were more variable. The highest recorded seepage losses were approximately 100 cubic feet of water per foot of levee per season (2 inches per season for a square 100-acre field bordered completely by this type of levee). The lowest recorded seepage losses were negligible or even showed net water gains in some cases where a field was bordered by another field with a higher water level. To our knowledge, the results presented here represent the first direct measurement of seepage and percolation in California rice

fields. Our ongoing work seeks to understand the factors influencing these subsurface water losses and potential sources of variability.

THE ROLE OF NITRIFICATION IN RICE SYSTEMS TO SUPPORT NIRTOGEN USE EFFICIENCY

❖ W.R. Horwath, J.L. Mazza Rodrigues, R. Ye, P. Gong (UC Davis)

We explored the importance of nitrification in three CA rice (Koshi, M-206, M-401) in the context of N acquisition, NUE and rice yield. Nitrification occurs at significant rates in CA rice, which, however, varied largely across the tested cultivars resulting in different concentrations of plant-available NH_4^+ in soils, but not NO_3^-. It is highly possible that the difference among the tested rice would lead to different uptake rates of NH_4^+ and NO_3^-, and hence the NUE and rice yields. The implications for this research are two-fold: 1.) rice varieties express different capacities to oxidize fertilizer ammonia to nitrate making the fertilizer N more available and increasing NUE, and 2.) The phenomenon of ammonia oxidation appears to be ubiquitous among rice varieties. Therefore, future management, particularly water level such as mid-season drainage can be timed better to take advantage of ammonia oxidation to increase NUE in rice plants. Overall, both rice breeding and field management should take advantage of these results to increase NUE in California rice.

TO TOPDRESS, OR NOT TO TOPDRESS, THAT IS THE QUESTION

❖ T. Rehman, A. Reis, N. Akbar & B. Linquist (UC Davis)

California rice (*Oryza sativa* L.) growers commonly apply topdress N fertilizer at panicle initiation (PI) stage. However, these applications are often without consideration of crop N status, and can result in losses both economically and environmentally. Although, some tools are available to guide in-season fertilization decisions, generally these techniques are time consuming, cumbersome, and limited by their small-scale sampling methods. Thus, a comprehensive method to assess in-season crop N status and develop sustainable fertilizer recommendations is needed for CA rice systems. Preliminary studies have shown that remotely sensed Normalized Difference Vegetation Index (NDVI) can predict in-season N status for several crops. Therefore, to investigate its potential in CA rice, on station and on farm N response trials were established over a 3-year period (7 site-years) across the Sacramento Valley rice growing region. The objectives of this study were to determine how NDVI correlates with PI N status in rice, establish the critical level of N required by PI to achieve maximum grain yield, and predict the response in grain yield to adding topdress N across different levels of PI N status. Initial results indicate that

NDVI measured with a handheld GreenSeeker correlates strongly with PI aboveground N uptake (biomass x N content). Moreover, PI aboveground N uptake is a strong predictor of final grain yield, and results show adding topdress fertilizer to a N sufficient crop can lead to significant yield loss. These findings demonstrate that NDVI can provide CA rice growers the information needed to make well informed, sustainable N fertilization decisions.

POTASSIUM AVAILABILITY AND FIXATION IN CALIFORNIA RICE FIELDS

❖ J.C. Campbell, R.J. Southard & B.A. Linquist (UC Davis)

In 2017, there are about 500,000 acres of rice planted in the Sacramento Valley of California, valued at more than $700 million. Productivity per hectare in this region has historically been higher than average, but yield growth has slowed in recent years. One important factor related to limits to rice productivity is soil potassium (K). As the soils in this area have historically been high in K, growers have not needed to apply it to their fields. However, after years of harvest without K replenishment, growers are beginning to observe K deficiencies. In attempts to correct them by supplying the soil with K fertilizers, growers are seeing little or no response from the crop. The reason for this lack of response to K amendments is likely K fixation, in which K ions are trapped in between soil particle interlayers and unavailable to plants. Preliminary data of soils sampled in rice fields across the Sacramento Valley shows that there is no clear relationship between a field's K budget and the extractable potassium in the soil or with the amount of K in the plant tissues, indicating that there is likely K fixation occurring. Preliminary data also shows that soils low in exchangeable K are also frequently K-fixing soils. The distribution of K fixation in the Sacramento Valley is suspected to be related to soil mineralogy, as the two sides of the valley have distinct mineral compositions, each with different K fixation capacities. Soil mineralogical analysis will help to elucidate the relationship between soil mineralogy and available soil potassium. Data from lab analyses and web soil survey will allow us to understand which areas are likely to have K fixation. Better understanding the relationship between soil type and K dynamics will help growers better manage their fertility and increase yields.

DECREASING ARSENIC IN RICE GRAINS WITH ALTERNATE WETTING AND DRYING (AWD) IRRIGATION

❖ D. Carrijo, N. Akbar, C. Li, S. Parikh, P. Green, B. Linquist (UC Davis)

High arsenic (As) levels in rice grains are a health concern for more than half of the world's population who depend on rice for food, since inorganic As has been classified as a class 1 carcinogen by the International Agency for Research on Cancer. As accumulation in rice grains is greatly influenced by irrigation management and Alternate Wetting and Drying (AWD) has been reported to decrease grain As concentration compared to Continuously Flooded (CF) irrigation. The objective of this study was to determine how the timing and duration of AWD drying periods impacted grain As. Results from a 2-year field experiment comparing AWD to CF show grain As concentration in polished rice decreased by 48% in AWD when the soil was dried to 35% volumetric water content (water potential of -41 to -95 kPa) before being reflooded, which corresponded to a drying period of 10 – 12 days. Drying the soil longer did not translate into a further decrease in As content in rice grains. In contrast, drying the soil until the perched water table reached 15 cm below the soil surface (threshold used in "Safe AWD") had no effect on grain As concentration; this may be attributed to the soil being close to saturation (water potential close to 0 kPa) before reflooding. Within drying periods of the same duration, grain As concentrations were lower when the drying period was imposed during panicle initiation and booting, compared to heading stage. Importantly, grain yields were similar across all treatments. These findings need to be verified in other soil types before being extrapolated.

GENETIC MAPPING OF OXYFLUORFEN RESISTANCE IN RICE

❖ C. Andaya, K. McKenzie, G. Yeltatzie & V. Andaya (RES)

Oxyfluorfen, a diphenyl ether compound, is a contact herbicide that controls broadleaves and also provides partial control of some grass species. Oxyfluorfen (brand name: Goal) penetrates into the cytoplasm causing the formation of peroxides and free electrons that then immediately destroy the cell membrane producing severe injury. In California, it is widely used in orchard crops (tree nuts, stone fruits, olives, etc.) and vine crops such as grapes and strawberries. Although not yet registered for commercial use in rice, the herbicide provides an exceptional control of broadleaf weeds in rice plots at the Rice Experiment Station in Biggs, CA.

