Dealing with the Drought

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 California drought has presented great challenges for California’s rice growers and the Rice Experiment Station is no exception. The top photos show water measurement by Richvale Irrigation District. The lower photo is the RES pump, drilled in 1978 during the last major drought and has been used extensively to supplement the reduction in available surface water that normally takes care of the RES rice research and seed production. We are extremely grateful to the Richvale Irrigation District Board, Management, Staff, and neighbors that have provided us the support and resources to get through this season without sacrificing our research plots and seed production fields.
California Cooperative Rice Research Foundation, Inc.

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2015 Rice Field Day Program

7:30—8:30 Registration and Poster Viewing

Posters and Demonstrations
1. Rice Waste Discharge Requirement: Farm Evaluation and Nitrogen Management Plan (California Rice Commission)
2. Rice Pesticide Program - Thiobencarb Exceedances and Management Practices (California Rice Commission)
3. Handouts from California Rice Commission on:
   - Butte Herbicide Section 18 and Registration Process
   - Armyworm Pesticide Options
   - Propanil and the Start-up of the Re-registration Process
4. Bentazon Efficacy for Sedges Control in Rice (A.S. Godar, W. Brim-DeForest, K. Al-Khatib, UCD)
6. Efficacy of Fluridone on Major Weeds Species of Rice in California (W. Brim-DeForest, K. Al-Khatib, A.J. Fischer, UCD)
7. Effects of Simulated Rice Herbicide Drift on Walnuts (M.F. Galla, B. Hanson, K. Al-Khatib, UCD)
8. Rice Herbicide Symptoms on Fruit Tree Crops (M.F. Galla, K. Al-Khatib, UCD)
11. Genetic Analysis of Seedling Vigor in Temperate Japonica Rice (*Oryza sativa* L.) (K. Cordero Lara [UCD], V.C. Andaya [RES], T.H. Tai [USDA-ARS])
12. Identification of Useful Grain Quality Characteristics in Rice Mutants Using TILLING and Forward Genetics (M. Yoon [RDA], A. Chun [RDA], T.H. Tai [USDA-ARS])
15. The Distribution and Build-Up of Salinity in Rice Fields and its Effect on Yield (M. Marcos, H. Sharifi, B. Linquist [UCD-UCCE])

17. A Methylmercury Budget For a Sacramento Valley Rice Field (C. Tanner, B. Linquist, UCD)


20. Effect of Infrared Drying on Physicochemical Characteristics of Stored White Rice (C. Ding, R. Khir and Z. Pan, UCD)


22. Disease Symptom Posters (P.L. Sanchez, RES)

23. California Rice Breeding- Yield Increase Rate Due to Semi-Dwarf Varieties Developed by the Rice Experiment Station, Updated to Include New Releases (S. O. PB. Samonte, V.C. Andaya, F. Jodari, C.B. Andaya, P.L. Sanchez, and K.S. McKenzie, RES)
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,
  Steven Willey, Chairman, RRT

- California Rice Research Board Report,
  Seth Fiack, 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, F. Jodari, S.O. Samonte, and P.L. Sanchez, RES)

Management of Invertebrate Pests in California Rice- Its More than Rice Water Weevil
(L.D. Godfrey, L. Espino, K. Goding, J. Bloese, UCCE & UCD)

10:30 - 10:45 a.m.  Refreshments - New Warehouse

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
Rice Weed Control: Herbicide Programs, New Chemicals, and Weed Management

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 and with seating at the tables on the lawns under the canopies

2.0 hours of Continuing Education credit for this 2015 Rice Field Day has been granted from Cal/EPA Department of Pesticide Regulation

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 2015. 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.

2015 has certainly proved to be a year challenging year for the California rice industry as I am sure all of you have experienced. I am pleased to report that we have been able to continue our breeding and research activities without any reduction. 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. RES does have a productive well drilled in 1978 that has been pumping to supplement to help cover our water needs. I would like to acknowledge the support we have received from the Richvale Irrigation District and growers in recognizing our critical role in California rice.

The highlight of the day's actives are the field tours where you are able to hear from the researchers and see the 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 program and will be reporting on that project. Dr. Farman Jodari will update you on his long grain program and varieties. Dr. Stanley Samonte will present his work on premium quality and short grain varieties. Dr. Paul Sanchez was hired this spring and overlapped with retiring Pathologist Jeff Oster will be speaking to you at the rice disease nursery. Dr. Larry Godfrey, UC Cooperative Extension will also present the ongoing work on rice insect pests on the main station tour.

Dr. Kassim Al-Khatib, UC Davis Professor, has taken over the leadership for rice weed control project and will be leading you on a walking tour of the weed research nursery at the Hamilton Road site.

Dr. Cynthia Andaya and Mr. George Yeltatzie have our DNA marker lab in full operation to support the RES Breeding Program.

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. The seed program is self-supporting and is not funded by the Rice Research Board. Two new varieties were released to seed grower in 2015, M-209 and Calmochi-203.

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.

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-two fellowships have been issued from 2000 to 2011.

Beginning in 2012 some changes were made to offer more financial support with two-year fellowship in the amount of $10,000 to encourage an undergraduate to pursue graduate study in rice research. This effort has not been successful, and the Board has decided to return to offering the previous annual fellowships and the 2015 recipient will be recognized at the Rice Field Day Business Meeting.
CALIBRATION AND VALIDATION OF ORYZA (V3) FOR SIMULATION OF US RICE PRODUCTION SYSTEMS

M.B. Espe, H. Yang, H. Sharifi, N. Guilpart, K.G. Cassman and B.A. Linquist (UCD)

Efforts to quantify the crop yield gap typically rely on application of physiological crop models outside of the environmental and management systems in which these models were originally developed. This is the case for Oryza(v3) which was originally developed to simulate tropical, transplanted rice production system sand has not yet been validated and calibrated for the temperate, direct-seeded rice production systems of the US. Here, we test how well this model can be calibrated and validated to simulate yield potential (Yp) for two major rice varieties (M-206 and CXL745) in the three major regions of US rice production. We find that Oryza(v3) is better able to simulate Yp for variety CXL745 in the Southern US regions, which are more similar to the production systems Oryza(v3) was developed under, compared to variety M-206 in the CA region. In the process of calibration and validation, we found three major areas where the model needs improvement. First, the model simulated leaf area index (LAI) and biomass poorly for all direct-seeded systems using default values. Second, cold-induced sterility and associated yield losses are poorly simulated. Lastly, the model is sensitive to the definition of physiological maturity used. Except for the simulation of cold-induced sterility, all issues could be remedied within the existing model structure. However, the simulation of cold-induced sterility represents a significant challenge to accurate simulation - one that will require changes to Oryza(v3)'s structure to address. Despite these issues, we show here that Oryza can acceptably simulate Yp in US production systems.

GENETIC ANALYSIS OF SEEDLING VIGOR IN TEMPERATE JAPONICA RICE (ORYZA SATIVA L.)

K. Cordero Lara (UCD), V.C. Andaya (RES) and T.H. Tai (USDA-ARS, UCD)

In Asia, transplanting of rice seedlings in puddled fields is typically employed in irrigated rice production systems. However, with dwindling resources, direct seeded rice (DSR) cultivation is becoming more widespread. Seedling vigor is an important trait for DSR cultivation. In California, germinated rice seeds are seeded aerially into flooded fields. Released varieties have very similar vigor under these conditions. M-203 and M-206 are medium grain temperate japonica varieties adapted for the California production environment.
Evaluation of these two varieties under direct seeding into soil revealed that M-203 exhibits better vigor than M-206 under controlled conditions consisting of a 12 hr photoperiod with constant (28°C/24 hr) under greenhouse conditions and outdoor basins conditions. A recombinant inbred line (RIL) population (F7, n = 180) has been developed from the cross M-203/M-206 and evaluated for seedling height 7 and 14 days after sowing (PH7 and PH14), growth rate (GR) and fresh weight of the aboveground biomass (FW). Ten seeds per line were sown in a randomized complete block design with 3 replications and 5 seedlings were evaluated. Under constant temperature conditions in a growth chamber the average PH7 = 9.8 cm (6.1 – 12.8 cm), PH14 = 41.2 cm (32.8 – 48 cm), GR = 4.5 cm/day (3.4 – 5.5 cm/day) and FW = 1.55 g (1.10 – 1.91 g). For greenhouse conditions, average PH7 = 3.3 cm (1.5 – 4.4 cm), PH14 = 13.3 cm (10.2 – 16.2 cm), GR = 1.43 cm/day (1.11 – 1.72 cm/day) and FW = 0.38 g (0.27 – 0.5 g). For outdoor basin conditions average PH7 = 6.8 cm (3.3 – 10.5 cm), PH14 = 13.3 cm (6.7 – 18.3 cm) and GR = 0.9 cm/day (0.5 – 1.5 cm/day). Six RILs were identified as consistently exhibiting greater vigor than M-203 considering all traits measured. The RIL population is currently being genotyped using a reduced representation sequencing approach and the resulting marker data will be used with the trait data to identify QTLs contributing to the different seedling vigor exhibited by M-203 and M-206.