Generation of mutant populations and discovery of useful mutations are an important and integral component of RES breeding program. Oxyfluorfen resistant rice mutants were isolated from EMS-mutagenized population of M-206. To determine the location of the gene responsible for the resistance phenotype, a mapping population was generated involving the cross between an aromatic long grain variety A-202 and the M-206 mutant line, G7. Progress on genetic mapping of the oxyfluorfen resistance will be presented.

PAR INTERCEPTION AND GRAIN YIELD OF VERY HIGH YIELDING RICE LINES

❖ S.O.PB. Samonte, V.C. Andaya, P.L. Sanchez, C.B. Andaya & K.S. McKenzie (RES)

It is common knowledge that light interception by plant leaves and grain yield are correlated. High yielding rice plant types have high leaf areas or masses that increase light interception. In the California Statewide Yield Tests from 2010 to 2014, maximum grain yields attained by cultivars M-209 and CM-203, both released by the Rice Experiment Station in 2015, were 12,260 and 13,470 kg/ha, respectively. At these top yield levels in research plots, can grain yield still be improved by increasing light interception? This study was conducted to determine the correlation between photosynthetically active radiation (PAR) intercepted by vegetation and grain yield in top yielding rice lines.

Six top yielding lines, that is, two each from the Short, Medium, and Long Grain Breeding Projects were evaluated at the Rice Experiment Station at Biggs, CA, in 2016. PAR intercepted percentages were estimated using PAR photon flux sensors located above and below the canopy of the six rice lines. Heading was estimated and served as the basis for comparing the six lines.

Correlation between PAR intercepted percentage and grain yield was highest and significant at 3 weeks before heading and at heading, with both registering correlation coefficients of $r = 0.74$. Between the two significant sampling dates, there was wider variation in PAR intercepted percentages at 3 weeks before heading (55 to 95%) than at heading (90 to 99%). Among the six top yielding lines, PAR intercepted percentage at 3 weeks before heading was 86% in the highest yielding plot (10Y2043; grain yield = 14,260 kg/ha) and only 56% in the lowest yielding plot (12Y3097; plot yield = 11,495 kg/ha).

Selection for high light interception at about 3 weeks before heading may be considered as an addition to indirect selection criteria (such as leaf angle, heading, and panicle size) for high grain yield and may be

applied in early generations when yield tests are not yet possible. Results presented here are from one season and require a verification study.

IDENTIFICATION OF USEFUL GRAIN QUALITY CHARACTERISTICS IN RICE MUTANTS USING TILLING AND FORWARD GENETICS

❖HyunJung Kim (UC Davis), Arem Chun (RDA, South Korea), Mira Yoon (RDA, South Korea), Sarah C. Magee (USDA-ARS) and Thomas H. Tai (USDA-ARS, UC Davis)

Rice is unique among major cereal crops as the vast majority is used directly for human consumption as whole milled kernels. In this form, rice starch provides the bulk of the daily calorie intake for billions of people worldwide. Major differences in local, eco-regional, or social-cultural preferences require the development of a wide array of grain quality characteristics to meet the needs of diverse consumers. Forward and reverse genetic approaches were applied to identify mutants of interest from populations derived from chemical mutagenesis of the varieties Nipponbare and Kitaake. Forward screens based on visual evaluation of grains for opaque endosperm resulted in the identification of about 30 mutants, which are being evaluated for changes in their starch properties. Genetic studies are underway to identify the mutations underlying these mutants. Targeting of Induced Local Lesions in Genomes (TILLING) and targeted sequencing by exon capture have been employed to identify mutations in starch synthesis-related genes. Over 150 mutations have been identified and are being verified. Most of these mutations are novel based on comparison to the natural variation present in the O. sativa germplasm of the 3,000 rice genomes project. Scanning electron microscopy and physicochemical tests are being performed to evaluate the effect of the mutations on grain quality.

IDENTIFICATION AND CHARACTERIZATION OF REDUCED EPICUTICULAR WAX MUTANTS IN RICE

❖Thomas H. Tai (USDA-ARS, UC Davis) and HyunJung Kim (UC Davis)

In land plants, epicuticular wax works together with other components of the plant cuticle to prevent uncontrolled loss of water and to protect against various environmental challenges. Chemically-mutagenized populations of rice derived from more than 5,000 M2 families were screened for adhesion of water droplets resulting in a wet leaf/glossy (wlg) phenotype. Mutants were identified in > 15 independently-derived M2 families. SEM analysis confirmed the association of the wlg

phenotype with a reduction in the epicuticular wax crystals of these plants. Initial analyses confirmed that the phenotypes of five of these mutants were due to single gene recessive mutations. Evaluation of mutants from three M2 families revealed significant reductions (> 50%) in surface wax content and increased cuticle membrane permeability. Progress on phenotypic and genetic characterization of the reduced epicuticular wax mutants will be presented.

FIELD TOURS OF RESEARCH

RICE VARIETY DEVELOPMENT

The RES breeding program consists of four research projects. Three rice breeding projects focus on developing adapted varieties for specific grain and market types and are each under the direction of a RES plant breeder. The rice pathology project, under the direction of the RES plant pathologist, supports the breeding projects through screening and evaluating varieties for disease resistance, rice disease research, and quarantine introduction of rice germplasm for variety improvement. All projects also linked with the DNA marker laboratory and are involved in cooperative studies with other scientists from the UC, USDA and industry, including off station field tests, nurseries, quality research, and biotechnology. Brief highlights of the RES breeding program are discussed here and will be presented during the field tour of the breeding nursery.

Medium and Long Grain
(V.C. Andaya, Director of Plant Breeding, RES)

The California rice cropping season started a bit late in 2017, due to delayed land preparation brought about by extended rain events up until end of April to early May. Rain is certainly welcome as water reservoirs were filled to the brim, ending officially the years-long drought in California. Nevertheless, rice acreage this year did not pick up down as some farmers opted to fallow rice field than risk lower yields due to late planting even with the abundance of water. RES managed to plant and set up all the yield trials, pedigree nurseries and seed maintenance plots at the station by May 26, 2017. Late or not, everything got planted notwithstanding.

The RES breeding program is composed of three breeding projects namely: 1) Medium Grain Rice, 2) Short Grain and Premium Quality Rice, and 3) Long Grain Rice. The medium grain breeding project is roughly 40% of the breeding program in terms of rice materials while the short grain and long grain rice breeding are about 30% each. Experiments such as yield trials, generation advance of progeny rows, or seed purification plots are mostly planted by hand at the RES breeding nursery in May while the F_2 nursery and seed maintenance plots are drill-planted. In the winter, advanced selections and new F_1 populations are planted in the Hawaii Winter Nursery in Lihue, HI,

for seed increase and generation advance around late October to early November. The breeding program employs both conventional and modified pedigree and DNA marker-based breeding methods. The DNA markers used for marker-assisted selection are mostly microsatellite and SNP markers, which are effectively used for fingerprinting and purity testing, breeding for disease resistance and grain quality screening.

Medium Grains Project

Calrose is distinctly different from the Southern U.S.A. medium grain varieties in terms of overall grain quality and agronomic performance. California medium grains have inherently better seedling and booting stage tolerance to low air and water temperatures, grain appearance and quality of cooked rice. The main goal of the medium grains breeding project is to develop new rice varieties with high and stable grain and milling yields with excellent grain quality. To achieve stable grain yield, rice lines are selected for high seedling vigor, with resistance to diseases and tolerance to low temperature-induced sterility. Milling performance, as a function of total rice and head rice yields, is given top priority in selecting advanced lines, while overall appearance of the grains or brown rice is evaluated starting in the earliest generation up to variety release.

Check varieties. Early-generation progenies and breeding materials are generally selected and evaluated at RES. Uniform and stable lines are then entered yield trials to screen advanced rice materials for yield potential and agronomic performance, as well as separate experiments for milling and cooking tests. A line that had been tested for minimum of two years in preliminary yield trials at RES are the entered in a two-replicate preliminary Statewide Yield (SW) test. The best lines out of the SW preliminary test are entered in the SW advanced test the following year, either in only one maturity group or all maturity groups of SW test. Lines are evaluated a minimum of three years in SW tests before they are considered for Foundation Seed increase. There is a large turnover of medium grain materials in the SW tests, and a number of them get dropped after only one year of evaluation.

Medium grain varieties that are in commercial production in California are being used as checks in preliminary and advanced yield trials at RES and SW, These are M-105, M-205, M-206, and M-209. Other varieties such as M-104 and M-208 are still being used as check but will soon be gradually phased out. Selection of appropriate check rice varieties is important to identify the best yielding and agronomically outstanding lines for more advanced testing. M-209 remained the top yielding check variety, registering an average yield

of 10,350 lb/acre in 2016 compared to M-205 and M-206 yields of 10,040 and 10,300 lb/acre, respectively. The 4-year average yield for M-209, M-205 and M-206 were 9,990 lb/acre, 9,510 lb/acre, and 9,500 lb/acre, respectively. M-209 was released in 2015 as an alternative or replacement for M-205. Its overall grain size is the biggest among the Calrose varieties. The very early maturing variety M-105 performed very well in 2016 because of the more favorable weather conditions. It registered an average yield of 10,160 lb/acre and 9,170 lb/acre overall. M-105 is one of the best varieties in terms of head rice yield, though its grains are slightly smaller.

Promising line - 12Y3097. A blast resistant advanced rice line, 12Y3097, is in the final stage of yield testing and grain quality evaluation. Breeder and Foundation seeds are being grown in 2017 and will be available for sale in 2018 if the line is approved for release. 12Y3097 is an early, glabrous, high yielding, blast-resistant, Calrose medium grain developed via backcross breeding using M-206 as the recurrent parent and 97Y315 as the donor of blast resistance gene *Pi-b* from a Korean variety, *Daegwanbyeo*. This line was developed using DNA markers. It is intended as a replacement for M-208. 12Y3097 was tested in the Statewide (SW) tests from 2013 to 2016. In 2016, the grain yield at RES of 12Y3097 amounted to 10,430 lb/acre compared to 10,300 and 9,490 lb/acre for M-206 and M-208 respectively, while the overall yield advantage over M-206 and M-208 was 2.7% and 8.7%, respectively. The seedling vigor and plant height of 12Y3097 were slightly lower compared to M-206 and M-208, while the grain attributes in terms of chalkiness, seed weight, and grain dimension is comparable with M-206 and M-208. Number of days to heading is similar to M-206.

On the Horizon. The medium grains project has started to explore the use of unique traits that may add value to Calrose as a brand. One of the traits being looked at is aroma similar to the one found in the long grain aromatic rice or the Jasmines. The goal was to recover most of the agronomic traits and performance of Calrose while adding the aroma gene through marker-assisted backcrossing and selection. The project used M-206 initially as the template or recurrent parent. Several backcross populations have been made and progenies possessing the aromatic trait with the medium grain type had been isolated using DNA markers. By 2017-2018, the project hopes to get enough seed of aromatic Calrose for grain quality and grain yield evaluation, and market testing.

Herbicide resistance is also being pursued aggressively by Dr. Kent McKenzie using M-206 as the initial template in inducing mutations that conferred resistance to herbicide such as oxyfluorfen. Some

herbicide resistant mutant rice lines have been identified earlier and their breeding derivatives developed through backcrossing. One backcross-derived line designated as 17Y3000 was entered in the SW tests in 2017.

Long Grains Project

Dr. Farman Jodari, the RES long grain breeder since 1999 retired effective June 30, 2017. His long and distinguished career as a rice breeder of long grain rice and specialty types not only for California but also for the Southern USA was noteworthy. With his retirement, the RES breeding program is undergoing consolidation, review, and reorganization.

The long grains project develops superior long grain varieties for California and comprised of conventional long grain and specialty types such as aromatic, Jasmine-type and Basmati-type long grains. The California conventional long grain rice market is based on quality characteristics of Southern US varieties, except for the unique specialty rice types. Extensive cooking quality screening and selection efforts in recent years have eliminated majority of the texture softness from the California long grain breeding material. Jasmine type breeding materials are the largest in the specialty group composed of low amylose, low gel aromatic types. Breeding objectives for jasmine type quality include low amylose, strong aroma, a high degree of whiteness, and a smooth cooked grain texture. The extreme photoperiod sensitivity of the original KDM Thai Jasmine has been a significant breeding barrier. Basmati-type rices, in general, constitute nearly 15% of the long grain breeding nursery. Cooking quality, cooked kernel elongation, elongation ratios, cooked grain texture, effect of aging on texture and flakiness, are just some of the basmati attributes that are being aimed for in breeding.

New Releases

L-207 is a new conventional type long grain variety released in 2016. It has intermediate height and early maturity with Southern long grain cooking quality. The two-year (2015-16) average grain yield in SW tests was 10,300 lb/acre as compared to 9,600 lb/acre for L-206. Cooking quality of L-207 was similar to Southern long grains, with intermediate amylose, intermediate gel type, and moderate RVA profile. This variety had significantly lower stem rot disease incidence compared with L-206 and M-206. Significant aggregate sheath spot resistance was also observed.