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

M. Yoon, A. Chun (RDA, South Korea) and T.H. Tai (USDA-ARS, UCD)

Rice (Oryza sativa L.) is unique among major cereal crops as the vast majority is used directly for human consumption, usually in the form of whole milled kernels. Climate change and consumer demand pose significant challenges to rice breeders with regard to maintaining and improving various grain traits that influence appearance, eating qualities, and utilization. Our objective is to employ Targeting of Induced Local Lesions in Genomes (TILLING) and forward genetic approaches to identify chemically-induced rice mutants with grains exhibiting novel cooking, eating, and processing qualities. Towards this end, we have recently identified over 60 putative mutations in 8 starch biosynthesis-related genes from a TILLING by sequencing screen of 2,048 Nipponbare M2 individuals. We have also visually evaluated brown rice grains from the M3 generation of approximately 2,000 Kitaake and 1,200 Nipponbare M2 lines. This has resulted in the identification of > 15 putative mutants exhibiting opaque grains.
Validation of the putative TILLING mutants and phenotypic characterization of the lines exhibiting altered grain appearance is underway.

**IDENTIFICATION OF PUTATIVE FUNCTIONAL NUCLEOTIDE POLYMORPHISMS IN CALIFORNIA ANCESTRAL CULTIVARS USING EXOME CAPTURE AND NEXT-GENERATION SEQUENCING**


Targeted sequencing is an approach in which specific genomic regions of interest are sequenced in order to reduce costs and increase the depth of sequencing coverage compared to whole-genome sequencing. In exome sequencing, the targets are protein-coding regions of the genome (i.e., the exome) which are selectively captured and sequenced. This enables more cost-effective detection of sequence variation that may correspond to functional differences in genes. In this study, three ancestral varieties (Caloro, Lady Wright, and Colusa) of Calrose-type rices were subjected to exome sequencing to identify single nucleotide polymorphisms (SNPs). For comparison, some modern California (L-202, M-204, M-205, and M-206) and southern U.S. long grains (Cypress, Dixiebelle, and Sabine) were also sequenced. SNPs that may impact gene function and can be converted to low-cost DNA markers have been identified.

**THE DISTRIBUTION AND BUILD-UP OF SALINITY IN RICE FIELDS AND ITS EFFECT ON YIELD**

M. Marcos, H. Sharifi, B. Linquist (UCD)

Current drought conditions have forced many rice growers to reduce the amount of water used to grow rice and to use a greater amount of water from non-district sources, increasing the likelihood that field water salinity will rise and result in yield reductions. Presently, the movement of salts within rice fields is insufficiently understood. This study aims to elucidate the distribution and build-up of salts in rice fields, and to develop water management strategies to mitigate the effects of salinity on yield while concurrently reducing water use. In 2014 and 2015, the water and soil salinity levels of 6 fields were monitored weekly. 9 sampling points, distributed throughout the top, middle and bottom checks were established in each field. In both years, there were early-season spikes in field water electrical conductivity (EC). The highest field water EC measurement obtained from the early-season spikes was 2.45 dS/m in 2014 and 6.06 dS/m in 2015. Additionally, an exponential relationship was found between
the distance from the inlet and the relative increase of water EC. In 2014, the water and soil salinity levels were sufficiently low, at all sampling points, to avoid yield losses; the highest season-average water EC level was 0.92 dS/m while the highest season-average soil EC level was 2.84 dS/m. Preliminary results indicate that allowing water to subside early in the season creates spikes in field water EC levels. The water salinity spikes occur when rice is most susceptible to damage from salinity, thus having the potential of reducing yield, especially in areas furthest from the inlet.

**EXPLORING FACTORS AFFECTING TADPOLE SHRIMP BIOLOGY AND POPULATION DYNAMICS**

- J.B. Bloese (UCD), L. Espino (UCCE), E. Goding, S. Rice, H. Hollister (UCD) and L.D. Godfrey (UCCE)

Tadpole shrimp (*Triops longicaudatus; TPS*) is a vernal pool crustacean, native to the western hemisphere. Historically, population levels were tolerable and seldom caused economic damage in rice. However over the past decade TPS has increasingly become a significant pest for California rice growers. TPS feeds on and uproots young seedlings; its swimming and burrowing habits increase the suspended silt in the flooded fields and disrupt the photosynthetic capacity of the young rice seedlings. TPS eggs can remain dormant for ~20 years or more (Brendonck and Meester, 2003). This evolutionary adaption could be key to the recent population explosion of TPS in California rice. By characterizing the spatial distribution of TPS eggs (eggs in diapause vs active eggs) through sampling farmers’ fields and analyzing TPS egg frequencies using geostatistical technique kriging, we can develop effective monitoring techniques. Eggs recovered from farmers’ fields are photographed using hyperspectral imaging to distinguish between diapause and active eggs. Using hyperspectral technology we can subsequently quantify changes in this ratio under various treatments, such as resource availability, temperature, and dissolved oxygen throughout the adults’ lifespan.

**A METHYLMERCURY BUDGET FOR A SACRAMENTO VALLEY RICE FIELD**

- C. Tanner and B. Linquist (UCD)

Methylmercury is a potent neurotoxin produced by microbes living in flooded soils, such as those in rice paddies. When methylmercury is exported to downstream ecosystems it can accumulate in fish, causing health problems for fish eating humans and wildlife. Methylmercury imports in irrigation water and exports in drainage water were monitored for a 55 acre rice field in the north east Sacramento Valley.
for a full year. During the growing season, methylmercury imports were greater than exports, and the field was a sink for 0.014 g of methylmercury. However, during the winter methylmercury exports exceeded imports, and the field was a source for 0.023 g of methylmercury. During both the growing season and winter flooded periods methylmercury concentrations in drainage waters were highest shortly after the field was flooded, and decreased as the season progressed. Methylmercury concentrations measured in this study were an order of magnitude lower than methylmercury concentrations measured in a study in the Yolo Bypass, but patterns of higher and lower concentrations were similar in both studies. This shows that there are important differences between rice fields in the Yolo Bypass and in the Sacramento Valley, possibly caused by differing concentrations of mercury in the soil.

DEVELOPMENT AND PERFORMANCE OF BLAST RESISTANT NEAR-ISOGENIC LINES OF RICE IN M-206 GENETIC BACKGROUND


The Rice Experiment Station (RES) located in Biggs, California, initiated a project to develop near-isogenic rice lines (NILs) containing different resistance genes to rice blast (*Magnaporthe grisea*) in the genetic background of M-206, a temperate Japonica medium grain variety. M-206, a commercial rice variety, is a popular and widely grown variety in the Sacramento Valley and is susceptible to rice blast. Ten blast resistance genes (*Pi* genes) were used in the gene introgression, namely, *Pi1*, *Pi2*, *Pi9*, *Pi33*, *Pi40*, *Pib*, *Pikh*, *Pikm*, *Pita2*, and *Piz5*.

Gene introgression was performed using at least seven backcrosses to M-206 using biological screening initially, followed by marker-assisted backcrossing using PCR-based DNA markers. Supplemental blast screening was performed to verify presence of resistance genes in plants used for crossing. The NILs were advanced to homozygosity and given individual designation that specifies the cultivar used and the resistance gene introgressed (e.g. M-206+*Pi33*). The agronomic and yield performance of the NILs, M-206, and check varieties were evaluated in replicated field experiments at RES and Statewide Yield Test.

This poster describes the development of the NILs and their performance in comparison to M-206 in terms of a number of agronomic and grain traits. It will also report if there are negative or
positive effects of individual blast resistance genes to these measured traits.

DEGRADATION OF AFLATOXINS IN ROUGH RICE BY PULSED LIGHT TECHNOLOGY

B. Wang, R. Khir, Z. Pan (UCD) and N. Mahoney (USDA)

Pulsed light (PL) treatment was proved as an effective method to degrade aflatoxins. The objective of this study was to investigate the degradation characteristics of AFB1 and AFB2 (aflatoxin B1 and B2) inoculated in different substrates using PL treatment. The photodegradation studies of AFB1 and AFB2 in filter papers and rough rice were performed under PL at different initial concentrations and irradiation intensities. The results revealed that the photodegradation of AFB1 and AFB2 in filter papers at the selected ranges of concentrations well fitted second-order reaction kinetics (R2 ≥ 0.98). The degradation rate was proportional to the initial concentrations of the aflatoxins and the intensities of the PL irradiation. With verification, the second-order reaction kinetics well fitted in rough rice as well.