A-202 is a conventional aromatic variety that was released in January 2014. It is intended as a replacement for A-301. Compared to A-301, A-202 is 9 days earlier, shorter, and has a significantly higher seedling vigor score. Average grain yield in SW tests in 2016 was 9,300 lbs/acre and 10,300 lb/acre for A-202 and L-207, respectively. Its head rice yield is around 61%. Aroma volatilization of A-202 is slightly less during cooking process, while flavor sensory is similar to A-301. Milled grains of A-202 are slightly bolder than A-301. Amylose content, gelatinization temperature type and RVA profile of A-202 is of typical conventional long-grain type, similar to A-301 and L-207. Areas of adaptation for A-202 include Butte, Colusa, Yuba, Glenn, and Sutter counties.

Promising lines

15Y84 is a Jasmine-type experimental line that showed superior agronomic performance and grain quality characteristics. The two-year average grain yields were 9,940 lb/acre for 15Y84 and 9,340 lb/acre for A-202. Milling yield for both entries was 60%. A Foundation Seed and head row/breeder seed production are being grown in 20174. If released, this will be the first Jasmine-type rice to be developed by RES that has quality characteristics that are similar to the imported Jasmine.

14Y1006 has shown further yield improvement over L-207, its sister line. The SW tests conducted during 2015 and 2016 indicated that 14Y1006 has 10% higher yield potential over L-206. Average yields over 17 experiments were 10,600, 10,310, 9,600, and 9,610 lb/acre for 14Y1006, L-207, L-206, and M-206, respectively. 14Y1006 matures two days than L-207. Average milling yield of 14Y1006 is similar to L-207 at 65%. Preliminary tests show that it is less chalky than L-207, with similar cooked grain textures, with slightly higher quality score.

Breeding Challenge

While the agronomic performance, grain yield and quality attributes of the conventional long grain are solid, the breeding progress in the Basmati-type rice, to some degree in the Jasmine-type rice, and the aromatic types in general lag behind because of the difficulty in combining grain yield with grain quality attributes of the imported rice. The specialty market in California or the world market put a premium on grain quality, while rice farmers demand higher yields in order to compete with imported Jasmine and Basmati rice market.

Breeding rice for the specialty market requires more effort than breeding for regular long, medium or short grains because of additional

time spent by breeders in grain quality evaluation, milling and cooking tests. The cost of breeding specialty rice types is higher but the return on investment is lower in comparison to conventional types. The RES breeding program with its challenge of retaining or recruiting personnel to carry on breeding and research in a reasonable time frame needs to strike a balance in allocating resources especially in dealing with specialty rice types.

Premium Quality and Short Grain (S.O.P.B. Samonte, Plant Breeder, RES)

The Premium Quality and Short Grains Breeding Project encompasses the improvement of the following rice varietal types:

- Short grain, waxy (SWX),
- Short grain, premium quality (SPQ),
- Medium grain, premium quality (MPQ),
- Short grain, conventional (SG),
- Short grain, low amylose (SLA), and
- Bold grain (BG).

All new rice lines are bred and selected for improved and stable grain yield and yield-related traits, high milling and cooking quality, reduced panicle blanking due to cold temperature, lodging resistance, very early to early and uniform maturity, and resistance to diseases. In addition, there are specific trait parameters that selected lines must possess in order to qualify for specific grain type. Experimental lines in nurseries and yield tests are compared against their respective grain type check varieties. Selected lines must show improvements over their respective checks.

Varieties and Elite Lines

Waxy Short Grain

Calmochi-101 (released in 1985) and **Calmochi-203** (released in 2015) are the current standard waxy short grain varieties. In all 55 SW Test environments from 2010 to 2016 wherein both varieties were evaluated together, CM-203 always yielded significantly higher than CM-101. In 2016, grain yields (averaged across 7 SW Test environments) were 10,420 lb/acre for CM-203 and 8,020 lb/acre for CM-101, for a 30% yield advantage. Compared to CM-101, CM-203 headed 2 days later (87 vs. 85 d), was taller (99 vs. 95 cm), lodged less (37 vs. 55%), had higher head rice percentage (63 vs. 60%), had low blanking percentages (both 5%) at San Joaquin, and had slightly lower SV ratings (4.8 vs. 4.9 in a 5-point rating scale).

This year, there are five SWX lines being evaluated in the SW Tests, with CM-203 and CM-101 serving as check varieties.

Premium Quality Short Grain

Calhikari-202 (released in 2012) continued to show desirable trait parameters compared to Koshihikari and **Calhikari-201** (released in 1999). Based on 71 SW Tests from 2010 to 2017, CH-202 had an average grain yield of 8,610 lb/acre, which was 5.7% higher than that of CH-201. In the 2016 SW Tests, when compared to Koshihikari, CH-202 had earlier heading (84 vs. 100 d), shorter height (90 vs. 117 cm), less lodging (74 vs. 95%), same high head rice percentage (66%), and a 70% yield advantage (8,270 vs. 4,870 lb/acre). Its seedling vigor was lower, and this trait is being targeted for improvement in SPQ rice.

There are six SPQ lines being evaluated along with check varieties CH-201 and CH-202 in the 2017 SW Tests. Ten early heading SPQ lines, produced through the mutation breeding of Koshihikari and verified as mutants through DNA analyses by Dr. Cynthia Andaya, are being evaluated in this year's PY Tests at RES. The top 5 yielding early Koshihikari (eKosh) mutant lines had an average heading of 81 days (16 days earlier than that of Koshihikari), while their average grain yield was 8,090 lb/A (1,500 lb/acre more than that of Koshihikari). These eKosh lines are being evaluated closely especially for quality and taste, using Koshihikari as check variety.

Premium Quality Medium Grain

M-401 and **M-402**, which were released in 1981 and 1999, respectively, are the standard premium quality medium grain varieties. In 2016, 12Y2175 continued to perform as the outstanding MPQ line. Based on seven SW test locations, **12Y2175** yielded an average of 10,220 lb/acre, with yield advantages over M-402 and M-401 at 20 and 13%, respectively. It also exhibited high SV ratings that were similar to M-401 and M-402. Early heading is a trait essential in saving irrigation water, and 12Y2175 headed 89 days after planting, which was at least 16 days earlier than the MPQ varieties. Head rice percentages of both 12Y2175 and M-401 averaged 61%, compared to 63% for M-402. However, their 4-year head rice percentages (2013 to 2016) averaged 63% for both 12Y2175 and M-402, and 58% for M-401. MPQ 12Y2175 is currently being purified and evaluated closely in the Experimental Seed Increase Nursery. It is also exhibited in the Short Grain Project Demo Plots.

There are six MPQ lines (including 12Y2175) being evaluated in the 2017 SW Tests, with M-401 and M-402 serving as check varieties.

Conventional Short Grain

The standard conventional short grain rice variety is **S-102** (released in 1996). In the 2016 SW Tests, 10Y2043 continued to be at the forefront of SG entries and was evaluated in both the very early and the early maturity groups. Grain yield of **10Y2043** (averaged across 8 test locations in 2016) was 11,310 lb/acre, which was 18% higher than that of S-102. Compared to S-102, 10Y2043 had slightly lower SV rating (4.9 vs. 5.0 in a 5-point rating), it headed later (84 vs. 82 d), was shorter in plant height (90 vs. 95 cm), had higher head rice percentage (64 vs. 60%), and had lower chalky area percentage (25 vs. 28%). Furthermore, 10Y2043 is glabrous (smooth hull), unlike the pubescent S-102. SG 10Y2043 is currently being purified in the Pre-Foundation Seed Increase Nursery, and it is exhibited in the Short Grain Project Demo Plots.

There are four SG lines (including 10Y2043) being evaluated in the 2017 SW Tests, with S-102 serving as check variety.

Low Amylose Short Grain

Calamylow-201, which was released in 2006, is the current SLA variety. However, its low grain yield, high lodging percentage, and pubescent seed are unattractive traits that need improvement. Compared to CA-201 in the 2016 SW Tests, SLA 15Y210 yielded 29% higher (10,190 vs. 7,890 lb/acre), headed later (94 vs. 92 d), and had similar SV ratings. However, its head rice percentage was low, and this is being verified along with new SLA entry 16Y2028 in this year's SW Tests.

Bold Grain

Bold grain or the Arborio-type of rice is grown on a small acreage in California. RES has not released a BG variety, but it has released 87Y235 as a germplasm in 1994. The development of improved BG lines is the first step to increase interest in this type of rice. This year, BG 16Y2058 is being evaluated in the SW Tests. Compared to 89Y235 in the 2016 PYT, 16Y2058 was shorter (95 vs. 101 cm), headed 1 day later (80 vs. 79 d), and had an 11% yield advantage (10,090 vs. 9,060 lb/acre).

Breeding for Disease Resistance

Disease reactions to stem rot, aggregate sheath spot, and blast pathogens by breeding lines of this project that are entered into the PY and SW Tests are being evaluated by RES pathologist Dr. Paul

Sanchez. Rice lines are being pyramided for blast resistance genes. Based on DNA marker-assisted analyses (conducted by Dr. Cynthia Andaya) and on agronomic trait observations (from yield tests and grain quality screenings), blast resistant lines with good agronomic trait parameters were selected and are currently being evaluated in this year's PY Tests. There are 3 SWX, 2 SPQ, 2 MPQ, 4 SG, 3 SLA and 3 BG blast resistant rice lines entered into the PY Tests this year.

DNA Marker Lab
(C.B. Andaya, Research Scientist, RES)

The DNA Marker Lab is a vital part of the RES breeding program, implementing approaches to support the goals of the different grain types as well as managing the execution of special projects. Its principal role is to assist the breeders in their selection work by using DNA marker technologies. The lab is involved in: marker-aided selection (MAS) for blast resistance, grain quality, aroma and herbicide resistance; fingerprinting and purity testing of advanced lines; genetic mapping studies of stem rot resistance and herbicide resistance to oxyfluorfen; and generation of mutant populations using both irradiation and chemical mutagenesis.

MAS for both blast resistance and grain quality is a routine activity. The use of molecular markers reduces the number of breeding lines that the breeders will advance and grow in the field through initial MAS, thereby reducing costs and increasing breeding efficiency. The lab uses microsatellite or simple sequence repeat (SSR) markers to screen for blast resistance in all grain types. In the long grain program, SNP markers and SSR markers are also being employed to predict the grain quality parameters. Another essential role of the DNA lab is to provide assistance in variety identity and purity assessment. The lab maintains a marker database of all rice varieties released at RES as well as other rice variety introductions. The lab fingerprints advanced lines before they are recommended as varieties. The fingerprint data generated for head rows ensure that materials advanced are uniform and homogenous. These varieties are also surveyed for identity against commercially grown varieties.

The DNA Lab is also supporting the herbicide resistance project by generating rice mutant populations using chemical mutagenic agent and validating the identity of the putative mutants using DNA markers. Oxyfluorfen mutants were isolated from EMS-mutagenized population of M-206. These mutants have been tested in the field by under different herbicide regimes and conditions. To identify the gene responsible for herbicide resistance, we generated a mapping

population and conducted genetic mapping studies of the trait. Progress on this work is presented in a poster this 2017 Rice Field Day.

The amount of materials submitted to the lab varies considerably from year to year depending on the need of the breeding program. On average, the DNA lab processes at least 12,000 rice lines for MAS and fingerprinting, generating around 65,000 data points work annually. Last year, a total of 8,275 lines were analyzed for all the breeding program at the station generating 66,817 data points. Fifty–three percent of the lines analyzed were for fingerprinting purposes while 47% were for MAS.

RES through the DNA Lab also addresses some of the urgent concerns of the rice growers and/ rice industry, if it can, by providing fingerprinting services to resolve identity and purity issues as well as offer answers to some genetic questions. There were other rice industry requests related to purity issues in grower's field; as well as identity issues of brown rice samples imported from Central America and milled rice from Spain both being marketed as Calrose. In these cases, the lab was able to identify whether the samples in question are protected PVP variety of CA rice growers and/or varieties still under patent.

For the last two years, the rice industry had been concerned with increased reports of red rice in fields across the CA rice growing areas. A morphological and genetic characterization of historical red rice collection and recent red rice submissions were conducted to determine the types of red rice present, their relatedness and possibly their distribution. The study aligned the accessions into 19 groups, forming about 6 clusters based on their marker relationships, phenotype, and accession location. There were 20 markers identified that can be used to validate the groupings. The samples and data were provided to UCD scientists as they carry out an extensive weedy red rice research.

Herbicide Tolerant Rice- ROXY (K.S. McKenzie, RES)

In 2014, a special 3 year CRRB project, "Herbicide Tolerant Rice for California- Screening for Herbicide Tolerance through Induced Mutation", was initiated.

Objectives were:

- Establish protocols and generate mutant populations for screening
- Establish protocols and screen large mutant populations

- Evaluate promising mutants for their merits for commercial level rice weed control and if merited move them quickly into the breeding program.