EFFECT OF INFRARED DRYING ON PHYSICOCHEMICAL CHARACTERISTICS OF STORED WHITE RICE

C. Ding, R. Khir and Z. Pan (UCD)

The objective of this study was to investigate the effect of infrared (IR) drying followed by tempering and natural cooling on the change of physicochemical characteristics of white rice during up to 10 months of storage. The physicochemical characteristics of IR-dried rice were also compared with those of conventionally dried rice. It took only 58 s to heat the rough rice from room temperature to 60 °C with IR, and 2.17 percentage points of moisture was removed. After four months of storage, the increases in yellowness index, water uptake ratio, and volume expansion ratio of the rice dried with IR were 73.8, 63.9, and 55.3% those of rice dried with an ambient air drying method, respectively. IR drying slightly decreased the gelatinization temperature, enthalpy, and viscosities, reduced the changes in microstructure, and maintained cooking characteristics during storage. Therefore, the IR drying process is recommended to maintain the quality of white rice during storage.
DEVELOPMENT OF INFRARED-ROTARY DRUM DRYER FOR ROUGH RICE

C. Ding, R. Khir and Z. Pan (UCD)

The objective of this study was to design and test an infrared (IR) rotary drum dryer and optimize its operating parameters to achieve efficient drying for rough rice. Medium grain rice, M206, with initial moisture content of 23.65±0.51% (d.b.) was used for conducting this research. A single factor of drying experiments were designed to investigate effects of operating parameters (emitter power (EP), resident time (RT), sample mass (SM), rotating speed (RS)) of IR dryer on the drying performance. Then, the response surface methodology was applied to optimize the operating parameters of the IR dryer to achieve high heating rate, high moisture removal, and low energy consumption with desirable milling quality. The results revealed that high heating and drying rates and high milling quality can be achieved by using IR rotary drum dryer. High correlations were found between drying performances (rice temperature (T), moisture removal (MR) and specific energy consumption (SEC)) and operating parameters (EP, RT, SM and RS). Based on the correlations, regression models were developed that could be used to predict T, MR and SEC as dependent factor to the operating parameters under the tested conditions. The optimized values of the operating parameters were determined to be EP of 1694 W, RT of 59.5 s, SM of 450 g, and RS of 10.7 rpm. The obtained results can lead to design large scale of IR dryers for rough rice.
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 Grain
(V.C. Andaya, Plant Breeder, RES)

Calrose medium grain rice varieties developed at the Rice Experiment Station are the most important component of the California rice industry. The Calrose brand throughout the years has earned a reputation of being one of the most recognizable commercial rice in both domestic and international markets.

The medium grain breeding project sets a long term mission of vigorously finding innovative ways to steadily and maximally make genetic improvement on Calrose quality and grain yield to achieve the goal of developing medium grain varieties with higher and more stable grain and milling yields, with excellent grain quality attributes, and tolerance to both biotic and environmental stresses. Making significant jumps in yield and quality is a challenge when the yield potential of current varieties is already high and any significant increase in grain yield quite often results to significant hit on grain quality, particularly on milling yields. This means combining high quality and high yield together in a single variety is indeed a challenging task. Conventional breeding at RES has been very effective throughout the decades but building it further by employing new tools and techniques, and by adding new expertise, will make it even more successful. RES, through the California farmers’ support,
has recently built a research building, improved the cold greenhouse refrigeration unit for cold screening, purchased a research combine and a small harvester, and upgraded research equipment in the DNA Marker Lab and Grain Quality Lab. These investments complement the breeders’ adjustments in yield trial management, the set-up of multiyear potential yield experiments, and efficient use of the San Joaquin cold nursery and Hawaii winter nursery. Moving forward, the medium grain project is taking steady and serious steps to further improve the Calrose grain quality and cooking attributes to match changing international market preference for better tasting rice while still aiming for highest possible grain yields.

To date, the early maturing medium grain M-206 is the dominant rice variety grown in California because of its high grain yield and quality, excellent milling performance even at low harvest moistures, and overall stability and wide-adaptability even when grown in colder rice areas of the Sacramento Valley. In terms of acreage, an early maturing M-205 is the second most-grown medium grain variety because of its higher yield potential, greater straw strength or resistance to lodging, and high milling yields. However, it has a restricted area of adaptation due to its low level of cold tolerance compared to M-206. A very early maturing rice variety named M-105 was released in 2011 as an alternative or a replacement to M-104. Prior to its release, M-105 registered the best milling yields during quality evaluation surpassing even M-206, and cooking quality evaluation by independent evaluators such as rice mills or marketing organization returned good evaluation comparable to other varieties. M-208 is the only blast resistant medium grain variety in California and carries the Piz gene which confers resistance to IG-1 blast pathogen but found recently to be susceptible to a new strain of the blast pathogen. New materials with blast resistance are about ready to go as a potential replacement to M-208. A longtime favorite, M-202, after 30 years in production, is finally moving on to a gradual phase-out in 2015 to make way for newer and better varieties in its maturity class. The legacy of M-202 as a very successful and well-liked variety will be remembered for years to come.

Medium grain varieties still in commercial production are routinely used as check varieties in preliminary yield trials at RES and in Statewide Yield Tests (SW) conducted by UCCE. Last year, averaged across all location in the SW test, M-205 got the highest overall grain yield of 9,820 lbs/acre, followed by M-206 at 9,670 lbs/acre. The M-105, averaged 8,630 lbs/acre while M-202 had the lowest yield of just 7,740 lbs/acre. At RES, pooled grain yield of the check varieties in 2014 was 8,960 lbs/acre compared to 10,270 and 10,750 lbs/acre in 2012 and 2010, respectively. It was a warm year in 2014, causing the
rice plants to flower earlier than previous years. The average combined number of days to heading of the check varieties is the shortest in the last 5 years. The occurrence of lodging is minimal as plants were shorter.

**Release of M-209**

In early 2015, The CCRRF Board of Directors approved the release of a new Calrose rice variety named M-209, formerly designated as advanced rice line 08Y3269. The complete pedigree designation of 08-Y-3269 is “M-205/5/M-201/M7//M-201/3/M-202/4/M-204”. It is a high yielding, early maturing, semi-dwarf, glabrous, medium grain developed using the pedigree selection method. The overall grain yield of M-209 in the Statewide Yield Tests from 2010 to 2014, a total of 38 yield experiments, was 9,680 lbs/acre compared to 8,820, 9,250, and 9,480 lbs/acre for the check varieties M-202, M-205, and M-206, respectively. Yield advantage over M-202, M-205, and M-206 were 10.2%, 5.5%, and 2.3%, respectively. M-209 is best suited in areas planted with M-202 or M-205, and has a slight yield advantage over M-206 in Butte and Colusa. M-209 may sustain damage from cold temperatures induced blanking if grown in cooler rice areas of California. It has comparable reaction to stem rot, aggregate sheath spot, and blast as the other MG varieties.

The milled rice grains of M-209 are heavier (1000-grain weight = 22.1 grams) and slightly longer (length = 5.94 mm) compared to M-205 (21.4/5.87) and M-206 (21.3/5.70). The length/width ratio is 2.2, 2.18, and 2.1 for M-209, M-205, and M-206, respectively. M-209 is best be harvested above 18% grain moisture content, and unlike M-205, M-105, and M-206, milling yield may drop when harvested below that moisture level. Milled rice samples of 08Y3269 or M-209 was evaluated by milling and marketing organizations for visual, cooked rice, and taste quality and was judged to be superior in grain quality and acceptable to the rice market compared to the current medium grain varieties.

**Disease Resistance Breeding**

In collaboration with Dr. Cynthia Andaya of the DNA Marker Lab and the recently retired RES Plant Pathologist Mr. Jeff Oster, we have developed 10 near-isogenic lines of M-206 containing individual blast resistance genes (Pi-1, Pi-2, Pi-9, Pi-33, Pi-40, Pi-km, Pi-kh, Pi-ta2, Pi-b, and Pi-z5). The initial phase of blast resistance gene introgression effort was started in 2005 by Mr. Oster and had concluded with the development of M-206 with different repertoire of blast resistance. The isolines were wholly developed using marker-assisted backcrossing. These were entered in preliminary yield test together with selected check varieties that included M-206 and M-208
to measure yield and agronomic performance and grain characteristics. Breeding for blast-resistant Calrose has gathered renewed attention in the last few years in response to the breakdown of resistance in M-208 containing the Pi-z gene.