The project was successfully concluded in 2016, meeting the objectives above. Research focused on medium grain mutant populations produced by the DNA Marker Lab and irradiation. Populations were screened in greenhouse (year round) and field tests (~20 acres) from 2014-2016. Putative mutants were recovered and tested to confirm tolerance. Lines were recovered from an M-206 population that gave a high level of resistance to the herbicide oxyfluorfen (Goal® 2XL and GoalTender®). Genetic studies by RES showed that this trait is inherited as a single recessive gene, and has been designated as **ROXY**. Greenhouse and field testing with pre-plant applications of oxyfluorfen have demonstrated the herbicide tolerance of the mutant lines and 1st generation breeding materials. Promising levels of weed control were also demonstrated in 2015 to 2017 field tests. Initial crosses, progenies and segregating populations involving herbicide-tolerant mutants were done by the medium grains project, and this trait has been passed on to the other projects as well. A patent has been filed and efforts are being pursued to obtain registration for this herbicide for use on rice in California. Materials will be shown on the RES Breeding Nursery Tour, and "herbicide partner" testing by UC weed scientists seen at the Hamilton Road Tour.

Rice Pathology
(P.L. Sanchez, RES)

Rice Pathology Project focus on the development of improved disease resistance screening and evaluation for Rice Experiment Station (RES) breeding projects. This is done by developing and applying advanced screening techniques to measure and score breeding lines for selection, advancement, and data on breeding lines. We are producing inoculum in the laboratory and managing disease nurseries for optimal disease development. Advanced entries in statewide (SW) and preliminary yield (PY) trials are evaluated for susceptibility to stem rot in the field and aggregate sheath spot and blast in the greenhouse. Several years of testing are required to accurately characterize the level of resistance in these entries.

Blast Resistance

Blast resistance conferred by the large-effect (no disease) *Piz* gene is already available in M-208. However, blast was found in growers' field in 2010 on M-208. Other large effect genes have been backcrossed eight times into M-206. Yield trials indicate these materials are very similar

to M-206. Four of these genes have been combined in M-206 by conventional screening and use of molecular markers to prevent the fungus from overcoming single gene resistance. Available Blast resistant lines were screened and evaluated inside the greenhouse. These pyramided gene materials are being purified for yield testing. Efforts are under way to transfer these genes to other RES varieties.

Stem Rot Resistance

Stem rot resistance has been derived from wild species of rice. Currently, the genes responsible for this resistance are being mapped in medium grain materials by the RES DNA Laboratory. An initial backcross population indicated at least four possible locations for genes, and further backcrosses are being evaluated to determine the location of these genes more precisely. Mapping populations are planted in the field and greenhouses for phenotypic and genotypic evaluation. The intent is to develop molecular markers useful in transferring this hard to evaluate trait. Long grain materials have been in state wide trials for some time, and are among the highest yielding materials.

Sheath Spot Resistance

Sheath spot resistance is also present in some rice germplasm materials derived from the wild species program for stem rot resistance. In this way, it may be possible to have resistance to two diseases simultaneously. Other sources of resistance have also been identified and crossed into M-206.

Ultimately, it is desirable to have resistance to all three diseases (blast, stem rot, and sheath spot) in a single variety. Use of advanced genetics and genomics approach for identifying and transferring blast, stem rot and sheath spot resistance genes will make production of more disease resistant California rice varieties in the future.

Rice Germplasm Collection, Conservation and Utilization

Pathology Project handles rice germplasm (wild and cultivated rice species) requests by the breeders which must go through quarantine. All seed imported from other countries and received from rice growing states in the US are treated according to a permit issued by the U.S. Department of Agriculture, Plant Protection and Quarantine (PPQ) and subject to inspections by California Department of Food and Agriculture (CDFA) to prevent introduction of new pathogens and pests into California. All received germplasm materials were grown and evaluated inside the RES quarantine greenhouse. Materials are then released for use in the breeding program. RES plant quarantine and rice germplasm conservation procedures ensure that the breeders

have access to traits important to the continuing improvement of California varieties.

Weed Control in CA Rice: Evaluation of New Weed Control Tools

(K. Al-Khatib, A.S. Godar, M. Lee, A. Ceseski, K.E. McCauley, J.R. Stogsdill, W. Brim-DeForest, B.A. Linquist, L. Espino, and R.G. Mutters, UCD and UCCE)

The UC Rice Weed Research Program at the Rice Experiment Station, Biggs, CA seeks to assist California rice growers in achieving their weed control and herbicide resistant management goals. This year's program focuses on the performance evaluation of new herbicides (including those under development) in mixtures and/or sequential combinations with existing herbicides primarily for continuously-flooded rice growing system. Other highlights of this year's program include evaluation of oxyfluorfen-resistant rice (ROXY) which is being developed by the Rice Experiment Station (RES). Other field demonstrations are the examination of new adjuvants for post-applied herbicides in continuously-flooded or pinpoint rice systems.

Continuous flood system has been historically the most common rice growing system in California as this system promotes suppression of most competitive rice weeds such as barnyardgrass, watergrass, and sprangletop. In this system, a water depth of 4 inches is maintained throughout the season after seeding rice into a flooded field. When late post-emergence foliar applications are needed, water depth is lowered to expose about two-thirds of weed foliage to the herbicide spray, but fields are never completely drained.

Several into-the-water herbicide products are available for controlling weeds in continuously-flooded rice which include Bolero, Butte, Cerano, Granite GR, League MVP, Shark H2O, and Strada CA. Butte is a new addition to the California rice herbicide portfolio. These herbicides can be applied early to provide good to excellent control of labelled (target) weeds. As they vary in the spectrum of weed control, it is sometimes useful to combine two of these herbicides in a program to expand the spectrum weed control.

This year, the predominant weed species were late watergrass, ducksalad, ricefield bulrush, smallflower umbrellasedge, followed by barnyardgrass, monochoria, waterhyssop, redstem and sprangletop. All weeds evaluated in our program are susceptible to herbicides

registered for California rice, but we also briefly discuss and give weed management options for fields with population(s) of resistant weed species.

Weed control efficacy of herbicide programs presented here primarily reflect the visual ratings (average of three or four replicates) 40 and/or 60 days after seeding (DAS) of rice. Rice injury (stand reduction, stunting and other injury) to an herbicide application and/or an herbicide program has also been noted wherever relevant.

Evaluation of ROXY: Crop Tolerance and Weed Control

ROXY is an oxyfluorfen-resistant rice which is currently under development by the RES. In this study, ROXY was evaluated for crop tolerance and weed control with oxyfluorfen applied alone or in combination with several other rice herbicides. Oxyfluorfen is a PPO-inhibitor (same mode of action as Shark H2O); and it has good activity on a broad-spectrum rice weeds.

ROXY was tested under a continuously-flooded system with 2 pt/A rate of Goal 2XL (oxyfluorfen 2 lb ai/gal) applied pre-flood. The ROXY seed material (17Y3000) used in this study showed only a minimal injury early in the season to the applied rate of Goal 2XL. The stand-alone application of Goal 2XL provided an excellent control of broadleaf weeds (ducksalad, monochoria, redstem and waterhyssop) and the control was at least 90% for late watergrass and barnyardgrass. Control of smallflower umbrellasedge with Goal 2XL alone was excellent; however, the control was only fair for ricefield bulrush. Overall, Goal 2XL alone provided a broad spectrum of weed control and offered an exceptional level of crop safety.

Inclusion of into-the-water herbicides such as Bolero (23.3 lb/A at 2.5 lsr), Butte (7.5 lb/A at 1 lsr), Cerano (10 lb/A at DOS), or Granite GR (15 lb/A at 2.5 lsr) into the program increased control of grasses and ricefield bulrush (> 98% control).

Similarly, an early follow-up application of Clincher (13 oz/A + 2.5% COC at 1 tiller) improved grass control (> 99%) and Regiment (0.67 oz/A + 2.0% v/v UAN + 0.2% v/v NIS) or Granite SC (2.5 oz/A 2.5% v/v COC) applied at 1 tiller improved control of both grasses and ricefield bulrush (> 99% control). A late tank-mix application of Stam 80 EDF and Grandstand (5 lb/A + 8 oz/A + 1.25% v/v COC) or RiceEdge (10 lb/A) following the pre-flood application of GOAL 2XL provided a perfect control of all major weeds.

This year's data suggest that a high majority of initial flush weeds could be controlled with Goal 2XL alone without causing a significant

injury to ROXY. In conclusion, preliminary results are encouraging in that the ROXY offers an excellent crop safety to oxyfluorfen, and fits well into the various weed control programs. The choice of an appropriate follow-up application or an inclusion of a granular herbicide may largely depend on the weed population pressure and/or resistance status of the weeds in the field.

Butte-Based Programs

Starting this year, Butte® is available to California rice growers. Butte® is a granular mixture of benzobicyclon and halosulfuron active ingredients developed by Gowan Company. The benzobiclyclon component of Butte® adds a new mode of action (HPPD-inhibitor) to the herbicide portfolio for water-seeded rice in California. Previous studies suggest that Butte provides good broad spectrum weed control; however, there is great need to consider using Butte in combination with other herbicide such as Clincher, Cerano, Granite, propanil, and Regiment to particularly to improve grass weed control. This year, weed control efficacy of Butte alone or in a program was examined in five separate studies.

In the first study, Butte was tested under a continuous flood system with two rates of application, both alone and in a program. Butte (7.5 or 9 lb/A) applied at day of seeding (DOS) provided excellent control of sedges (ricefield bulrush and smallflower umbrellasedge), ducksalad, monochoria, and sprangletop. In addition, Butte provided a good control (~90%) of watergrass and barnyardgrass, and a fair control of redstem. Overall, Butte alone provided a broad spectrum of weed control and offered an exceptional level of crop safety.

Butte (7.5 lb/A at 1 lsr) with other into-the-water herbicides such as Cerano (12 lb/A at DOS or 1 lsr) or Granite GR (15 lb/A at 2.5 or 5 lsr) provided overall greater control of grass weed species compared to the stand-alone application of Butte applied. A follow-up foliar application of Clincher (13 oz/A + 2.5% v/v COC) or Regiment (0.67 oz/A + 2.0% v/v UAN + 0.2% v/v NIS) at 1 tiller stage improved barnyardgrass and watergrass control. Similarly, a tank-mix of Stam 80 EDF and Grandstand (5 lb/A + 8 oz/A + 1.25% v/v COC at 1 tiller stage) or Granite SC (2.8 oz/A + 2.25% v/v COC at 2.5 or 5 lsr) following Butte (7.5 lb/A at 1 lsr) provided exceptional control of all weeds, including all grass weeds and redstem. The choice of the appropriate follow-up application or an inclusion of a granular herbicide (for example Cerano, Granite GR) may largely depend on the weed population pressure and/or resistance status of the weeds in the field.

In the second study, a single rate and timing of Butte (7.5 lb/A at spikelet stage) was tested under a continuous flood system with a

follow-up into-the-water application of Granite GR at two rates (13 or 15 lb/A at 3.5 lsr) or a foliar application of Granite SC (2.5 oz/A + 2.5% v/v COC) at 1 tiller with or without an additional tank-mix application of Stam 80 EDF and Grandstand CA (5 lb/A + 6 oz/A + 2.5% COC at mid tiller stage). Cerano (10 lb/A at DOS) and Granite SC (2.5 oz/A + 2.5% COC) at 1 tiller with or without the tank-mix application of Stam 80 EDF and Grandstand CA programs were also included. Butte followed by all the timings and/or formulations of Granite provided an excellent control of grasses (late watergrass, barnyardgrass, and sprangletop), sedges (ricefield bulrush and smallflower umbrellasedge), broadleaf weeds (ducksalad, monochoria, redstem, waterhyssop) without the need for an additional tank-mix application of Stam 80 EDF and Grandstand. The Cerano plus Butte program was as good as Butte plus Granite programs in controlling weeds; however, Cerano or Granite (particularly Granite GR applied early) applications caused some rice injury early in the season which mostly disappeared by 50 days after seeding (DAS). In conclusion, Butte followed by Granite herbicides offered a broad spectrum of weed control and an excellent crop safety in continuously-flooded rice system.

Herbicide programs in the third study included Butte (7.5 lb/A at 2 leaf stage) with a follow-up tank-mix application of Stam 80 EDF and Grandstand (5 lb/A + 6 oz/A + 2.25% v/v COC) or a tank-mix application of Stam 80 EDF and Londax (5 lb/A + 1.2 oz/A + 1% v/v COC at 1-2 tiller). Both the programs were very effective in controlling all weeds present in the field.

The fourth study compared the efficacy of weed control between Butte (7.5 lb/A) and League MVP (30 lb/A) applied at 2 lsr in a stand-alone situation or followed by Regiment CA (0.67 + 0.4% v/v Dyne-Amic) applied at 1 tiller stage of rice. Butte alone provided at least 80% control of late watergrass and barnyardgrass, and an excellent control of other weed species. League MVP alone was better (at least 90% control) compared to Butte alone in controlling late watergrass and barnyardgrass; however, the control of most other weeds except ricefield bulrush was similar. League MVP provided only 75% control of ricefield bulrush. The overall weed control increased to at least 98% with the follow-up application of Regiment in both situations.

A similar study was also conducted in a non-replicated large plot setting (700 ft2 plots). Overall weed control with the Butte or League MVP followed by the Regiment programs was excellent.