In 2013, five near-isogenic lines of M-206 were entered in SW yield test and again in 2014. Results showed that among the isolines, 12-Y-113 containing the Pi-z5 out yielded M-206 by 2.5% and M-208 by 7% using the average yield in tests conducted over 2 years. 12-Y-113 is two days later maturing, taller, but tend to have a higher degree of lodging. Another isolines, 12-Y-3097 containing the Pi-b gene out yielded M-208 by 4%. Both lines are being purified in head rows and entered in SW test locations in 2015.

Stem rot resistant lines that recovered the medium grain type from M-206 were isolated from the stem rot resistance mapping effort of Dr. Andaya and Mr. Oster. Now that Mr. Oster retired, Dr. Paul Sanchez, the newly hired plant pathologist will continue the effort to screen rice population for stem rot resistance. The stem rot resistant lines were used in further backcrossing to M-206 and the progenies are advanced until they are stable. Promising advanced lines were entered in preliminary yield test at RES. One of the line, 14-Y-3060, had superior grain yield (10,990 lbs/acre) compared with the highest yielding check variety (M-205=10,750 lbs/acre). However, the line did not have the high level of resistance as 87Y550, had smaller grain size, and low head rice yield. This line is being used for crossing.

**Mutation Breeding**

The Medium Grain Project is continuously searching and evaluating traits that may add value to rice in California by using mutation breeding either through chemical mutagens or radiation. By generating mutant populations derived primarily from M-205 and M-206, and recently using M-209, the medium grain project hopes to recover beneficial mutation or mutants that are very early maturing, more vigorous, or perhaps with tolerance to certain herbicides. Generation of mutants and screening protocols is currently handled by Dr. C. Andaya. Mutation breeding has become an integral component of the Calrose breeding project where the potential benefit to the California rice farmer is great if useful mutants are identified and get incorporated in major RES-developed rice varieties.
Premium Quality and Short Grain  
(S.O.P.B. Samonte, Plant Breeder, RES)

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

- Short grain, premium quality (SPQ),
- Medium grain, premium quality (MPQ),
- Short grain, waxy (SWX),
- 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, milling and cooking quality, reduced delay in maturity and 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 are selected to qualify a line into a specific grain type. Experimental lines in nurseries and yield tests are compared against check varieties, which include S-102 for SG types, Calamylow-201 (CA-201) for SLAs, Calmochi-101 (CM-101) for SWXs, Calhikari-202 (CH-202) and Koshihikari for SPQs, M-402 and M-401 for MPQs, and 87Y235 for BGs. Selected lines must show improvements over their respective checks.

**RICE VARIETIES and ELITE LINES**

**Waxy Short Grain**

*Calmochi-101 and New Variety Calmochi-203*

Calmochi-101, which was released in 1985, has been the standard SWX variety, being grown in approximately 2.8% of rice acreage in California. There is, however, a newly released SWX rice variety that addresses the low yielding ability and undesirable seed pubescence of CM-101.

Early this year, the high yielding, semi-dwarf, early-maturing, glabrous, short waxy rice Calmochi-203 (CM-203) was approved for varietal release by the CCRRF Board of Directors. CM-203 was produced from a cross made in 2000 between female parent M7//D51/R57/3/M-302/4/CM-101(87Y259)/5/CM-101/6/NFD108/7 and male parent M-102/CM-101/3/Akenohoshi//CalPearl/CM-101.

Calmochi-203, which had a designation of 09Y2141 in yield tests, had been evaluated in 38 UCCE Statewide (SW) Tests from 2010 to 2014. It had significantly higher grain yield than CM-101 in all 38 SW test environments from 2010 to 2014. Averaged across environments, grain yield was 9,650 lb/acre for CM-203 and 7,590 lb/acre for CM-101, for a 27% yield advantage. Compared to CM-101, CM-203 was
similar in seedling vigor, taller by about 5 cm, it required one more
day to reach heading and 11 more days to reach maturity (20% MC),
and it lodged slightly more. Furthermore, CM-203 had higher head
rice percentages, larger grain size dimensions, and had lower
viscosity than CM-101. Blanking, based on the San Joaquin Trials,
was about 3% higher in CM-203 than CM-101. Currently, the SG
project is evaluating two SWX lines in the very early maturing and
preliminary group of the SW Tests, alongside check varieties CM-101
and CM-203.

Premium Quality Short Grain
Calhikari-201 and Calhikari-202
Calhikari-202, which was released as a variety in 2012, has continued
to show its advantages over Koshihikari and CH-201 (released in
1999) in yield, agronomic traits, quality, and taste. In the SW Tests
from 2010 to 2014, CH-202 had higher grain yield than CH-201 in 34
out of 53 test environments, for a 5-year average of 8,555 lb/acre,
which was 4.7% higher than that of CH-201 (8,174 lb/acre). When
compared to Koshihikari in 2014, CH-202 had higher yield (by about
66%), it had similar seedling vigor ratings, and shorter height by 27
cm. Except for the similarity between Koshihikari and CH-202 in
their seedling vigor rating, CH-202 out-performs Koshihikari in
heading (19 days earlier), lodging (13% less), head rice percentage
(1% higher at 67%), and Satake Taste Analyzer rating (Satake score
of 71 for CH-202 vs. 69 for Koshihikari). In SPQ grain types, lower
head rice protein concentration is associated with better taste, and
CH-202 had lower protein concentration at 6.1%.

This year, four SPQ lines are being evaluated in the Preliminary
Group of the SW Tests, including 12Y2167, which had higher yield (in
2013), lower lodging (in 2013 and 2014), less blanking (in 2013), lower
chalkiness (in 2013 and 2014), and higher Satake Taste scores (in
2014) when compared to CH-201 and CH-202.

Premium Quality Medium Grain
M-401 and M-402
M-401 and M-402, which were released as varieties in 1981 and 1999,
respectively, are grown in about 6 and 1% of the rice acreage in
California, respectively, and are the standard premium quality
medium grain varieties. Based on the SW Tests from 2012 to 2014,
their average grain yields were 8,540 and 8,590 lb/acre, respectively,
while head rice percentages were 57 and 67%, respectively.

This year, there are nine MPQ lines that are being evaluated and
compared against M-401 and M-402 in the SW Tests, with 11Y2183
at the forefront of the these selections. Based on averages across 17
SW Tests from 2012 to 2014, 11Y2183 produced higher grain yields (14% more than M-402), had earlier heading (9 and 14 days earlier than M-402 and M-401, respectively), shorter height than M-401 (by 10 cm) but taller than M-402 (by 2 cm), and less lodging than M-401 (by 21%). Its kernel size was similar in length to M-401 and similar in width to M-402, and was less chalky than both M-402 and M-401. Its head rice percentage was 64%, compared to 57% for M-401 and 67% for M-402. MPQ 11Y2183 is currently being grown in the experimental seed increase nursery in 2015.

Also noteworthy among the nine MPQ entries is 12Y2175, which had higher grain yields and earlier heading than both 11Y2183 and M-402 in 2014.

**Conventional Short Grain**

*S-102*

S-102, which was released as a variety in 1996, is a very early maturing conventional short grain rice. This year, four SG lines are being evaluated in the SW Tests, including 10Y2043. In 2014 SW Tests, 10Y2043 had the highest grain yield among SG entries, with an average (across 8 SW test locations) of 9,970 lb/acre compared to 8,390 lb/acre for S-102. When compared to S-102 based on trait parameters averaged across the 2013 and 2014 SW Tests, 10Y2043 headed 2 days later (84 vs. 82 days), had shorter plant height (92 vs. 94 cm), higher lodging (42 vs. 28%), and higher head rice percentage (63 vs. 62%). 10Y2043 and S-102 were similar in seedling vigor (4.9 vs. 5.0 rating, respectively), and panicle blanking in San Joaquin (7 vs. 6%, respectively).

**Low Amylose Short Grain**

*Calamylow-201*

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. This year, SLA 14Y2110 is being evaluated in the SW Tests for the first time. Compared to CA-201 in the 2014 Preliminary Yield Test (PYT) at the Rice Experiment Station (RES), 14Y2110 was similar in seedling vigor and plant height, but it had a 52% higher yield, lower lodging percentage, higher head rice percentage, and glabrous seed. Amylose percentages were 6.6% for of 14Y2110 and for CA-201.
Bold Grain

Bold grain or Arborio rice types are 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. Currently, three advanced BG lines are being evaluated in the PYT at RES.

BREEDING for DISEASE RESISTANCE

Disease reactions to stem rot, aggregate sheath spot, and blast by breeding lines of the SG project that are entered into the PYT and SW Tests are being evaluated by RES pathologist Dr. Paul Sanchez. Rice lines of the various grain types in the SG Breeding Project are being pyramided for blast resistance genes. Based on DNA marker-assisted selections conducted by RES geneticist Dr. Cynthia Andaya and field observations, the selected F5 lines will be advanced to the winter nursery at Kauai in 2015-2016 and then to yield trials in 2016.

FIELD DAY TOUR STOP

The Tour Stop of the Premium Quality and Short Grains Project will feature demo plots of current rice varieties and elite lines of SWXs (CM-101 and CM-203), SPQs (CH-202), MPQs (M-401, M-402, 11Y2183, and 12Y2175), SGs (S-102 and 10Y2043), and SLAs (CA-201 and 14Y2110).

Long Grains
(Farman Jodari, Plant Breeder, RES)

The objective of the long grain project is to develop superior conventional long-grain and specialty long-grain varieties for California. Main emphasis in the conventional (southern) long-grain breeding category includes superior cooking quality, yield potential, milling yield, milling yield stability, cold tolerance, seedling vigor, and disease resistance.

L-206

This is a very early to early maturing semi-dwarf, conventional long-grain variety. It has improved cooked grain texture and higher grain yield over earlier long grain varieties. Average heading date in statewide tests at RES is 1 day earlier than M-206. Plant height is 11 cm shorter than M-206. L-206 has slightly stronger amylographic profile, as shown by higher cool paste viscosity and RVA setback values. Consequently cooked grain texture of it is less sticky than L-204. Similar to Southern long grain, L-206 has intermediate amyle and gelatinization temperature types.
L-206 is adapted to most rice growing areas in California except the coldest locations of Yolo and San Joaquin counties. Average grain yields of L-206 during 2006 to 2014 early statewide trials (RES, Butte, Colusa, Yuba), was 9480 lb/A, as compared to 9370 for M-206. Average head rice yield of L-206, however, is 62 %, which is 3% lower than M-206. Fissuring studies indicate that L-206 is significantly more resistant to grain fissuring than L-204, indicating a better milling yield stability at lower grain moisture contents.

Results of a comprehensive study sponsored by USA Rice federation and conducted by Southern US experiment stations and commercial milling companies have indicated that L-206 is highly favored for packaging quality. These results indicated that L-206 was ranked 1st among all US long grain varieties and hybrids for package quality by the participating rice mills. The evaluation criteria were bran streaks, chalk, kernel color, uniform length, and overall appearance. Concerted effort continues in the long grain project to maintain and further improve the marketability qualities of advancing long grain breeding material.

Among promising experimental long grain lines that are being tested in 2015, entries 12Y20 and 11Y1005 have shown excellent agronomic and quality traits. Detailed performance of these lines is included in RES annual reports (http://www.crrf.org). Entry 12Y20 has shown an average yield of 10300 lb/A in 2012 and 2013 very early statewide tests. This is 680 lb/A higher than L-206. Milling yield of this line is also 3% higher than L-206. In 2012 - 2014 very early statewide tests average yield of entry 11Y1005 was 730 lb/A higher than L-206. During the same period, 11Y1005 showed 2% higher head rice yield. Cooking quality and grain appearance of these lines are similar to L-206. Entry 12Y20 is currently under foundation seed increase. Both experimental lines are being tested in all 8 statewide test locations in 2015.

The genetic base of long grain breeding material at RES has been significantly expanded in recent years through the use of germplasm from Southern US and world collection sources. This diversity is being used to incorporate the desirable agronomic and quality traits in the elite RES lines.

**Specialty Long Grain**

Breeding efforts continue in an accelerated pace, as market demand for these types continues to increase. Currently, efforts are underway to develop soft cooking aromatic jasmine, elongating aromatic basmati, and conventional long-grain aromatic types adapted to
California. Specialty long grains currently occupy nearly half of the long grain breeding nursery.

*Calmati-202*

This is an early maturing basmati type variety. Quality improvements in this variety include more slender kernels, higher cooked kernel elongation ratio, and more flaky grain texture. Grain yield of Calmati-202 (CT-202) has averaged 6740 lb/acre. Head rice yield of this variety is considerably lower than standard varieties due to its slender grain shape, averaging 58%. CT-202 has a semi-dwarf pubescent plant type with good seedling vigor. Maturity is 93 days to 50% heading. Milled kernels of this variety are longer and narrower than CT-201 but not as slender as imported basmati. Grain fissuring studies have shown that CT-202 is susceptible to fissuring at low harvest moistures. Timely harvest and proper handling is recommended to preserve milling as well as cooking qualities of this variety. Due to slender grain shape and pubescent hull and leaf, drying rate of the grain at harvest is significantly faster than standard varieties. Recommended harvest moisture is 18 to 20%.

New series of basmati lines have been developed, including 7 entries that are currently being tested in 2015 statewide trials. These lines have shown cooking qualities that are nearly indistinguishable from imported basmati types. Grain and milling yields of these lines, however, seem to be similar to or lower than CT-202. Current breeding efforts are directed toward increasing both grain yield and milling yield while maintaining their basmati quality traits. Their adaptability thus far is limited to warmer rice growing region.

Efforts have significantly increased in jasmine type breeding, which currently occupy the largest section of the specialty nursery. Conventional pedigree and mutation breeding methods are being used. In 2015 SW Tests, 8 jasmine type selections are being tested. One entry, 11Y106, is currently being produced as foundation seed. It has shown good cooking qualities with soft cooking texture and strong aroma. Three additional jasmine selections with similar amylographic profiles to those of imported jasmine are currently being purified as preliminary headrows.

Quality testing was further expanded in 2015 for all advanced long grain selections including conventional as well as specialty types. Screening for amylographic profile through RVA was nearly doubled with the acquisition of a second RVA analysis instrument. This is in an effort to match the cooking quality of conventional, jasmine and basmati types to those of the current market.
**A-202**

This is a conventional cooking type aromatic variety that was released in January 2014. This variety is intended to be a replacement for aromatic variety A-301. A-202 is early maturing, semi-dwarf, and glabrous. Compared to A-301, A-202 is 9 days earlier, 4” taller, and has significantly higher seedling vigor score. Average yields, in lb/A in 2012 - 2013 ‘early’ statewide tests was 9100 and 7300 for A-202 and A-301, respectively. In 2014 it was tested in all 8 statewide locations and averaged 9170 lb/A. Average headrice yields during the same period were 60% and 53% for A-202 and A-301, respectively. Milled kernels of A-202 are slightly bolder than A-301. The recommended ratio of water to rice for cooking of A-202 is 2 to 1. Amylose content, gelatinization temperature type and amylographic profile are similar to A-301. Aroma volatilization of A-202 is slightly less during cooking process. Flavor sensory of this variety, however, is similar to A-301. Preliminary tests conducted in 2012 have also shown that under organic production system A-202 has considerable yield advantage over A-301 variety. A-202 is susceptible to cold induced blanking and not recommended for production in cold locations. Areas of adaptation for A-202 include Butte, Yuba, Colusa, Glenn, and Sutter Counties.

**Stem Rot**

Resistance breeding efforts continues in cooperation with RES plant pathologist. The *Oryza rufipogon* source of resistance has been incorporated to various long grain backgrounds. Majority of these lines are early maturing and possess good level of cold tolerance. Two high yielding Stem rot resistant lines, 14Y1061 and 14Y1143 are being tested in 2015 statewide tests.

**Rice Pathology**

*(P.L. Sanchez, RES)*

Rice Pathology Project focus is on the development of improved disease resistance screening and evaluation for the 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 yield 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.
Germplasm Collection
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 (USDA, PPQ) and subject to inspections by California Department of Food and Agriculture (CDFA) to prevent introduction of new pathogens and pests into California. Germplasm materials are then released for use in the breeding program. The plant quarantine procedure ensures that the breeders have access to traits important to the continuing improvement of California varieties.

Blast Resistance
Blast resistance conferred by the large effect (no disease) Piz gene is already available in M-208. However, blast was found in 2010 on M-208. Therefore, other large effect genes have been backcrossed eight times into M-206. Yield trials indicate these materials are very similar to M-206. Blast resistance genes (Pil, Pi2, Pi9, Pi33, Pi40, Pikh, Pikm, Pita2, Pib, and Piz5) have been combined in M-206 by conventional screening and use of molecular markers to prevent the fungus from overcoming single gene resistance, as occurred in M-208. These pyramided gene materials are being purified for yield testing. Efforts are already under way to transfer these genes to other 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 DNA Marker 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. 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.

Virgilio “Butz” Andaya is Director of Plant Breeding & Medium-Grain Project Leader, Farman Jodari is the Long-Grain Project Leader, Stanley O.P.B. Samonte is Premium Quality & Short-Grain Project Leader, Paul Sanchez is Rice Pathologist, and Cynthia Andaya is Research Scientist (DNA Lab) at RES.