NAI-1777 (new herbicide)-Based Programs

NAI-1777 is a granular formulation of 1.8% pyraclonil (a PPO-inhibitor) which is currently under development for weed control in CA

rice by Nichino America, Inc. This herbicide has similar mode of action to Shark H2O. In the previous years' studies, stand-alone application of NAI-1777 in continuously-flooded rice system provided an excellent control of broad-spectrum of CA rice weeds with an excellent level of crop safety.

This year, NAI-1777 was evaluated in combination with other herbicides in several weed control programs. The programs included NAI-1777 (14.9 lb/A at DOS alone or in combination with Cerano 6 lb/A at DOS, Butte 7.5 lb/A at 1.5 lsr or Bolero 23.3 lb/A at 1.5 lsr) followed by propanil (6 lb ai/A + 1% v/v COC at 1-2 tiller). Two other programs, NAI-1777 14.9 lb/A at DOS followed by Regiment CA (0.80 oz/A at 1-2 tiller) or Strada CA (1.2 oz/A at 2.5 lsr) were also included.

All the NAI-1777-based programs were exceptionally effective in controlling all weeds present in the field. The only program that included Bolero caused significant long-term crop injury (as much as 30% stand reduction and 40% stunting 60 DAS). Rice injury with all the other programs, including those that caused significant initial injury (Cerano) was mostly recovered by 60 DAS.

NAI-1777 is a very promising tool for weed control in CA rice, most importantly for controlling and managing a variety of herbicide-resistant weeds in California rice fields.

Shark H2O-Based Programs

Shark H2O can be a good option for a program aimed at controlling ALS inhibitor- and/or propanil-resistant sedges and ALS-resistant redstem. Shark H2O alone (4 oz/A at 1 tiller) provided a good control of ricefield bulrush and smallflower umbrellasedge (> 90% control). An application of tan-mix of Shark H2O and propanil (4 oz/A + 6 lb ai/A + 1% COC at 1 tiller) was as good as tank-mix application of Grandstand CA and propanil (8 oz/A + 6 lb ai/A + 1% % v/v COC at 1 tiller) and provided at least 90% control of late watergrass and barnyardgrass, more than 98% control of the sedges and a good control of other broadleaf weeds. Inclusion of into-the-water herbicides, Cerano (12 lb/A at DOS) or Granite GR (15 lb/A at 2.5 lsr), in these programs significantly reduced the early weed pressure and increased the efficacy of tank-mix applications, thus providing a superior weed control.

Evaluation of Various New Adjuvants for Weed Control Efficacy

In the first study, four adjuvants from WinField Solutions, LLC. were studied under continuous flood system. Efficacy of Regiment CA (0.53 oz/A at 5 lsr), Clincher CA (13 oz/A at 1 tiller) or Stam 80 EDF (5 lb/A 1-2 tiller) herbicides were tested with or without AG13064 (3 oz/A),

InterLock (4 oz/A), MasterLock (6 oz/A) or DownDwarf (5 oz/A) adjuvants. The Regiment and Clincher applications were stand-alone whereas Stam 80 EDF applications were made following Cerano applied at DOS (12 lb/A). The Stam 80 EDF applications with all the three adjuvants (> 90% control) except DownDwarf (< 70% control) provided similar control of sedges and major broadleaf weeds. Note that most of the grasses were already controlled with Cerano in these plots. The Regiments applications, regardless of the adjuvants included, provided excellent control of all weed species except sprangletop and no clear differences in weed control efficacy among the adjuvants were observed. In general, grass weed control ¬was poor with Clincher without the adjuvant (< 85 % control) or with InterLock (< 92% control) compared to Clincher with other adjuvants (at least 95% control).

The second study evaluated two adjuvants, OR 108G (0.0625 or 0.125% v/v) and OR 009 (0.25% v/v), from Oro Argi for weed control efficacy when included with Granite SC (2.5 oz/A at 5 lsr) and Clincher CA (13.5 oz/A at 1-2 tiller) applied sequentially, or tank-mix of Abolish and Regiment (1.5 qt/A + 0.53 oz/A at 5 lsr) in a pinpoint system. For comparison, separate applications of Granite, Clincher or tank-mix of Abolish and Regiment with COC (2.5% v/v) were also included. The field was completely drained during the period of herbicide application to expose weed foliage to herbicide applications, thus allowing the opportunity to achieve the best efficacy of POST-applied herbicides.

The sequential applications of Granite SC and Clincher with all adjuvants provided more than 90% control of grasses, sedges and broadleaf weed except redstem (> 25% control). Herbicide applications that included the higher rate of OR 108G or OR 009 generally provided slightly superior control (> 95%) of weeds compared to the applications with the low rate of OR 108G or COC. The tank-mix applications of Abolish and Regiment with all the adjuvants provided overall good weed control (> 85%), including redstem. However, barnyardgrass and late watergrass control with these applications were slightly poor compared to those with sequential applications of Granite SC and Clincher. The higher rate of OR 108G or OR0 09 performed slightly better (> 90%) in controlling of grasses compared to the applications with the low rate of OR 108G, COC, or Dyne-Amic.

Herbicides used and their active ingredient

Herbicide	% ai	lb ai/gal
Abolish 8EC (thiobencarb)	84	8.0
Bolero Ultramax (thiobencarb)	15	NA
Butte (benzobicyclon + halosulfuron)	3 + 0.64	NA
Cerano 5 MEG (clomazone)	5	NA
Clincher CA (cyhalofop-butyl)	29.6	2.4
Goal 2XL (oxyfluorfen)	22.3	2
Grandstand CA (triclopyr)	44.4	3.0
Granite GR (penoxsulam)	0.24	NA
Granite SC (penoxsulam)	24	2.0
Londax (bensulfuron-methyl)	60	NA
NAI-1777 (pyraclonil)	1.8%	NA
Regiment CA (bispyribac-sodium)	80	NA
RiceEdge (propanil + halosulfuron)	60 + 0.64	NA
Shark H2O (carfentrazone)	40	NA
Stam 80 EDF (propanil)	81	NA
Strada CA (orthosulfamuron)	50	NA

K Al-Khatib, Professor, Department of Plant Sciences, UCD; AS Godar, SRA III, UCD; M Lee, Junior Specialist, UCD; A Ceseski, PhD Student, UCD; KE McCauley, PhD Student, UCD; JR Stogsdill, SRA III, UCD; W. Brim-DeForest, Farm Advisor, Sutter, Yuba-Placer-Sacramento CO., UCCE; BA Linquist, Cooperative Extension Specialist, UCCE; L Espino, Farm Advisor, Colusa-Glenn-Yolo CO., UCCE; RG Mutters, Farm Advisor, Butte CO.

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EQUIPMENT DISPLAY

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