**Management of Invertebrate Pests in California Rice- It’s More Than Rice Water Weevil (L. D. Godfrey, L. Espino, K. Goding, and J. Bloese, UCCE and UCD)**

Insect and other invertebrate pests continue to hinder rice production in California. These pests inhibit stand establishment and reduce rice growth, tillering, and yield. Recently, a group of insect pests appear to be feeding on the developing panicles and potentially impacting grain quality. Rice water weevil has been a pest of California rice for more than 50 years. This insect is still a pest to contend with and is still inflicting damage in many areas. In recent years, tadpole shrimp has developed into a significant pest that has to be controlled in many areas in order to establish a rice stand. In 2015, growers experienced unusually high levels of armyworms, the highest in 25 years. This pest warranted control measures in many fields. Finally, stink bugs (potentially several species but most commonly red-shouldered stink bug) appear to be on the increase as a pest. In spite of these changing pest conditions, many serious insect pests that occur in the southern U.S. rice production area as well as in other temperate rice regions are not present in California. Effective quarantine and regulatory efforts have kept these pests from entering California and it is important to maintain these programs.

Why has the list of serious insect pests in California increased from only rice water weevil in the early 2000’s to a list of multiple pests now. My best guesses are changing conditions in the Sacramento Valley rice production area. Changing conditions in the rice fields may be affecting tadpole shrimp levels. Recent environmental conditions during the winter are likely allowing greater survival of armyworms. Finally, the agroecosystem overall in the Sacramento Valley may be allowing more stink bugs to be present in the area. More details will follow as well as the present-day pest management tactics that are available for these pests.
**Rice Water Weevil**

A significant amount of research has been done on this pest over the years. Cultural control methods such as controlling the vegetation (grassy weeds) on the levees in the spring before rice seeding and winter-flooding of fields have been shown to be effective management techniques. Some very “vigorous” rice cultivars seem to withstand root pruning by weevil larvae better than other varieties. Therefore, rice varieties can play an important role in rice water weevil management. Finally, insecticides have been used to manage this pest in California rice for the last 40 years. Pyrethroid products (two different active ingredients) are most commonly used; however, diflubenzuron (Dimilin\textsuperscript{®}) and most recently clothianidin (Belay\textsuperscript{®}) are also available and effectively control this pest. A biological insecticide based on *Bacillus thuringiensis* (Bt) subsp. *galleriae* has also been shown to cause significant mortality to rice water weevil but the cost effectiveness and marketability of this product have not been fully evaluated.

**Tadpole Shrimp**

This pest, a crustacean, is not new to California rice but the severity has increased in recent years. Tadpole shrimp feed on the germinating rice seeds and small seedlings. They can uproot small seedlings after they have started to root down. By the time the rice is in the ~2 leaf stage, it is no longer susceptible to tadpole shrimp injury. But in these few days from seeding to the seedlings pegging down, they can decimate the stand. Management methods for tadpole shrimp have emphasized doing everything possible to get a stand established in as few days as possible; basically trying to get the rice past the susceptible stage before the levels of tadpole shrimp can build-up. The laser-leveled fields and relatively low water depths adopted by the industry should facilitate this. However, some of the slow water deliveries/flows and very dry soils in recent years have resulted in longer than desired initial flood times. Insecticides can also be used but these are generally preflood treatments thus they are preventative, i.e., applied before it is known if a population will develop. My lab, in conjunction with Luis Espino, is currently researching this pest to determine why it is so much more common and problematic than it was a few years ago. We theorize that changing field conditions related to the way straw is now being handled and changes in production practices could be playing a role. See poster in the poster area for more details.

**Armyworms**

Two species of armyworms can infest rice but the biology and damage from these is fairly similar. The infestations commonly occur in August and September with the earlier infestations damaging plant
foliage and the later infestations feeding on developing panicles. The larvae take ~20 days to fully develop after egg hatch (in our typical summer temperatures) with the smaller larvae being very difficult to detect in a fully-enclosed rice canopy. During the last ~10 days of the larval period, they are large enough and feeding on more exposed parts of the plant and can thus be more easily seen. This is also the period when the larvae do the most damage to the plant. Armyworm larvae in August/September are commonly parasitized; I had a project in my lab in 2013 where we wanted to collect larvae for laboratory studies. At that time, more than half the larvae were parasitized and died within a couple of days of collection. The parasitoids (small wasps) attack the armyworm larvae 4-7 days after egg hatch but the larvae do not die for another week or so thus they are fairly large when they succumb.

In 2015, the armyworm infestation started in June, which along with the high levels, was the primary problem. I had not seen this early timing for armyworm outbreak in rice in 25 years. Why? This pest spends the winter as a fully-developed larva and/or pupa that persists in residue on the soil surface or even in the top few inches of soil. This typically occurs in warmer areas and the moths migrate northward. For instance, the armyworms do not overwinter in Iowa but instead overwinter in the southern U.S. fly north to the Midwest. The Sacramento Valley is borderline for these armyworm species successfully overwintering. But in a warm winter such as 2014-15, the armyworms could definitely overwinter in this area. In addition, the dry conditions aided the overwintering; often times moist soil conditions allows microbes to infect the overwintering soft-bodied larvae and kill them. These unusual winter conditions in 2014-15 likely resulted in the early outbreak of armyworms in rice. There was also an early armyworm outbreak in the San Joaquin Valley in May affecting alfalfa and row crops in 2015.

Pyrethroid insecticides and Sevin® are recommended for armyworm control. However, these products are not strong enough to handle high populations of armyworms, especially large-size larvae and applications made to rice not with a fully-closed canopy (they are best deposited on foliage allowing the larvae to consume them). Dimilin® is a very effective product on armyworms but it has a very long pre-harvest interval on rice. Several Bacillus thuringiensis products have a strong profile on lepidopterous larvae including armyworms but their strength is on small-sized larvae. Effects are underway to bring additional products for use in rice for armyworm control.
Stink Bugs

Pecky rice is generally not a factor in rice production in California. The standards for seed damage are relatively low (0.5% damage) and the grain quality in California is of utmost importance and a key to the marketability. The rice stink bug (Oebalus pugnax) is a key rice pest in the southern states and an important IPM challenge for rice production. This insect is not known to occur in California.

In recent years, some reports of “pecky” rice have been received from parts of the Sacramento Valley. Pecky rice can be caused by sucking insects but similarly appearing damage can also be caused by several agronomic and environmental factors. In 2012, Luis Espino and I searched for possible insect causes in one of the areas with some pecky rice in 2011. A low level of red-shouldered stink bug, Thyanta pallidovirens (= T. accerra), was found. This insect has been reported from Mississippi as a pest of rice causing peck as well as it was mentioned in a report from 1965 as damaging rice in 1939 in California. Stink bugs overall appear to be increasing in severity statewide on several crops. It appears that the biology of several species is changing in terms of numbers and length concern during the season. In addition, there are several invasive species of stink bugs that are poised to cause IPM problems on several crops. Studies were conducted in 2013 and 2014 to determine the damage potential of red-shouldered stink bug to rice. In addition, we surveyed 49 grower rice fields in September for stink bugs. Stink bugs were found in fields of five of the six rice production counties and in about 30% of the fields. Red-shouldered stink bug was the most common species found and, in addition, nymphs of this species were found in four counties (later in the season than had been previously reported). Consperse stink bug and three other species were also found. These species are all common Sacramento Valley stink bugs often found in field crops as well as weedy areas. Rice fields with higher stink bug numbers, based on out 2014 studies, tended to have a higher level of grassy weeds, be near riparian habitat, and be in areas with more crop diversity (row crops).

Larry Godfrey is a UC Cooperative Extension Specialist and Entomologist in the Agricultural Experiment Station, Department of Entomology and Nematology, UC-Davis; Luis Espino is a Rice Farming Systems Advisor Colusa, Glenn and Yolo Counties, Colusa; Kevin Goding is a Staff Research Associate, Department of Entomology and Nematology, UC-Davis; Joanna Bloese is a Graduate Student Researcher, Department of Entomology and Nematology, UC-Davis.
Rice Weed Control: Herbicide Programs, New Chemicals, and Weed Management

The UC Rice Weed Research Program at the Hamilton road site at the Rice Experiment Station, Biggs, CA includes the performance testing of herbicides, and their mixtures and sequential combinations for the common rice growing systems in California (continuous flood, pinpoint flood, and drill-seeded rice systems). We have also continued testing new products primarily aimed at assisting the rice industry in the registration of new herbicides as options become available. Our efforts seek to assist California rice growers in achieving economic and timely broad-spectrum weed control, preventing and managing issues of evolved herbicide-resistant weeds, and complying with personal and environmental safety requirements.

Here we highlight results from our 2015 field operation for the major rice growing systems used in California. Herbicide program efficacy comments presented here primarily reflect the average visual ratings of four replicates for major weed species approximately 40 days after seeding (DAS) of rice which covers the critical period of competition (30 days). Crop response (stand reduction, stunting and other injury to rice) has also been highlighted wherever relevant.

Continuously-Flooded Rice
This system promotes suppression of certain weeds such as barnyardgrass and sprangletop. These two weeds would otherwise be dominant in dry-seeded systems. After seeding rice into a flooded field, a water depth of 4 inches is maintained throughout the season. 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. This year, watergrass (early and late) were the predominant weeds, followed by ducksalad, ricefield bulrush, smallflower umbrella sedge, redstem and sprangletop. All weeds evaluated in our program are susceptible to rice herbicides registered in California, but we discuss and give weed management options for fields with population(s) of resistant weed species.

For this system, several granular into-the-water herbicide products are available for controlling weeds in rice including Bolero, Cerano, Granite, Halomax, Londax, and Shark H₂O. These herbicides can be
applied early to provide good to excellent control of labelled (target) weeds. As they vary in their target weeds (spectrum of weed control), it is useful to combine two of these herbicides in a program to offer broad spectrum weed control.

POST-applied (foliar) herbicides are often necessary to achieve excellent weed control in rice. The follow-up POST application of herbicides not only extend spectrum of weed control, but also may help delay and/or manage herbicide-resistant weeds through overlapping activity on the same target weed species. Thus, the choice of POST-applied herbicides is primarily dictated by composition of weed species and the presence or absence of resistant weeds. The rice herbicide options for the foliar application include Abolish, Clincher, Granite SC, Regiment, RiceEdge, Shark H₂O, SuperWham or Stam, Halomax and Londax.

All Bolero-based programs, with Bolero applied at the 1 leaf stage of rice (lsr) offered excellent control (100%) of watergrass, sprangletop and smallflower umbrella sedge. Inclusion of SuperWham at 6 qt/A + 1.25% v/v Crop Oil Concentrate (COC) at 1-tiller stage or Regiment (0.8 oz/A + 2% v/v UAN + 0.2% v/v NIS at 4 lsr) in this program improved (>90%) control of ducksalad; however, neither of these two programs provided more than 85% control of ricefield bulrush. A tank-mix of Granite SC (2 oz/A) and SuperWham (6 qt/A + 1.25% v/v COC) applied at 4 lsr maximized (100% control) the control of ricefield bulrush. Although Bolero-based programs offer excellent control of grasses and ALS- and propanil-resistant smallflower umbrella sedge, a substantial level of stand reduction of rice is observed.

Cerano applied at the day of seeding (DOS) provided good control of watergrass and sprangletop (>90% control) 20 days after seeding (DAS). A foliar application of SuperWham (6 qt/A + 1.25% v/v COC) at 1-tiller stage following Cerano was exceptionally effective in controlling watergrass (100% control), however, the control of ricefield bulrush and smallflower umbrella sedge was poor (<75% control) 40 DAS. Cerano supplemented with a granular application of Shark H₂O (7.5 oz/A) with Londax (1.66 oz/A) or Halomax (1.33 oz/A) at 3 lsr and followed by a foliar application of SuperWham (6 qt/A + 1.25% v/v COC) at 2-tiller stage provided complete control of all the weed species. An alternative to this program with similar efficacy was Cerano followed by Granite GR (15 lb/A) at 3 lsr followed by a tank-mix foliar application of Abolish (1.5 qt/A) + Regiment (0.53 oz/A) with 2% v/v UAN and 0.2% v/v NIS at 5 lsr.
Granite GR (15 lb/A at 2-3 lsr) offers a broader spectrum of weed control (including ducksalad and ricefield bulrush) compared to Bolero and Cerano; however, it lacks efficacy on sprangletop and redstem control. While a follow-up foliar application of SuperWham (6 qt/A + 1.25% v/v COC at 1-tiller stage) alone offers overlapping control of some weed species and help controlling certain ALS-resistant weeds, it does not control sprangletop and redstem. Granite followed by a tank-mix application of Abolish (1.5 qt/A) + Regiment (0.53 oz/A) + UAN (2% v/v) + NIS (0.2 % v/v) at 5 lsr provided 100% control of sprangletop. An addition of Shark H₂O (0.53 oz/A at 2.5 lsr) on top of this program maximized the overall weed control (100% control of all the weed species including redstem).

The Shark H₂O-based programs offer control of ALS- and propanil-resistant sedges (ricefield bulrush and smallflower umbrella sedge) and the Bolero-based programs offer control of ALS- and propanil resistant smallflower umbrella sedge. Programs with a follow-up application of a tank mix of Abolish (1.5 qt/A) + Regiment (0.53 oz/A) + 2% v/v UAN + 0.2% v/v NIS at 5 lsr offer control of multiple-resistant watergrass escapes. Another option is to use Regiment at the highest label rate (0.8 oz/A) with 2% v/v UAN + 0.2% v/v NIS at the 4 lsr. For Clincher-resistant sprangletop, a program with granular application of Cerano (DOS) or Bolero (1 lsr), followed by a foliar application of Abolish at 5 lsr is recommended. For Cerano-resistant sprangletop, Bolero applied at the 1 lsr, followed by a foliar application of Clincher (at the 3-4 lsr) is recommended.

**Pinpoint Flood**

In this system the field is completely drained during the period of foliar application of herbicide (at about the 2-4 leaf stage of rice). The complete drainage of the field is intended to expose weed foliage to herbicide applications, thus allowing the opportunity to achieve the best efficacy of POST herbicides. Weeds present in this system were (in order of relative density) ricefield bulrush, ducksalad, watergrass (early and late), smallflower umbrella sedge, redstem, and sprangletop.

The SuperWham-only (6 qt/A + 1.25% v/v COC at 4 lsr to1-tiller stage) application was excellent in controlling (97% or more) watergrass, ricefield bulrush and smallflower umbrella sedge. SuperWham when tank-mixed with Clincher (6 qt/A + 13 oz/A + 2.5% v/v COC at 4 lsr) was effective in controlling both watergrass and sprangletop.

A tank-mix application of Clincher (13 oz/A) and Granite SC (2 oz/A) with 2% v/v COC at 3 lsr provided excellent (>99%) control of all
weeds including ducksalad within a week after treatment. With two follow-up applications of Shark H₂O (4 oz/A) at 4 lsr and Abolish + Regiment (1.5 qt/A + 0.53 oz/A + 2 % v/v UAN + 0.2% v/v NIS) at 5 lsr the overall efficacy of this program was excellent (100% control of all weeds). Addition of Shark H₂O to the weed management program offers improved efficacy including control of ALS-inhibitor- and/or propanil-resistant sedges; whereas the tank- mix application of Regiment + Abolish provokes synergism on watergrass control and also helps in controlling multiple herbicide-resistant watergrass. This program offers an excellent ‘reactive’ as well as ‘preventive’ herbicide-resistant weed management in rice.

A single application of three-way tank-mix of Clincher (13 oz/A), Granite SC, (2 oz/A), Abolish, (1.5 qt/A) with 2.5% v/v COC applied at 2-3 lsr provided 100% control of watergrass and sprangletop, and an excellent control of ducksalad, ricefield bulrush, smallflower umbrella sedge. This program will not control certain ALS-inhibitor-resistant ricefield bulrush and thiobencarb-resistant watergrass populations; however, it is a good alternative for fields with ACCase-resistant (Clincher-resistant) sprangletop populations. Similar results were obtained when Regiment (0.67 oz/A + 2% v/v UAN + 0.2% v/v NIS) or Granite SC (2 oz/A + 2.5% v/v COC) were applied at 3-4 lsr followed by tank mix of SuperWham + Clincher (6 qt/A + 13 oz/A + 2.5% v/v COC) at 1-tiller stage.

An excellent control of watergrass, sprangletop and ricefield bulrush, and smallflower umbrella sedge (>98%) were achieved by Clincher (13 oz/A + 2.5% v/v COC) alone at 3-4 lsr followed by a tank mix of SuperWham + Grandstand (6 qt/A + 8 oz/A + 1.25% v/v COC) at 1 t-tiller stage or Abolish + SuperWham (1.5 qt/A+ 6 qt/A 1.25% v/v COC) at 3-4 lsr followed by Granite SC (2.8 oz/A + 2.5% v/v COC) alone at 1-tiller stage. Grandstand effectively controls ricefield bulrush and redstem, and it is particularly useful when the field has herbicide-resistant populations of these weeds. Abolish is a better choice than Grandstand when ducksalad is predominant in the field.

**Drill-Seeded Rice**

Typically a period of three to four weeks elapses between the first flush and permanent flooding in drill-seeded rice system. This period offers flexibility for herbicide use when proximity to sensitive crops imposes restrictions to aerial applications. During this period weeds adapted to dryland seedbeds such as barnyardgrass, sprangletop, watergrass and smallflower umbrella sedge become established, whereas aquatic weeds such as ricefield bulrush, ducksalad, and redstem are less favored or eliminated. Thus, this system when alternated with the water-seeded system may be useful for reducing
aquatic weed pressure in water-seeded system, and *vice versa*. Weeds present in this system were the *Echinochloa* complex (early and late watergrass, and barnyardgrass), and smallflower umbrella sedge and sprangletop.

Abolish and Prowl are valuable residual herbicides which provide early weed control up to the start of permanent flood. Both herbicides suppress watergrass and barnyardgrass; however Abolish is more active on smallflower umbrella sedge than Prowl. Regular flushing before permanent flood activates these herbicides and also helps in the establishment of rice. For a delayed pre-emergence application (DPRE) of these herbicides, the rice seed is first drilled into dry soil, the field is then flushed once and then an herbicide is applied onto a moist soil surface. As these pre-emergent herbicides do not provide complete control of weeds, one or two foliar applications of herbicides/herbicide mixtures on emerged weeds are necessary.

The DPRE application of Prowl (2 pt/A) provided 62% control of *Echinochloa* species and 31% control of smallflower umbrella sedge. Abolish (1.5 qt/A) was less effective on *Echinochloa* species (43% control) than Prowl; however it was exceptionally effective in controlling smallflower umbrella sedge (99 to 100% control).

All the foliar applications (described later) that followed DPRE application of Prowl provided excellent control of smallflower umbrella sedge (98 to 100% control), thus, providing flexibility in the herbicide program for controlling herbicide-resistant biotypes of this weed.

A foliar application of SuperWham (6 qt/A 2% v/v COC) alone following the DPRE Abolish or Prowl application improved control of *Echinochloa* species (85 to 90%) compared to its control by DPRE applications alone; however, the control was still not adequate. The DPRE application followed by a tank-mix of Abolish + Regiment (1.5 qt/A + 0.53 oz/A + 2.0% v/v UAN + 0.2% v/v NIS) at 5 lsr greatly improved *Echinochloa* control (>97 %). Two foliar applications of Prowl + SuperWham + Clincher (2 pt/A + 4 qt/A + 13 oz/A + 2.5% v/v COC) at 3 lsr and Shark H₂O (4 oz/A) at 4 lsr following the DPRE application provided excellent control (98 to 100%) of *Echinochloa* species. In this program, the second application of Prowl suppresses *Echinochloa* emergence for extended period whereas the tank-mix application of SuperWham and Clincher provide overlapping efficacy on emerged barnyardgrass and watergrass. Shark H₂O supplements SuperWham for controlling smallflower umbrella sedge (including propanil-resistant biotypes). This is an intensive program for controlling *Echinochloa* and sedges, thus, it is particularly suitable
for controlling herbicide-resistant populations of grasses and sedges. Similar levels of weed control may be achieved without Shark H2O when Abolish is used as a DPRE application, and *Echinochloa* and smallflower umbrella sedge are susceptible. Use of Abolish and Prowl in alternate years will add to delaying evolution of resistant *Echinochloa* species.

**New Weed Management Products**

**RiceEdge®**

RiceEdge® is a dry flowable mixture of propanil and halosulfuron product delivered by RiceCo, LLC, CA. The herbicide was tested under a continuous flood and a pinpoint flood (drained for one week at the 3-4 lsr). In both trials, it was applied at the highest label rate of 10 lb/A with 1.25% v/v COC at 20 DAS. RiceEdge® provided excellent control (>95%) of watergrass, ricefield bulrush, and smallflower umbrella sedge in both systems. Ducksalad control was often poor (<50%) with this herbicide product.

**Butte®**

Butte® is a granular mixture of benzobicyclon and halosulfuron product developed by Gowan. The benzobicyclon component of Butte® adds a new mode of action (HPPD-inhibitor) to the herbicide programs in water-seeded rice.

Butte® was tested under a continuous flood system with two rates of application, both alone and in a program. An early POST application of Butte® at 7.5 lb/A rate or a slightly higher rate (9 lb/A) at 1 lsr (7 days after seeding) provided excellent control (>98%) of all weeds including watergrass, ricefield bulrush, smallflower umbrella sedge, ducksalad, and monochoria. These applications provided a broad spectrum of weed control and offered an exceptional level of crop safety. A follow-up application (at 1-tiller stage) of SuperWham + Grandstand (6 pt/A + 6 oz/A + 1.25% v/v COC), Granite SC (2.8 oz/A + 1.25% v/v COC), or Regiment (0.67 oz/A + 2.0% v/v UAN + 0.2% v/v NIS) provided exceptional control (100% control of all weeds including redstem 40 DAS). While stand-alone application of Butte® offers excellent weed control in water-seeded rice, a follow-up application or an inclusion of a partner granular herbicide (for example Cerano) will maximize the spectrum of weed control.

**Strada®**

Strada® is a granular formulation of orthosulfamuron (an ALS-inhibiting herbicide) developed by Nichino America. Efficacy of Strada® was tested under a continuous flood in a Cerano-based program in a tank mix with SuperWham or Shark H2O applied at 35
days after seeding (approximately at 2-tiller stage of rice). Cerano (10 lb/A at DOS) followed by a tank mix of Strada (2.1 oz/A) with SuperWham (6 qt/A + 1% v/v COC) or Shark H$_2$O (4 oz/A + 0.25% v/v NIS) provided a very good control of watergrass (>95%) and a fair control of ricefield bulrush (>80%). Smallflower umbrella sedge control was much better (>95%) with the program containing SuperWham than that containing Shark H$_2$O (<50%).

**Weed Management**

The evolution of herbicide resistance in major weed species of California rice, including *Cyperus difformis* L. (smallflower umbrella sedge) and *Echinochloa phyllopogon* (Stapf) Koss (late watergrass), has necessitated the search for alternative management options, including alternate herbicide modes of action and tillage practices in conjunction with the use of a stale seedbed. In addition to the prevailing water seeding and continuous flooding in rice, reduced irrigation schemes are being explored for water conservation, which is expected to alter the usual weed recruitment patterns.

**Weed Germination, Emergence and Growth Models:**

To establish appropriate timing of weed control interventions under variable field conditions, it is necessary to be able to predict the dynamics of weed germination and emergence under those conditions. The population-based threshold models (PBTM) combine information about irrigation method and soil temperature to provide species-specific emergence and growth curves, allowing growers to better time application of herbicides and manage weeds using cultural controls. Our updated model and validation work for *C. difformis* and *E. phyllopogon* are in their final stages, and publications on the field-validated models are expected within the next year.

**Weed Population Dynamics in Alternative Irrigation Systems**

Due to looming water resource issues in California, we have also been evaluating the dynamics of weed emergence in alternative irrigation systems. Since 2013, we have been evaluating three systems: i) Water-Seeded Alternate Wet and Dry (WS-AWD): flooded for initial seeding by air, and until canopy closure of the rice, subsequently allowed to drain and then flushed again when Volumetric Water Content (VWC) reached 35%; ii) Drill-Seeded Alternate Wet and Dry (DS-AWD): drill-seeded, then flushed again when VWC reached 35%; and iii) Water-Seeded Conventional (WS-Control): permanent flood of 10-15 cm, which was maintained until the field was drained approximately one month prior to harvest. Evaluations of weed dynamics in these systems are in their final stages, and publications are expected in the near future.
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<th>Herbicide</th>
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<td>Abolish 8EC (thiobencarb)</td>
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Kassim Al-Khatib, Professor, Department of Plant Sciences, UCD; Amar S. Godar, SRA III, UCD; Whitney Brim-DeForest, PhD Student, UCD; J. Ray Stogsdill, SRA II, UCD; Rafael Pedroso, PhD Student, UCD; Mariano F. Galla, PhD Student, UCD; Bruce A. Linquist, Cooperative Extension Specialist, UCCE; Luis Espino, Farm Advisor, Colusa-Glenn-Yolo Co., UCCE; R.G. Mutters, Farm Advisor, Butte Co., UCCE
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PRODUCT/SUPPLIES

Biggs Farming Group (Straw Bales)
Butte County Mosquito & Vector Control District
John Taylor/Wilbur Ellis Company (Cerano®)
FMC Corporation (Shark \( H_2O \)®)
RiceCo (Super Wham®)

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LaserMan, Inc. dba Ag One Solutions